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ENHANCING HEALTH MONITORING SYSTEMS DURING HAJJ 2024 USING OPEN SOURCE EPIDEMIC INTELLIGENCE

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Abstract

Background: The annual Hajj pilgrimage in Mecca, Saudi Arabia, attracts over two million people, creating a high-risk environment for public health emergencies, including infectious disease outbreaks and heat-related illnesses due to extreme temperatures and mass gatherings. Traditional surveillance systems can be challenged by the event's scale and speed. This study evaluates the integration of Open Source Epidemic Intelligence (EIOS) to enhance real-time health monitoring and response during Hajj 2024.

Methods: A cross-sectional study was conducted using the EIOS platform, which aggregates and analyzes data from digital sources like news and social media. During the Hajj period (June 2-21, 2024), 877,000 articles were screened. A multi-step process involving screening, triage based on predefined public health criteria, and risk assessment by experts was used to identify and classify relevant health signals.

Results: From the initial 877,000 articles, 96 unique health cases were identified. Heat-related illnesses were the most prevalent, with Heat Stroke (18 cases) and Heat Stress (15 cases) being the top concerns. Infectious diseases like Cholera (15 cases) and Dengue (12 cases) were primarily detected outside Saudi Arabia before Hajj. Statistical analysis revealed a significant increase in health incidents during Hajj ($p<0.05$), with 33.3% (n=32) of cases classified as moderate-to-high risk, predominantly heat-related events occurring inside Saudi Arabia.

Conclusion: The EIOS system proved effective for real-time public health surveillance during Hajj 2024, successfully identifying and prioritizing critical health threats, particularly heat-related illnesses. The findings underscore the value of EIOS as an early warning tool for mass gatherings. Future implementations should focus on integrating predictive AI modeling, automating data processing, and combining EIOS with traditional health data to enable more proactive and targeted public health interventions.

1. Introduction

The Hajj pilgrimage represents one of the most significant global religious events, annually drawing over two million Muslims to Mecca, Saudi Arabia. This immense gathering not only underscores the spiritual unity of Muslims worldwide but also presents complex public health challenges due to the high concentration of individuals in a relatively confined area. The potential for rapid transmission of infectious

diseases, management of chronic health conditions in a crowded setting, and the risks associated with large crowd dynamics such as stampedes or heat-related illnesses necessitate robust health surveillance and rapid response systems.

Given the global nature of the pilgrimage, with attendees coming from diverse epidemiological backgrounds, the risk of introducing and disseminating various pathogens, including those of respiratory, gastrointestinal, and vector-borne diseases, is significantly heightened. Previous occurrences of health emergencies during Hajj have demonstrated the critical need for an advanced monitoring system capable of handling the unique demands of such a massive and transient population.

In this context, the utilization of Open Source Epidemic Intelligence (EIOS) offers a modern and technologically advanced approach to public health surveillance. Open Source Epidemic Intelligence (EIOS) leverages data from a wide array of digital sources including social media, online news outlets, and health forums, providing real-time data that can enhance early detection and facilitate rapid public health decision-making[6]س. This system has shown promising results in other large-scale international gatherings, proving its effectiveness in enhancing disease surveillance and response through the aggregation and analysis of vast amounts of unstructured data [1,2,5].

This proposal aims to explore the integration of EIOS in enhancing health monitoring systems for Hajj 2024, focusing on its capability to improve early detection of health threats, streamline response efforts, and ultimately safeguard the health and well-being of millions of pilgrims. Through a comprehensive review of related literature and planned methodological approaches, this study intends to demonstrate how leveraging open-source intelligence can transform public health strategies during mass gatherings of significant event like Hajj.

The Hajj pilgrimage represents a unique set of public health challenges due to its religious importance, the diversity of its participants, and the environmental conditions of the region. Firstly, the high concentration of people can facilitate the rapid transmission of infectious diseases, which is particularly concerning given the international nature of the event. Diseases can not only spread more quickly but also cross borders upon the pilgrims' return, potentially causing global health emergencies.

Secondly, the climatic conditions in Mecca, characterized by extreme heat, can lead to a high incidence of heat-related illnesses, such as heat exhaustion and heatstroke. These conditions are exacerbated by the physical exertion required during Hajj rituals, increasing the risk of dehydration and cardiovascular problems among pilgrims, particularly the elderly and those with pre-existing health conditions.

Thirdly, the logistical challenges of managing such a large crowd in a relatively small geographical area raise the risk of injuries from stampedes and accidents, which have occurred in the past with tragic consequences. The complexity of crowd management and the need for effective emergency response and evacuation strategies are therefore critical components of Hajj planning and execution.

The integration of Open Source Epidemic Intelligence (EIOS) into public health strategies offers a promising solution to these challenges. EIOS harnesses data from a wide array of digital sources, including social media, news reports, and online health forums, to provide real-time surveillance of health-related events. This approach has been successfully implemented in other large-scale international events, such as the Tokyo 2020 Olympics [3] and the FIFA World Cup 2022 Qatar [4], where it played a crucial role in early threat detection and the coordination of public health responses.

The utility of EIOS in a setting like Hajj is divergent. Firstly, it can significantly enhance the timeliness and accuracy of disease surveillance, enabling health authorities to detect and respond to outbreaks more quickly than traditional surveillance methods allow. Secondly, EIOS can improve the monitoring of environmental and safety conditions, providing data that can inform crowd management strategies and emergency responses. Lastly, the ability of EIOS to aggregate and analyze diverse data sources can support more informed decision-making by health officials, ensuring that interventions are based on comprehensive and up-to-date information.

4. Objectives

- Primary Objective:

Evaluate the effectiveness of EIOS in enhancing public health surveillance during Hajj 2024.

- Secondary Objectives:

- Explore the potential of EIOS in improving health threat detection speed and accuracy during Hajj 2024.
- Develop guidelines for EIOS deployment in large-scale public health scenarios in upcoming mass gathering events.

5. Methodology

1.Study design

This a cross-sectional descriptive design, that allows for a snapshot of health monitoring practices and the effectiveness of EIOS during the Hajj pilgrimage. This design is advantageous for collecting data on various infectious diseases and health risks that may arise during the event.

2. Data Collection

2.1. Time Frame

Data will be retrieved from the EIOS dashboard over a specified period in Hajj 2024, ensuring that the information is current and relevant.

2.2. Establishment of EIOS Dashboard

An EIOS dashboard was created by Public Health Operation Center (PHOC) and facilitated by EMRO-WHO. Filtering process were done according to EIOS selection criteria that categorize relevant open-source articles, ensuring real-time processing of health-related information. This criteria created by PHOC experts and approved by the general supervisor of PHOC.

2.3 EIOS selection criteria

Signals selection criteria:

1. Filtering process:

a. Surf for signals from the different sources

b. Identify duplicate information that is being reported by more than one source

c. Identify and discard information that is not a public health threat:

-information that has no impact on human health

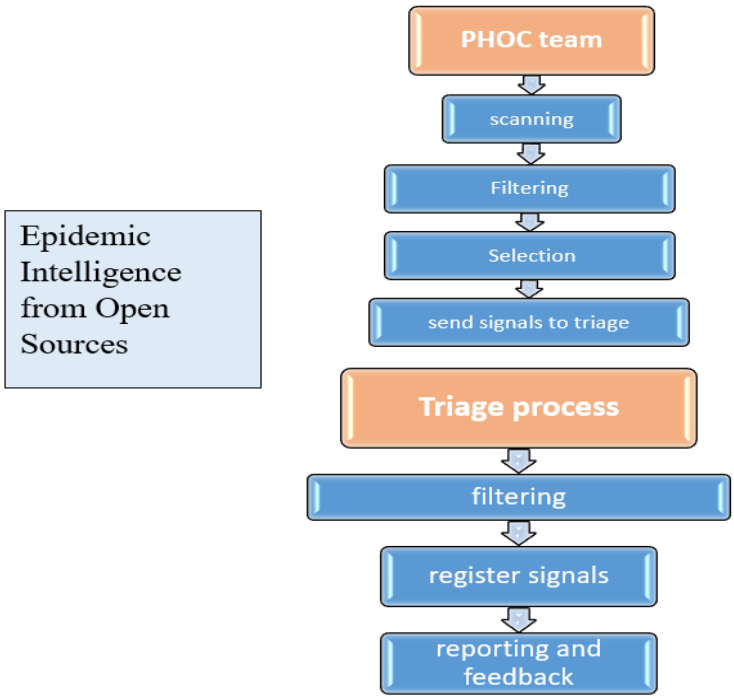
-studies/literature reviews that are mainly descriptive

-mild disease that affects a single person

-a localized event that is already being managed or can be managed

-Increased (three-fold/four-fold/etc) number of cases that are in accordance with the seasonal pattern

- Elevated number but in conformity with what is expected at the beginning of the transmission season
-Slightly increased number of what is expected but within the annual variations
Proceed to the selection of signals



2.4. Data Retrieval Period

The data retrieved from the EIOS from the 2nd of June to 21st of June 2024 ensuring that all information is relevant to Hajj 2024.

2.5. Data Processing Steps

The data collection process will involve several key steps, as outlined below:

Step 1: Screening

All articles (n = 877,000) that appear on the EIOS dashboard during the designated period will be titled screened out for irrelevance, duplication, incompleteness, and unconfirmed information. After which, full-text screening will be done on the remaining articles to pick out those that may be signal relevant to public health.

Step 2: Triage

The triage process will occur for the remaining information, select those that fit into the following criteria:

Criteria 1 according to diseases/events targeted for epidemiological surveillance and its importance:

In The Kingdom of Saudi Arabia article 11 of the health profession regulation states that once the health practitioner examines a patient who is suspected as having an infectious disease, then he/she has to report that event to the health authorities. The ministry of health then makes it an order to the health practitioners and the laboratory services providers to notify certain types of diseases of public health importance to the Public Health Agency(15). During the Hajj season, There is a list of diseases/events targeted for epidemiological surveillance, and signals have been selected for these diseases. The diseases are Neisseria Meningitis, Meningitis other, Hemorrhagic Fever other, Acute Flaccid Paralysis, Covid-19, Cholera, Influenza,

Food Poisoning outbreak, Middles East Respiratory Syndrome, Mpox, Malaria, Measles, Dengue Fever, Ebola, Yellow Fever, and Outbreak of notifiable disease, Emerging or Re-emerging Disease.

The importance of the diseases/events are determined with the following factors:

1) Unknown illness
2) Unusual event (detection of new features of a disease, atypical signs, and symptoms, significantly high number of cases over a short period in a limited geographic area, newly imported disease, occurrence in an area outside the endemic areas in the country)
3) The risk to the health system (affects a significant proportion of health workers, Case fatality rate (CFR) of the disease is significantly higher than expected, the occurrence of disease outside the normal seasonal pattern, re-emergence of communicable diseases, affects a conflict area)
4) International disease spread
5) Disease for elimination or eradication
6) Suspected, accidental or deliberate biological or chemical threats
7) Sensational report or high media attention expected

Criteria 2 according to the occurrence of signals/events inside SA

Any illness or health event happening in or happening in Hajj regions (Makkah and Madina) or in Saudi Arabia during Hajj period

Criteria 3 according to the impact of the signals/events on pilgrims

Any illness or health event related to pilgrims

Step 3: Verification and Risk Assessment

Signals that meet criteria of triage will undergo a verification process and immediate risk assessment by a team of PHOC experts. This assessment will categorize signals into low (criteria 1 alone) and moderate – high risk (criteria 2 or/and criteria 3 with or without criteria 1).

3. Data Analysis Procedures

3.1. Statistical Methodology

The analysis will focus on summarizing signal characteristics using frequency and percentage distributions. An empirical probability estimation will be employed to calculate the likelihood of capturing relevant articles from the EIOS dashboard. The analysis will include:

Chi-Square Tests: To determine significant associations between hazard categories and other variables such as region and detection timing.

4. Data Availability

The raw data utilized in this study will be generated by the Ministry of Health in Saudi Arabia. Derived data supporting the findings will be made available from the corresponding author upon request.

5. Budget and Timeline

The project will outline costs associated with technology setup, training, data analysis, and dissemination, spanning Q1 to Q4 2025 from setup through post-event analysis.

6. Ethical Considerations

The study will adhere to ethical standards regarding data privacy, ensuring all data used is anonymized and publicly available, or utilized under appropriate consent.

Results

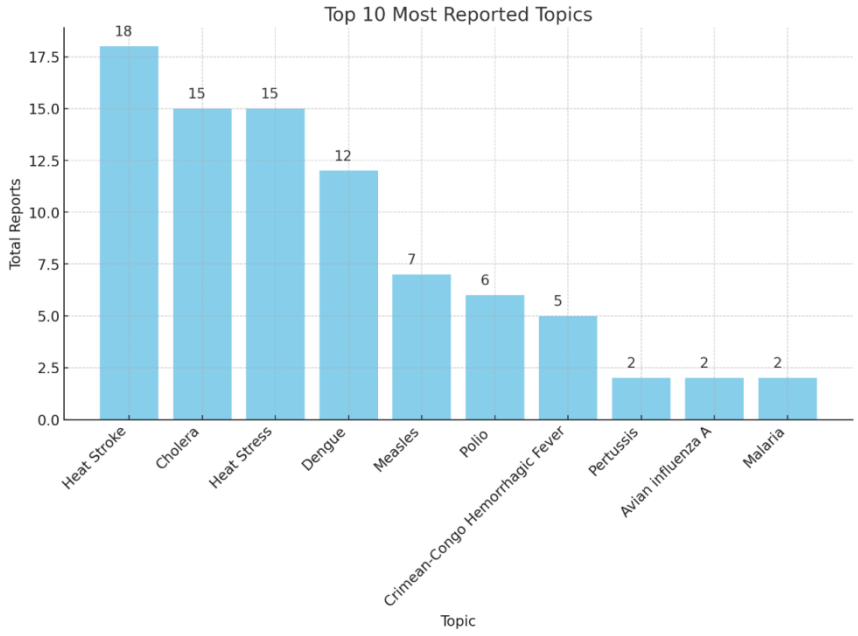
Between June 3 and June 23, 2024 (Hajj period), 877,000 articles were screened, with 96 articles retained after triage, corresponding to 96 unique health-related cases. The most frequent topics were Heat Stroke (18 cases), Heat Stress (15 cases), Cholera (15 cases), and Dengue (12 cases). Other topics included infectious diseases (e.g., Measles, Polio) and environmental health issues. Heat Stroke topped the list, likely due to extreme temperatures and physical exertion. Of the 96 cases, 64 (66.7%) were classified as low risk, indicating manageable issues, while 32 (33.3%) were moderate–high risk, reflecting critical threats like severe heat stroke and cardiovascular events requiring urgent attention (Table 1).

Table(1): Descriptive statistics of total number ofarticles and their risk level

	Number of articles
Total number of articles undergo screening	877,000
Number of articles undergo triage	111 (0.013%)
Total Reported Cases after triage	96 (86.4%)
Most Reported Topic	Heat Stroke (18 cases)
Low Risk Cases	64 (66.7%)
Moderate – high risk cases	32 (33.3%)

In figure 1 the bar chart represents the top 10 most frequently reported health-related topics during the Hajj period based on the number of reports received.The highest-reported topic is significantly more frequent than others (heat stroke, cholera and Heat Stress), indicating it was a major health concern.There is a gradual decline in the number of reports as we move from the highest-reported topic to the 10th most reported one.The differences in report counts suggest that some health issues were more prevalent or concerning than others during the Hajj period.

Figure (1): Top 10 Reported Topics in hajj period



A comparison between event occurrences Before and During Hajj in Figure 2 shown that Before Hajj The number of events gradually increases leading up to Hajj. However, During hajj, inJune 18–20 sees the highest cases, pilgrimage gathering in Muna and Arafat and spending extended hours under the sun.Mass gatherings and physical strain contribute to the peak.Lack of cooling mechanisms or hydration may have exacerbated the situation.After the peak, the event occurrences drop sharply, though they remain slightly higher than before Hajj.Towards the later dates (June 21 onward), there were a smaller fluctuations but still higher than the pre-Hajj period.

Figure (2): Comparison of event occurrences over time (Before/During Hajj)

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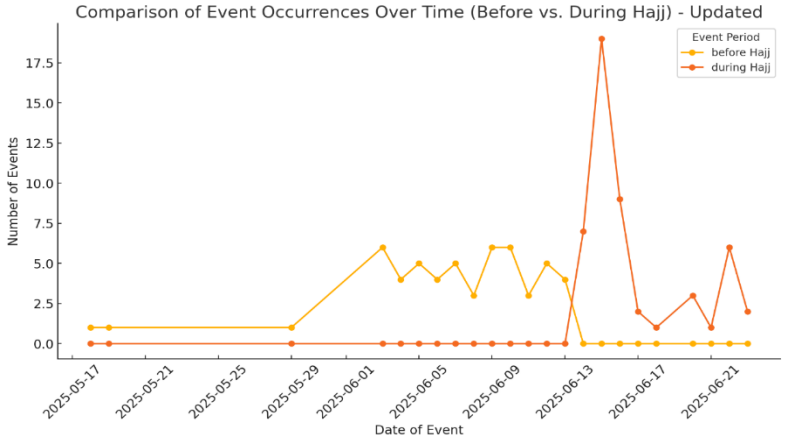


comparative analysis was conducted of key health incidents before and during Hajj, categorized by the location of the signal/event (inside or outside KSA). It showsthatHeat Stress and Heat Stroke were exclusively reported Inside KSA and mostly During Hajj, highlighting the impact of extreme temperatures in the region and they significantly contribute to mortality. However, high-risk infectious diseases (Cholera, Dengue and Measles) are mostly reported Outside KSA Before Hajj. Cholera Increased from 6 cases before Hajj to 9 cases during Hajj, with all cases reported outside KSA.Dengue most cases (10 out of 12) occurred before Hajj, with very few detected during Hajj but Outside KSA .and lastly, Measles increased from 3 cases before Hajj to 5 cases during Hajj, still confined outside KSA(table 2).

Table(2): Comparison of Health Incidents Before & During Hajj according to location of signal/event

Topic	Before Hajj	During Hajj	Location of signal/event
Cholera	6	9	15 Outside KSA
Dengue	10	2	12 Outside KSA
Heat Stroke	1	17	18 Inside KSA
Measles	3	5	8 Outside KSA
Heat Stress	10	5	15 Outside KSA

The Chi-Square analysis examines whether the frequency of the top reported health incidents differs significantly between the periods before and during Hajj based on location of the event (Inside/Outside KSA). It shows that the p-value ($p < 0.05$) which suggests a statistically significant difference in the distribution of health incidents before and during Hajj based on event location.This indicates that certain health incidents are more likely to occur during the Hajj period.Cholera, Dengue, and Measles cases are predominantly reported before Hajj Outside KSA. While Heat

strokes and Heat Stress incidents increase significantly during Hajj Inside KSA.(table3).

Table 3: Observed / Expected Frequency Table

Topic	Event Occurrence	Inside KSA	Outside KSA
Cholera	before Hajj	0 (2.96)	6 (3.04)
Cholera	during Hajj	0 (4.43)	9 (4.57)
Dengue	before Hajj	0 (4.93)	10 (5.07)
Dengue	during Hajj	0 (0.99)	2 (1.01)
Heat Stress	before Hajj	10 (4.93)	0 (5.07)
Heat Stress	during Hajj	5 (2.46)	0 (2.54)
Heat Stroke	before Hajj	1 (0.49)	0 (0.51)
Heat Stroke	during Hajj	17 (8.37)	0 (8.63)
Measles	before Hajj	0 (2.46)	5 (2.54)
Measles	during Hajj	0 (0.99)	2 (1.01)

Table 3: Chi-Square Comparative Analysis: Top Reported Health Incidents Before & During Hajjcategorized based on location of events

Chi-Square Statistic	67.0
Degrees of Freedom (dof)	9
P-Value	0.0000000
Statistical Significance	Yes ($p < 0.05$)

In table (4) chi-square test were conducted to show the relation between reported topics and risk level. The p-value was extremely low (< 0.05), meaning that there was a statistically significant relationship between health topics and their assigned risk levels.This confirms that certain health topics are not randomly assigned to low or high risk categories; instead, their classification follows a strong pattern.

Heat stroke (18 cases) is correctly recognized as a high-risk event—mitigation efforts should continue.Heat stress (15 cases) may need closer evaluation, ensuring no cases escalate unnecessarily. Cholera, Dengue and Measleswere all classified as "Low Risk". Post hoc analysis was done to show how strong the association is between each topic and its assigned risk level (figure 4.2). the results shown that Heat Stroke is the most strongly associated with "Moderate - High Risk" (Residual: +3.07).This confirms that fatalities among pilgrims were the most serious health concern.Heat Stress was moderately associated with Moderate – High risk (Residual: +2.08). Cholera and Dengue were significantly associated with Low Risk (Residuals: +2.68 and +2.4).These diseases were almost never classified as High Risk.This suggests cholera and dengue cases were perceived as manageable rather than high risk.This means these non-infectious incidents are viewed as critical risks.

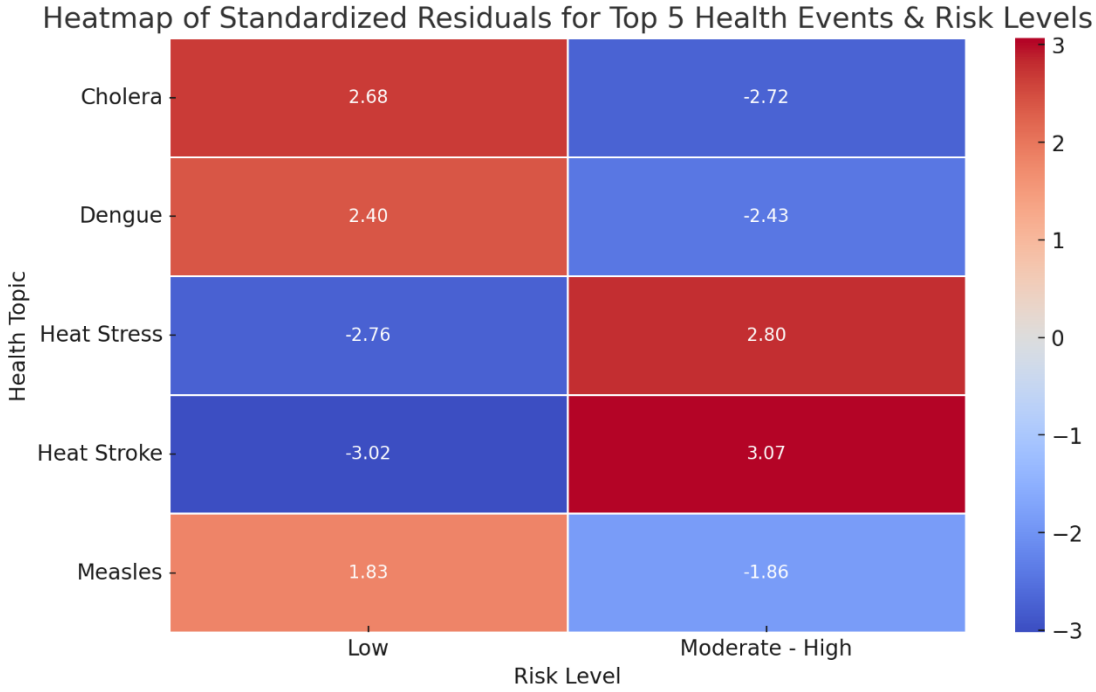
Table 4: Chi-Square Test Results: Top 10 Reported Topics relation to Risk Level

Chi-Square Statistic	67.0
Degrees of Freedom (dof)	4
P-Value	0.0000000
Statistical Significance	Yes ($p < 0.05$)

Table (4.1)Observed/Expected FrequencyTable (Top 5 Reported Topics)

Topic	Low	Moderate - High
Heat Stroke	0 (9.13)	18 (8.37)
Cholera	15 (7.61)	0 (7.39)
Dengue	12 (6.09)	0 (5.91)
Measles	7 (3.55)	0 (3.45)
Heat Stress	0 (7.61)	15 (7.39)

Figure (4.2)Heatmap of Standardized Residuals (Post Hoc Analysis - Top 5 Topics)



Standardized Residual Interpretation

< **±1.96** Not significant (random association)

±2 to ±3 Moderately significant

> **±3** Strongly significant association

Discussion

The results from the study on Enhancing Health Monitoring Systems During Hajj 2024 Using Open Source Epidemic Intelligence (EIOS) reveal critical insights into the effectiveness of digital epidemic intelligence in managing public health risks during mass gatherings. The findings underscore the utility of real-time surveillance in identifying and mitigating health threats, particularly in extreme environmental conditions like those experienced during Hajj. Comparing it with findings from Ukraine (conflict surveillance), Qatar (FIFA World Cup 2022), and Tokyo (Olympics

2020). The results indicate that Heat-related illnesses (Heat Stroke: 18 cases, Heat Stress: 15 cases) were the most reported health incidents during Hajj, highlighting the impact of extreme environmental conditions. Infectious diseases such as cholera (15 cases) and dengue (12 cases) were primarily detected outside Saudi Arabia before Hajj, reinforcing the importance of pre-travel health screening. The prevalence of heat-related illnesses is consistent with previous studies on mass gatherings in extreme heat conditions, such as the Hajj 2015 heatwave and the 2018 Kumbh Mela in India. Similarly, the Ukraine conflict studythe infectious disease outbreaks surged due to the collapse of formal surveillance in conflict zones, with a 447% increase in reports of cholera, tuberculosis, and HIV/AIDS. In contrast, The FIFA World Cup in Qatar faced respiratory and airborne disease concerns, with a 0.85% probability of detecting public health signals. Also, The Tokyo 2020 Olympics primarily monitored imported infectious diseases, screening 103,830 articles but ultimately finding no major threats. These findings demonstrate the adaptive role of EIOS in different public health contexts, from mass gatherings to crisis zones.

The peak in health incidents in Hajj occurred between June 18–20 coincided with the most physically demanding parts of the pilgrimage, particularly in Mina and Arafat. This finding aligns with past research, demonstrating that mass gatherings, combined with heat exposure, significantly increase health risks. Similarly, Qatar FIFA World Cup's health threats increased on matchdays, showing a link between mass movement and disease transmission. However, Tokyo Olympics maintained a steady health risk level throughout the event due to strict pre-event screenings and travel restrictions. Lastly, Ukraine showed a progressive increase in disease burden over time, suggesting a cumulative effect of war-related disruptions on public health. This findings highlight that short-term events have peak risk periods, whereas crisis zones require sustained monitoring.

A spatial comparison showed heat-related illnesses occurred exclusively within Saudi Arabia, whereas infectious disease reports were more common outside KSA before Hajj.

Notably, infectious diseases like Cholera and Dengue were consistently classified as low risk during Hajj 2024, despite their global severity. This classification likely stems from their detection primarily outside Saudi Arabia before Hajj, coupled with effective pre-Hajj vaccination and screening programs that minimized their spread during the event. This underscores the importance of pre-travel surveillance in mitigating imported disease risks.

A Chi-square analysis confirmed a statistically significant difference ($p < 0.05$) in health event occurrences before and during Hajj, as well as their location (Inside/Outside KSA). Heat-related illnesses were strongly associated with high risk, requiring urgent mitigation strategies.

Comparison between KSA, Qatar, Tokyo and Ukraine study

Study	Primary Health Risks	EIOS Effectiveness	Unique Public Health Challenges
Hajj 2024 (Saudi Arabia)	Heat stroke, heat stress, cholera, dengue	Detected environmental health trends effectively	Extreme heat, crowd density, pre-travel disease importation
Ukraine Conflict 2022	Cholera, botulism, TB, HIV/AIDS	Replaced formal surveillance in a	Healthcare infrastructure

		war zone	collapse, disease outbreaks in displaced populations
FIFA World Cup 2022 (Qatar)	Airborne diseases, MERS-CoV, foodborne infections	0.85% probability of detecting relevant signals	High-density crowd events, matchday disease risks
Tokyo 2020 Olympics (Japan)	Imported infectious diseases (dengue, respiratory infections)	Captured global health signals but required high manual effort	International participation, risk of disease importation

Effectiveness of Epidemic Intelligence in Different Surveillance Models

A. Mass Gatherings: The Need for Real-Time Detection

Hajj in KSA, FIFA World Cup in Qatar, and Olympics in Tokyo relied on EIOS for early warning signals, but response measures varied. Hajj in KSA lacked a predictive model to anticipate heat-related illnesses before they peaked. However, FIFA World Cup in Qatar response was mostly reactive to detected airborne disease signals. Moreover, Olympics in Tokyo successfully integrated EIOS with traditional surveillance, reducing public health risks. This suggests that EIOS is best used in combination with preemptive mitigation strategies for mass gatherings.

B. War and Conflict: Filling the Gap in Surveillance

Ukraine relied on EIOS not as a supplementary tool but as a primary disease tracking mechanism due to the breakdown of formal reporting. Unlike mass gathering settings, where EIOS detected disease risk before major outbreaks, Ukraine's EIOS data reflected ongoing epidemics in real-time. This proves that EIOS is highly adaptable—it can function as both an early warning system (mass gatherings) and a core surveillance replacement tool (conflict zones).

Previous research has highlighted the role of digital and social media platforms in predicting and managing outbreaks. For example, Twitter activity has been shown to anticipate disease outbreaks before official reports, underscoring its potential in epidemic intelligence systems [7]. Similarly, during the 2010 cholera outbreak in Haiti, social and news media provided valuable early insights that enabled faster epidemiological estimations compared to traditional surveillance [8].

In addition to infectious disease surveillance, digital platforms have been applied in pharmacovigilance, where Twitter monitoring was used to detect early safety concerns related to pharmaceutical products [9]. This demonstrates the broader applicability of digital epidemic intelligence beyond communicable diseases.

Systematic reviews further reinforce the importance of integrating social media and online data into surveillance frameworks. These studies confirm that such platforms can serve as complementary tools to traditional systems, enhancing outbreak management and public health response [10,12,13]. In line with this, global health experts have recommended hybrid surveillance models that combine event-based digital intelligence with traditional reporting to strengthen early detection and improve response timeliness [11].

Finally, the emerging concepts of "infodemiology" and "infoveillance" emphasize the systematic use of online health information and digital behavior tracking for public health purposes. These approaches not only provide real-time insights for epidemic preparedness but also align with the increasing reliance on open-source intelligence in global health security [14].

Public Health Preparedness and Policy Implications

The successful use of Open Source Epidemic Intelligence (EIOS) highlights its potential as a proactive surveillance tool in mass gatherings. Real-time data collection allowed health authorities to identify and respond to threats quickly, enhancing public health preparedness

1. Tailored Surveillance Strategies:
   - In KSA in Hajj, environmental monitoring is crucial due to heat-related risks.
   - In Qatar and Tokyo, infectious disease importation monitoring is essential.
   - In Ukraine, real-time epidemic tracking in conflict zones can replace traditional surveillance when it fails.
2. Pre-Event Health Screening:
   - Pre-Hajj vaccination programs and screenings can help reduce imported infectious diseases.
   - Better sanitation infrastructure in conflict zones like Ukraine can mitigate waterborne outbreaks.
3. Need for AI-Driven Automation:
   - Tokyo's study required extensive manual data validation, suggesting that improvements in machine learning and AI filtering are needed to streamline epidemic intelligence processing.
   - Qatar's study demonstrated a probability of 0.85% for detecting public health threats, highlighting that AI models should prioritize high-risk events.

Guidelines for EIOS Deployment in Large-Scale Public Health Scenarios

The Early Intelligence Open Source (EIOS) system is an advanced epidemic intelligence platform designed to enhance public health monitoring during large-scale events. This document outlines best practices for deploying EIOS in future mass gatherings, incorporating lessons learned from Hajj 2024.

1. Pre-Event Phase (Preparation & System Optimization)

1.1 Integrating EIOS with National Health Surveillance

- Ensure interoperability between EIOS and national public health monitoring systems.
- Establish automated alerts for high-risk signals to reduce false negatives.
- Improve language processing to accurately classify health reports in different languages.

1.2 Defining Event-Specific Risk Criteria

- Develop specialized filters for event-related health threats (e.g., heat stroke, respiratory diseases).
- Enhance data validation to cross-check EIOS signals with hospital reports.

1.3 Strengthening Pre-Travel Disease Surveillance

- Monitor importation risks for communicable diseases such as Cholera, Polio, and Dengue.
- Implement border health screenings based on EIOS early warnings.
- Enforce mandatory vaccinations for high-risk infections.

2. During Event Phase (Real-Time Surveillance & Response)

2.1 Deploying On-Ground EIOS Monitoring Teams

- Assign dedicated EIOS teams at high-risk locations (e.g., pilgrimage sites, stadiums).
- Develop real-time dashboards for health officials to access live reports.
- Use automated AI alerts for detecting sudden spikes in health incidents.

2.2Exploring AI-Driven Predictive Modeling

Future deployments of EIOS should incorporate predictive modeling to enhance proactive surveillance. Logistic regression models could predict disease hotspots based on environmental factors (e.g., temperature, crowd density) and epidemiological data. During Hajj 2024, predictive models were not implemented, but retrospective analysis suggests their potential to anticipate heat-related illness peaks (e.g., June 18–20). Future events should:

Develop models to forecast high-risk periods using historical data.

Integrate real-time environmental data (e.g., humidity, heat index) into predictions.

Optimize resource allocation (e.g., hydration stations, EMS) based on predictive analytics.

2.3 Future Research Directions

Testing Predictive Models:

Future studies should pilot AI-driven predictive models during mass gatherings, using Hajj 2024 data as a baseline to validate their accuracy in forecasting heat-related and infectious disease risks.

2.4 Strengthening Rapid Response Mechanisms

- Coordinate with emergency medical teams to validate EIOS-reported cases.
- Establish hydration stations and emergency clinics in high-risk areas.
- Implement tracking mechanisms for locating missing individuals.

3. Post-Event Phase (Evaluation & System Improvement)

3.1 Conducting Post-Event Data Validation

- Compare EIOS reports with hospital admission records.
- Identify under-reported health threats and adjust filtering criteria.
- Evaluate the timeliness of alerts and response times.

3.2 Refining Machine Learning Models

- Improve classification algorithms using chi-square analysis and ROC curve evaluation.
- Implement human-in-the-loop validation for AI-generated reports.
- Regularly update disease trend models based on historical event data.

3.3 Publishing Guidelines for Future Mass Gatherings

- Share EIOS findings with global public health organizations.
- Develop standardized protocols for EIOS deployment in large-scale events.
- Update international health regulations based on EIOS data-driven insights.

4. Recommended Statistical Approaches for EIOS Performance Evaluation

4.1 Chi-Square Test for Event Pattern Analysis

- Determines whether specific diseases increase significantly during mass gatherings.
- Helps differentiate between random fluctuations and real outbreaks.

4.2 Logistic Regression for Risk Prediction

- Predicts the likelihood of an event being classified as high-risk.
- Uses environmental and epidemiological factors as key predictors.

4.3 Cohen's Kappa & ROC Curve for Accuracy Measurement

- Cohen's Kappa measures agreement between EIOS and actual reports.
- ROC Curve evaluates how well EIOS classifies high-risk incidents.
- Optimizes false positive and false negative thresholds for improved accuracy.

Limitations of the study

Data Processing Efficiency:

As seen in Tokyo and Qatar studies, EIOS required significant manual effort for signal verification. In Hajj 2024, the lack of direct integration with hospital data limited real-time clinical validation, potentially delaying responses to emerging threats.

Bias in Data Sources:

EIOS relies heavily on media and online reports, which may underreport outbreaks in regions with weak journalism infrastructure (e.g., low-resource countries). This could skew perceptions of disease prevalence.

Scalability Challenges:

Deploying EIOS in resource-constrained settings may be difficult due to the need for advanced technical infrastructure and trained personnel, limiting its accessibility for smaller health systems.

False Positives and Negatives:

The triage process, while rigorous, may have missed subtle signals (false negatives) or included marginally relevant articles (false positives). Automated filtering algorithms require further refinement to balance sensitivity and specificity.

Cultural and Linguistic Barriers:

Variations in reporting styles and language nuances across diverse sources may have affected signal accuracy, particularly for non-Arabic or non-English reports, potentially underrepresenting certain health threats.

These limitations suggest areas for improvement, such as integrating clinical data, enhancing AI algorithms, and tailoring EIOS to diverse cultural contexts.

Future Research Directions

To enhance the effectiveness of EIOS for public health surveillance, future studies should focus on:

1. Integrating Real-Time Medical Data:
   - Hajj in KSA and Qatar studies suggest combining hospital records with EIOS tracking for better validation.
   - Ukraine's study could benefit from cross-referencing satellite and humanitarian data sources.
2. Improving AI and Machine Learning for Epidemic Intelligence:
   - The Tokyo study required extensive manual effort, underscoring the need for automated data filtering and validation.
   - Enhancing AI-driven anomaly detection can improve the accuracy of EIOS-generated health alerts.
3. Developing Event-Specific Surveillance Protocols:
   - Hajj in KSA should prioritize heat-related illnesses, while Qatar and Tokyo should refine airborne disease detection.
   - Ukraine's crisis response model should be adapted for other war-affected regions.

Recommendations for Future Hajj Events

1. Strengthen Heat Mitigation Measures
2. Enhance Pre-Hajj Infectious Disease Screenings
3. Leverage Digital Surveillance for Real-Time Response

4. Increase Health Awareness Campaigns for Pilgrims
5. Optimize Emergency Medical Services (EMS) Deployment

Conclusion

This study demonstrates that EIOS is a powerful, adaptable tool for epidemic surveillance in mass gatherings and crisis settings. However, its full potential can be unlocked through AI improvements, better global coordination, and integration with clinical data sources. Future implementations should focus on proactive rather than reactive public health interventions, ensuring a safer environment for global events and faster responses to emerging health threats.

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