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Forecasting and Quantifying Event-Induced Stress during the Prayagraj Maha Kumbh Using Machine Learning and a Composite Event Stress Index

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***Abstract* - Large-scale public events create short-term but intense environmental and social pressures that challenge urban planning and sustainability goals. These pressures and future expectations are critical to sustainable event planning and mitigation of risks. This study is a time-series forecasting, machine-learning analysis, and composite index construction built into a unified framework exploring four Maha Kumbh cycles that have taken place in Prayagraj (1989, 2001, 2013, and 2025). Forecasting models are used to predict future trends in air pollution, water quality, waste generation, crime incidents, visitors, and sentiments. The relative impact of environmental and social drivers is determined using machine-learning methods, in particular, Random Forest, and transformed into objective weights to create an Environmental-Social Stress Index (ESI). Normalization and aggregation of all indicators produce event-year comparative stress scores. The proposed framework provides a logical method of assessing environmental and social stress in massive gatherings. The analysis of forecasting, data-driven weighting, and composite indexing can inform policymakers in taking action to enhance preparedness, resource allocation, and sustainability plans of future Kumbh cycles and other mass gatherings.**

Keywords: Maha Kumbh, Event Stress Index, Time-Series Forecasting, Random Forest, Mass Gathering Analysis, Prayagraj.

I. INTRODUCTION

The religious and cultural mass movements all over the world are some of the strongest temporary mobilizations of human beings. Such meetings, temporarily, turn the host areas into overcrowded an area, which exerts too much pressure on the environment, infrastructures, and social structure. The recent studies on globally significant pilgrimages, including the Hajj in Saudi Arabia and the Arba'een pilgrimage in Iraq, show that a quick increase in population is commonly accompanied by air pollution, water pollution, garbage, and health-security hazards (Albalawi *et al.*, 2025). These events also demand complicated systems of governance to control the movement of the crowd, sanitation services, and security of the people, especially when tens of millions of people attend in a limited geographical area.

Although the focus on mass gatherings in scholarly research has been growing, much of the existing literature is still focused on health surveillance, emergency response, and management of crowd safety. Environmental effects and social reactions are studied in isolation, leading to a limited understanding of the correlations between different stressors in such events (Nouri, 2023). According to the recent public health studies, it has been established that environmental degradation, behavioral stress, and infrastructural strain tend to occur simultaneously and may exacerbate each other in the case of large-scale pilgrimages (Azizi *et al.*, 2024). Nevertheless, a clear gap remains between the lack of combined analytical frameworks that integrate the environmental indicators with the social and behavioral measures, in particular, in the predictive framework.

The Kumbh Mela is one of the oldest Vedic Hindu festivals that is held alongside four river banks destinations at regular intervals around the world, an event that is also the one of the greatest mass events, which is currently held at a regular frequency. The occasions are especially celebrated at the Prayagraj Kumbh, which is known in the world due to its amazing size, and the number of pilgrims who attend it is estimated at tens of millions during the main bathing days. The festival entails prolonged human habitation along the river banks, immense bathing pressure during peak days, heavy pressure on hotels and accommodation facilities, continuous mass movement, and extensive short-term infrastructure development (Central Pollution Control Board, 2023). All these make the Prayagraj Kumbh a significant case to examine environmental stress, specifically air quality, the situation in river-water and waste management.

Environmental monitoring data of previous Kumbh activities demonstrate that both overbathing and a substantial number of pilgrims had quantifiable negative effects on the

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quality of water, including high contamination rates and reduced bathing suitability of certain areas of rivers. Similar issues have been noted in the research on other pilgrimages, where transport movement and energy consumption resulted in an immediate loss of air quality during peak visitor events. Also, social issues like crime incidents, crowd anxiety, and mood change among the population add to these environmental factors to the overall stress levels incurred during the event (Kanaujiya & Tiwari, 2022). Empirical research on mass gatherings has indicated that population density and perceived environmental degradation can cause a major impact on collective behavior and the level of satisfaction (Narimani *et al.*, 2025).

One of the most notable benefits of the Kumbh Mela to study is that it is cyclical. The event takes place at regular intervals with similar cultural and geographical circumstances that can be long-term compared over the years. Later versions, especially the 2025 Prayagraj Kumbh, have also included digital crowd-monitoring services, real-time environmental sensors, and data-driven management systems to create more detailed datasets than previously capable of being delivered (Government of Uttar Pradesh, 2025). The developments open the way to implement forecasting and machine-learning methods to learn changing stress patterns and can facilitate evidence-based planning.

In this regard, the current research compares four Maha Kumbh cycles that took place in Prayagraj (1989, 2001, 2013, and 2025) with the combined time-series forecasting, machine-learning models, and composite index construction. To forecast the future movement of air pollution, water quality, waste generation, crimes, total number of visitors, and sentiments, time-series forecasting is used. The relative effects of environmental and social variables are determined by the use of Random Forest models, which are then converted into objective weights to create a composite Environmental-Social Stress Index (ESI). The combination of forecasting, machine learning, and weighted indexing is used to make the study a complete framework of evaluation of historical performance and predicting future obstacles related to big religious meetings.

In general, this study can add to the ever-expanding literature on mass-gathering analysis, as it provides a data-driven methodology that encompasses both environmental and social aspects of stress. The developed framework of the Prayagraj Kumbh can be used by the policymakers and planners to enhance the preparedness, resource allocation and sustainability plans of future Kumbh cycles and other large-scale events across the world.

II. LITERATURE REVIEW

Mass events with a vast majority of participants have become more and more understood as complicated socio-environmental systems where the extreme density of the crowd, temporary infrastructure, and increased consumption of resources create the stress on the city in the short term but intensive (Haghani *et al.*, 2023). Worldwide, Hajj pilgrimage in Saudi Arabia, Olympic Games, and significant music festivals in Europe and North America have been fully researched in terms of their implications on the overall health of people, the environment, and the capacity to serve (Azhar *et al.*, 2025). This viewpoint was codified by the World Health Organization as mass gatherings were established to be in high-risk settings that necessitated combining the evaluation of the environmental, health, sanitation, mobility and emergency response aspects (WHO, 2017). This universal cognition (Bossio *et al.*, 2021) defined that, as the scale of crowds goes beyond regular urban capacity, stress does not arise because of a singular determinant but the interactions of subsystems.

Developing on this international framing, empirical research studies on the Hajj have shown that crowd density and movement restrictions increase health hazards, heat pressures, and emergency management dilemmas, and structured risk management and surveillance systems are created (Samarkandi *et al.*, 2025). In a similar manner, research on host cities of the Olympics indicates temporary air pollution peaks, an increase in waste, and transport congestion, especially during the busiest days (Jeremy *et al.*, 2025). These cases across international borders show that as the crowd grows in size, environmental and infrastructural stressors start to compound one another, where the research focus is on the individual indicators becomes more system-based.

Among the wider literature of mass gatherings, the Kumbh Mela in India is an extreme and one-of-a-kind scenario because of its scale and patterns of congregations that were ritual-seeking (Singh *et al.*, 2025). Kumbh Mela events have been tracked in terms of sharp rises in healthcare demand and incidence of injuries also reflecting sanitation pressure on host cities, which confirms that the event is a high-intensity stressor on host cities (Singh *et al.*, 2021; Gautam *et al.*, 2021). The pressure on environmental and civic systems is more apparent as the number of the crowd increases, which in turn leads to future research focused on the quantifiable effects of the same on the environment (Zhang *et al.*, 2023).

River water quality deterioration during the celebrations of Kumbh Mela of Prayagraj has been the most systematically studied aspect of the environmental dimension. The 2019

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Kumbh and analysed through Multivariate and Water Quality Index indicate that there occurred a significant degradation of physicochemical and microbial parameters at the times of the mass bathing at the Sangam and downstream locations (Varma *et al.*, 2022; Kanaujiya *et al.*, 2024). These results clearly define environmental stress in Kumbh as an eventual stress and not a seasonal stress. Nonetheless, concentrating on the water quality only demonstrates only one manifestation of a more complex process of stress occurring on the level of various urban systems (Nikolopoulos *et al.*, 2022).

In parallel to the water quality effects, the problems of sanitation load, and solid wastes generation have also been recognized as crucial operational issues in the context of Kumbh and Magh Mela events Temporary settlements, food delivery areas, and excessive density of people as the primary factors contribute to the significant growth of dumped waste quantities and sanitation overload, which, in turn, significantly deteriorates the environmental pollution and health hazards of the population (Central Pollution Control Board, 2025). Sanitation stress is increasing and with the pressure of the crowds and environmental degradation, this stress acts together, showing that integrated analysis is required as opposed to sector-specific (Li and Liu, 2025).

Forecasting and machine learning methods of understanding and predicting these complex interactions in the environment and urban environment have become common in the literature of environmental and urban analytics over the last few years. Specifically, it has been demonstrated that the models based on the random forest can effectively capture the non-linear relationships, as well as the dominant drivers in air quality and environmental stress prediction (Patel *et al.*, 2025; Yenkikar *et al.*, 2025). Meanwhile, index-based methods, including the Crowd Stress Index, proved the usefulness of integrating various dimensions of stress into useful measures where decisions could be made (Parsons, 2004). However, these methods are mostly dissociated from the situations of religious mass gatherings.

Collectively, the literature demonstrates a strong development: global mass events demonstrate system-level stress; Kumbh Mela research studies prove that events impose environmental and infrastructural stress and new methods provide tools that can be used to combine the dimensions. The only area that has not been thoroughly investigated is a forecast-enabling structure integrating environmental degradation, the infrastructure load, and crowd pressure into one measurable, interpretable value in regards to events of such magnitude as the Prayagraj Maha Kumbh.

III. METHODOLOGY

3.1 Data Source and Study Scope

The research relies on secondary data, which is a publicly accessible Kaggle dataset called *Mahakumbh_Complete_Dataset*. The dataset will include event level data on several Maha Kumbh sites and years. Only the records related to Prayagraj are selected in this study because the aim is to estimate the stress dynamics related to the Prayagraj Maha Kumbh.

Let the filtered dataset be represented as:

$$\text{Dataset } D = \{Y_1, Y_2, \ldots, Y_n\} \quad (1)$$

Where

Y_n represents the nth Maha Kumbh year of Prayagraj;

n refers to the total number of years of analysis of events.

3.2 Variable Selection and Stress Dimensions

Variables are clustered in three conceptual domains to measure multidimensional event stress: The indicators of environmental stress are:

1. Environmental stress indicators

- Air Pollution Level
- Water Quality Index
- Waste Generated (tons)

2. Crowd-related indicators

- Total Visitors

3. Social stress indicators

- Crime Incidents
- Positive Sentiment Percentage
- Negative Sentiment Percentage

All the variables are retained as they were presented in the dataset, and no synthetic indicators are developed, which guarantees transparency and reproducibility.

3.3 Data Normalization

The values of the chosen indicators are measured using various scales and units, thus they need to be normalized before aggregation and machine learning analysis.

Min–max normalization is applied to each variable:

$$x_{i,t}^{norm} = \frac{x_{i,t} - min\,(x_i)}{max\,(x_i) - min\,(x_i)} \quad (2)$$

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where $x_{i,t}$ represents the original value of the i[th] indicator in event year t, $x_{i,t}^{norm}$ denotes the normalized value of the ith indicator for year t, i indexes the selected stress indicators, and ttt denotes the Maha Kumbh event year. The terms $\min(x_i)$ and $\max(x_i)$ represent the minimum and maximum values of indicator i computed across all event years.

This step ensures that all indicators lie within the range [0, 1] and contribute comparably to subsequent analyses.

3.4 Time-Series Forecasting of Stress Indicators

Time-series forecasting has been used to predict the future stress, including air pollution level, waste generation, water quality index, and crime incidents, to study the temporal changes and predict future stress.

Each indicator was modeled as a function of time:

$$X_t = T_t + E_t + \epsilon_t \qquad (3)$$

where

- X_t is the observed value of the indicator at event year t
- T_t represents the long-term trend component
- E_t captures event-specific deviation
- ε_t denotes random error

Forecasting outputs are used to analyze future stress trajectories and are not used to generate synthetic data for model training.

3.5 Construction of a Composite Stress Proxy

In order to provide machine learning–based identification of stress drivers, a composite stress proxy is constructed by combining key stress-related indicators.

The raw stress score S_t for event year t was computed as:

$$S_t = AP_t + WG_t + NS_t + WQ_t \qquad (4)$$

where

- AP_t = Air Pollution Level
- WG_t = Waste Generated
- CI_t = Crime Incidents
- NS_t = Negative Sentiment Percentage
- WQ_t = Water Quality Index

This specific formulation represents the hypothesis that higher levels of water quality lead to lower stress and, conversely, higher levels of stress are associated with air pollution, waste, crime, negative sentiment.

3.6 Random Forest–Based Identification of Stress Drivers

Random Forest regression has been used to assess the relative significance of each indicator in the overall stress.

Let the predictor matrix be:

$$X = [x_1, x_2, \dots\dots, x_k] \qquad (5)$$

where X_k denotes the k[th] normalized stress indicator, and the target variable is S_t (Equation 4).

The Random Forest prediction is given by:

$$\hat{S}_t = \frac{1}{M}\sum h_m(X) \qquad (6)$$

where

- h_m represents the m[th] decision tree
- M denotes the total number of trees

The mean decrease in impurity is applied to obtain feature importance values FI_i which show the contribution of each indicator to stress prediction.

3.7 Weight Derivation for Event Stress Index

The Random Forest feature importance values are normalized to derive weights for index construction:

$$w_i = FI_i / \sum FI_i \qquad (7)$$

where

- w_i is the normalized weight of the i[th] indicator
- $\Sigma w_i = 1$

These weights ensure that indicators contributing more strongly to stress receive proportionally higher influence in the index.

3.8 Event Stress Index (ESI) Computation

The Event Stress Index for each event year has been calculated as a weighted aggregation of normalized indicators:

$$ESI_t = \sum (w_i * X_{i,n,t}) \qquad (8)$$

where

- ESI_t represents the cumulative stress score for year t
- $X_{i,n,t}$ is the normalized value of indicator i for year t

Higher ESI values indicate greater cumulative stress during the Maha Kumbh event.

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3.9 Identification of the Most Stressful Event Year

The most stressful Maha Kumbh event has been identified by:

$$Y^* = \arg\max(ESI_t) \qquad (9)$$

where

- Y* denotes the event year with the maximum ESI value

This step enables ranking of Maha Kumbh events based on cumulative stress.

3.10 Computational Implementation

All steps are implemented using Python in a Google Colab environment. The workflow included data filtering, normalization, forecasting, Random Forest modeling, weight derivation, and index computation. This ensures full reproducibility and transparency of the analytical process.

IV. RESULTS

4.1 Environmental Stress Dynamics during Prayagraj Maha Kumbh

The historical study shows that, there is a high relationship between environmental degradation and the strength of the Maha Kumbh in Prayagraj. The level of air pollution is steadily on the rise during the years of large events, and the quality of water follows a downward pattern, especially during the periods of maximum congregation. Air pollution and water quality are inversely related, which implies the existence of the compounded environmental stress due to the increased motor movement, the short-term infrastructure development, and the mass bathing processes.

The projections towards the future show that the levels of air pollution might stabilize, but on the other hand, the production of waste is likely to increase significantly, and the quality of water is likely to decrease significantly unless the current mitigation measures are altered. The rise in waste production and water quality decline simultaneously indicates that waste management capacity will become one of the significant limiting factors in future Maha Kumbh events. All these trends point at the fact that future events will put more and more pressure on the environmental systems.

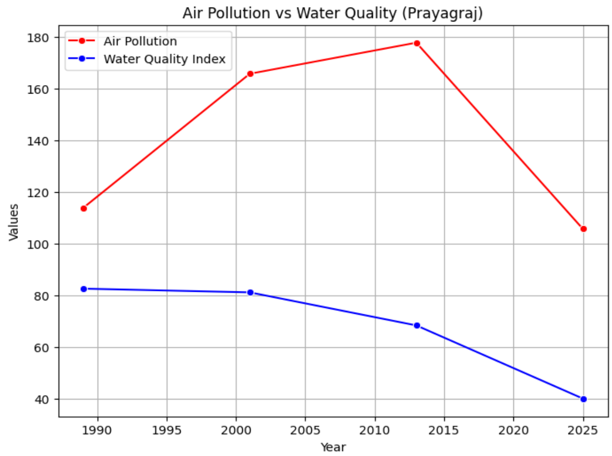

Figure 1: Air Pollution vs Water Quality (historical trend)

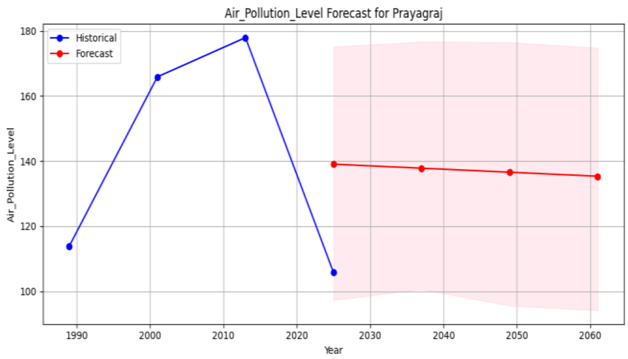

Figure 2: Air Pollution forecast

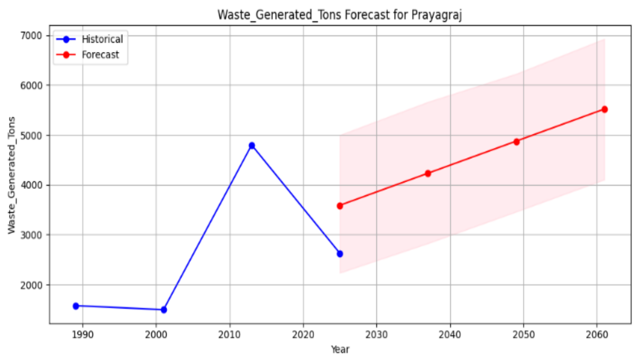

Figure 3: Waste Generated (historical + forecast)

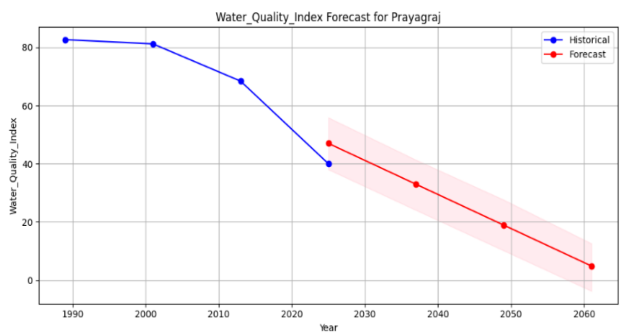

Figure 4: Water Quality Index (historical + forecast)

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4.2 Social Stress and Public Order Patterns

Crime event analysis shows that there was moderate but steady social stress in Maha Kumbh events. Higher crime incidents are recorded during peak event years indicating high level of crowd density and temporary population increase. According to the forecasted outcomes, it is believed that the number of crime incidents will decrease slowly over time, but the sheer magnitude of crowd concentration in Maha Kumbh will present significant social management issues, especially in the ritual peak days. This implies that the decline in the number of crimes might not be a complete measure of the social pressure behind the massive religious events.

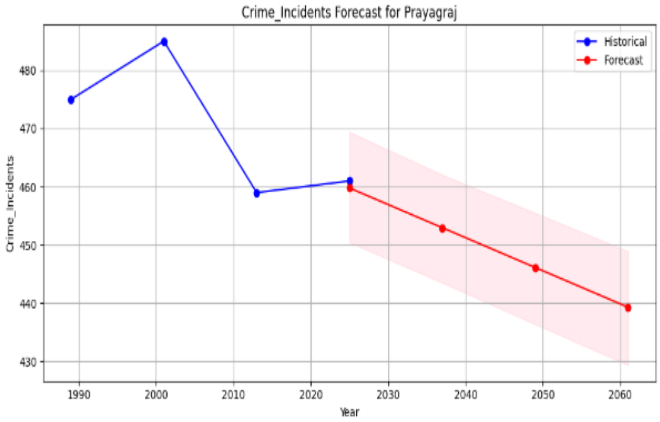

Figure 5: Crime Incidents (historical + forecast)

4.3 Machine Learning–Based Identification of Stress Drivers

The Analysis of Random Forests points to environmental indicators as the strongest determinants of the overall event stress at the Prayagraj Maha Kumbh. Among all variables, air pollution level and waste generation emerge as the most influential stress drivers, followed by total visitor count and positive public sentiment. This trend shows that crowd intensity and perception does enhance stress, but the major cause of cumulative pressure in Maha Kumbh events is the environmental load.

The dominance of visitor intensity also indicates that a scale of crowd is a major determinant of stress multifaction on the environment, and sentiment indicators reflect the perceptual aspect of stress that arises during massive religious events. It proves that the stress at Maha Kumbh is motivated by a correlation between the environmental degradation and the crowd-related factors, but not by social indicators.

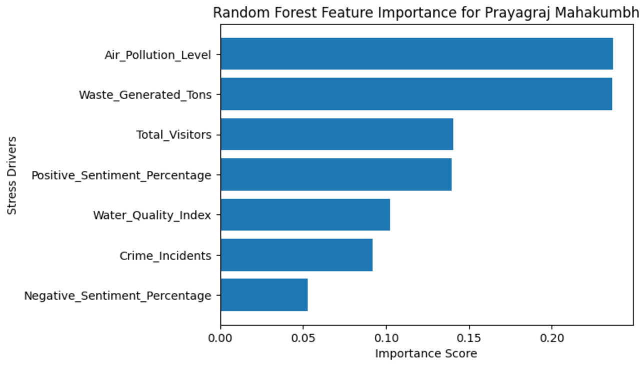

Figure 6: Random Forest Feature Importance (Prayagraj)

Table 1 summarizes the relative importance of stress drivers as identified by the Random Forest model.

Table 1: Random Forest Feature Importance for Prayagraj Maha Kumbh Stress Drivers

S. No.	Rank Variables	Importance Score
1.	Air Pollution Level	0.237
2.	Waste Generated (tons)	0.236
3.	Total Visitors	0.140
4.	Positive Sentiments (%)	0.140
5.	Water Quality Index	0.103
6.	Crime Incidents	0.092
7.	Negative Sentiments (%)	0.053

4.4 Event Stress Index (ESI) Assessment

The Event Stress Index combines stress measures of the environment, social, and crowd into one composite measure. This pattern in the ESI trend is characterized by an acute peak in Maha Kumbh years of high intensity, and the recent events partially moderated it. This trend indicates that administrative and infrastructural measures could alleviate some of the elements of stress, but the systemic pressure that comes with the influx of visitors is still high.

The ESI has been shown to measure cumulative stress behavior, which cannot be observed using individual indicators, without its usefulness in supporting the holistic monitoring and planning of large-scale religious events. Table 2 indicates that the Maha Kumbh of 2001 has the highest ESI value, which means that it was the most stressful event in the frame of the study.

Table 2: Event Stress Index (ESI) Values for Prayagraj Maha Kumbh Events

Year	ESI
1989	0.165
2001	0.939
2013	0.498
2025	0.574

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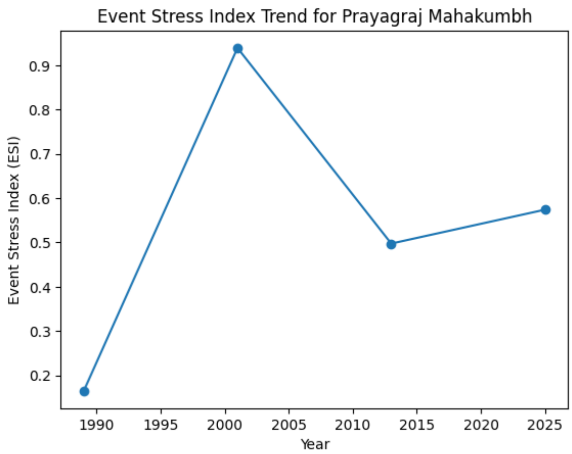

Figure 7: Event Stress Index (ESI) trend for Prayagraj

4.5 Interrelationships Among Stress Indicators

The correlation analysis shows that there are strong interdependencies between the key stress variables. Waste generation and air pollution have a positive and significant relationship with visitor volume, whereas the relationship between visitor volume and water quality is negative. Social indicators such as crime incidence and negative feelings also show significant correlations with the variables of environmental stress, supporting the idea of a multidimensionality of Maha Kumbh-related stress. These correlations are associative patterns but not causal relationships, highlighting the need to adopt cross-sectoral planning strategies and no single interventions.

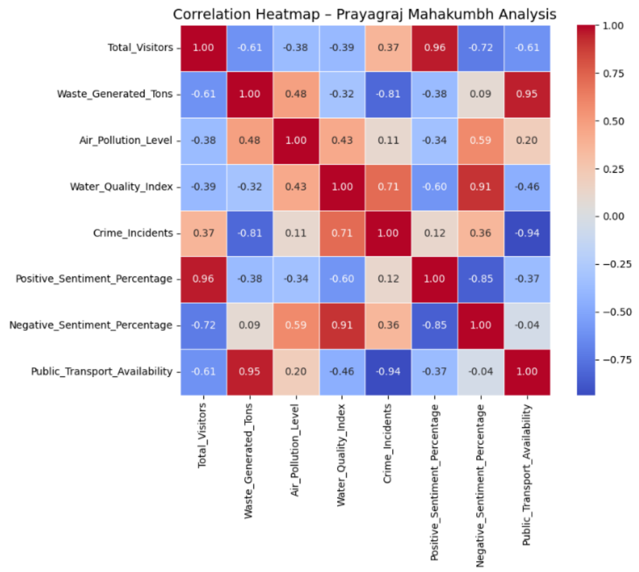

Figure 8: Correlation heatmap of selected stress indicators

V. DISCUSSION

The present study analyzes the multidimensional stress of the Prayagraj Maha Kumbh based on a time-series forecasting model, a Random Forest model-driven driver identification model, and composite Event Stress Index (ESI). The findings confirm the interpretation of how large religious events are complex systems where the environmental degradation, the intensity of the crowd, and social pressures interact to create a cumulative stress instead of being isolated phenomena.

5.1 Environmental Stress in the Context of Maha Kumbh

The dominance of air pollution and waste production as the key drivers of stress, the discoveries of the Random Forest analysis, is consistent with the current empirical reports concerning the ecological effect of the Maha Kumbh. Previous studies on the Prayagraj Kumbh Mela have invariably documented the remarkable degradation of the river water quality and addition of loads of pollutants during periods of peak bathing due to mass human activity and release of wastes (Varma *et al.*, 2022; Kanaujiya *et al.*, 2024). The same has been recorded in major events all over the world, where temporary increases in population exceed the urban environmental carrying capacity (World Health Organization, 2017).

This current investigation builds on this literature by showing that environmental stress is not a mere event but also a structure when considered alongside other dimensions of stress. The fact that waste generation is of high significance specifically contributes to the fact that previous public health evaluations of the Kumbh Mela have cited solid waste management as one of the most enduring operational issues during the large-scale religious ceremonies (David *et al.*, 2016). The findings imply that environmental degradation is the lower layer of stress, on which other pressures act.

5.2 Implications of Forecasting for Future Maha Kumbh Events

The forecasting component of this study provides forward-looking insights that complement historical analysis. It is projected that the amount of waste will continue to grow in the Maha Kumbh events in the coming years, and the quality of water will continue to degrade unless the management practices are changed. Such trends resonate with the literature on mass gathering in the world, stating that environmental and infrastructural burdens are likely to escalate with the rise in the scale and frequency of events (World Health Organization, 2017).

Recent empirical evaluations of Kumbh Readiness include the development of preparedness frameworks by comparing them to subsequent events and the importance of considering predictive tools in the planning cycles. To take an example, papers that explore future Kumbh cycle preparedness have found that the resource scaling and pre-

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positioning of infrastructures based on forecasts are significantly beneficial in terms of operational readiness (Sharma & Gupta, 2026).

Through the incorporation of the results of forecasting into the framework of the stress assessment, the research crosses the boundary of retrospective assessment to a proactive planning. The capacity to simulate future stress directions enables the planners to recognize the high-risk situations in advance, facilitating the prior allocation of resources and the scaling of infrastructure. This predictive dimension applies especially to recurring events like the Maha Kumbh, where decisions taken in the long-term planning are cumulative in terms of impacts on repetitive event cycles.

5.3 Crowd Scale, Perception, and Machine Learning Insights

Although environmental indicators become the most prominent stressors, the other notable outcomes of the Random Forest show the great impact of the total count of visitors and the sentiment of people. This observation is consistent with research on the dynamics of crowds' interaction whereby large density and limited movement are reasons why people respond under psychological and behavioral stress in a mass gathering (Beermann *et al.*, 2023). The significance of sentiment-related variables implies that the public perception reflects a component of stress that cannot be directly observed with the help of physical indicators only.

Regarding a methodological point of view the application of Random Forest modeling is that which allows the detection of non-linear relationships between stress drivers. Machine learning technologies have been used in more and more environmental forecasting and risk evaluation scenarios, but have not been widely used on religious mass gatherings. The current research shows that the feature importance of the Random Forest implementation can deliver practical insights into the process of stress amplifications especially in places where there are complicated effects between environmental load and crowd actions.

5.4 Significance of the Event Stress Index (ESI)

The Event Stress Index (ESI) represents a composite measure of cumulative stress that combines environmental, social, and crowd-related indicators into one single measure (year-by-year). Index-based methods have been already suggested in the study of crowd safety, e.g., the Crowd Stress Index, which has been created to assess the strain caused by density (Parsons, 2004). The ESI is an extension of this idea with the addition of the environmental degradation and social pressure to provide a more comprehensive representation of stress during mass religious events

According to the ESI results, it is clear that the most stressful Maha Kumbh event during the study period was 2001, as the environmental degradation, crowd pressure, and social stress were at the same peak. Such an outcome proves the practical applicability of the ESI in prioritizing the severity of the events over the years and evidence-based priorities. The mitigating effect of ESI values on future events indicates that administrative interventions might have alleviated some of the components of stress, but the rising volumes of visitors are still placing an upward influence on cumulative stress.

5.5 Interconnected Stress Dynamics and Policy Implications

The observed patterns of correlation in the study guarantee that there are strong interrelations between dimensions of stress during the Prayagraj Maha Kumbh. There are positive correlations between air pollution, waste production, and the number of visitors, and negative correlations between water quality and the effects of an event, which underscores the systemic nature of event-induced stress. The same interdependencies have been highlighted in global mass gathering risk frameworks, which propose coordinated planning in the context of environmental, health, and governance (World Health Organization, 2017).

As experience with recent sustainability evaluations of the Kumbh Mela suggests conservation-oriented measures - integrating cultural heritage preservation with environmental management and community integration - to minimize cumulative event stress; conservation-oriented measures complement the effectiveness of waste-oriented interventions and interacting behavior change campaigns to existing infrastructural improvements (Singh *et al.*, 2026).

Policy-wise, these results highlight the shortcomings of sector-based interventions. The environmental management, crowd regulation, and social governance have to be considered in parallel to attain sustainable results. Forecasting, machine learning-based driver detection, and composite indexing can be combined to provide a data-driven basis for transitioning reactive management to integrated, anticipatory planning of subsequent Maha Kumbh events.

5.6 Limitations and Future Research

The study is also restricted by the fact that it uses event-level annual data, which might fail to reflect intra-event changes in the short term. Further research may include more precise temporal data, spatial analytics, and real-time monitoring to give the stress assessment an even more precise form. Using the suggested framework on other big-scale religious and cultural events would also assist in determining how well the framework can be generalized.

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VI. CONCLUSION

This study develops and evaluates the stress dynamic related to the Prayagraj Maha Kumbh through an integrated system of analysis using time-series prediction, driver detection using the Random Forest, and a complex Event Stress Index (ESI). The findings confirm the hypothesis that stress in the Maha Kumbh is cumulative and systemic, it comes about through the combination of environmental degradation, intensity of the crowd, and social pressures and not as a result of a particular variable.

The Random Forest analysis has shown air pollution and waste generation to be the most significant stressors of the overall event, with the intensity of visitors and sentiment of the populace serving as the boosters. These results show that environmental load is the basis of stress in the Maha Kumbh, and the size and perception of the crowd enhance its effect. The Event Stress Index also allows the yearly comparison of cumulative stress and makes it very clear that the 2001 Maha Kumbh was the most stressful occasion in the study period.

The results of forecasting suggest that further Maha Kumbh events can be characterized by escalating environmental pressure, especially the growth of waste production and the further strain on water systems, which proves the necessity of proactive, rather than reactive, measures in managing the event. The proposed framework combines predictive insights and machine learning-derived driver importance to provide a practical evidence-based planning and prioritization tool.

In general, the analysis shows that machine learning-based composite indexing through forecasting can substantially improve the knowledge and control of large religious events. The framework has a high level of transferability and scalability and can be used as a great source of guidance on the sustainability and resilience of future Maha Kumbh events and other mass gatherings of such magnitude in other parts of the world.

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