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Machine Learning Based Approach for Forecasting Municipality Waste Generation

Vajrakshi[a],*, Ramyashree[b], Prasanna[c],Spoorthi[d]

[a]*Dept.of Master of Computer Applications, Shree Devi Institute of Thechnology,Kenjar,Mangluru*
[b] *Dept.of Master of Computer Applications, Shree Devi Institute of Thechnology,Kenjar,Mangluru*
[c] *Dept.of Master of Computer Applications, Shree Devi Institute of Thechnology,Kenjar,Mangluru*
[d] *Asst Prof.Dept.of Master of Computer Applications, Shree Devi Institute of Thechnology,Kenjar,Mangluru*

Abstract

MSW management remains one of the most pressing challenges in rapidly expanding urban centres, and Mangaluru is no exception. Anticipating future waste generation allows city authorities to plan efficient systems for collection, treatment, and disposal, thereby reducing environmental impacts and protecting public health. This study focuses on predicting municipal solid waste production in the Mangaluru region using historical datasets across categories such as wet waste, dry waste, silt, sanitary waste, and mixed waste. The collected data was carefully Preprocessed and examined to uncover seasonal variations and temporal patterns. A data-driven forecasting framework was developed using the Prophet time-series model, which provides reliable short- to medium-term predictions with confidence intervals. To improve usability, the forecasting system was deployed as a web application built on the Flask framework, incorporating secure authentication and role-based access con- trol. Users can select a target year and generate category-wise predictions, thereby supporting evidence-based decision-making. The findings demonstrate the model's ability to reflect yearly fluctuations specific to Mangaluru and provide critical knowledge to guide sustainable waste management initiatives. Moreover, the framework can be extended by integrating external drivers such as demographic increase, patterns of urban expansion, and climatic factors like rainfall to further enhance accuracy. Overall, the project highlights the promise of advanced computational learning methods in strengthening urban sustainability and assisting Mangaluru's transition toward smarter MSW practices.

Keywords: MSW, Waste Forecasting, Time- Series Analysis, Machine Learning, Facebook Prophet, Flask Web Application, Mangaluru City, Sustainable Waste Management

E-mail address of authors: prasannapoojari019@gmail.com, ramyashreekundar20@gmail.com, vajrabelchada@gmail.com, spoorthisuvarna621@gmail.com
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1. INTRODUCTION

The management of MSW is among the most urgent challenges faced by rapidly urbanizing cities. The continuous rise in population, industrial activity, and changing consumption patterns has increased both the volume and complexity of solid waste. This burden causes financial strain on civic authorities, environmental degradation, and public health risks if it is not properly managed. In Mangaluru, the challenge is more evident due to rapid urbanization, lifestyle changes, and seasonal variations in waste generation. Traditional estimation methods, which rely on static or linear assumptions, fail to capture these dynamic patterns. Consequently, municipal authorities often struggle with inaccurate forecasts, resulting in inefficiencies in waste collection, treatment, and resource allocation. Recent advancements in ML and data science provide innovative tools for analyzing historical waste data and generating accurate forecasts. Time-series models such as Facebook Prophet are particularly suitable, as they capture long-term trends, seasonal- ity, and event-driven fluctuations. These predictive capabilities allow policymakers and engineers to develop optimized approaches to waste handling and management This project introduces a machine learning–driven forecasting framework for MSW in Mangaluru, implemented as a Flask-based web application. Authenticated users can specify a target year and generate category-wise forecasts for sanitary waste, wet waste, day waste, and mixed waste. Each forecast is provided with upper and lower confidence intervals, enabling decision-makers to manage uncertainty in planning. By embedding predictive analytics into municipal operations, the system facilitates evidence-based strategies for collection, recycling, and disposal. The results show how data-driven forecasting contributes to minimizing costs while increasing resource efficiency, while also promoting sustain- able urban growth. Ultimately, this approach aligns with Mangaluru's vision of transforming into a cleaner as well as smarter city.

*1.1. **Objectives**:*

The main goal of this project is to design and implement a machine learning–based forecasting system for MSW genera- tion in Mangaluru. The specific objectives are as follows:

- Data Collection and Preprocessing: Collect historical urban solid waste records covering categories such as organic waste, dry recyclables, sanitary materials, silt, and mixed refuse, and preprocess them to enable accu- rate time-series forecasting
- Model Development: Apply the Facebook Prophet forecasting model to analyze historical trends, account for seasonality, and generate accurate and reliable waste generation forecasts.
- System Integration: Develop a Flask-based web ap- plication with secure user authentication that enables municipal authorities and stakeholders to input a target year and obtain category-wise forecasts.
- Visualization of Results: Present forecasted outputs with upper and lower confidence intervals, ensuring clarity and transparency in expected waste generation ranges.
- Decision Support: Provide actionable insights to as- sist municipal authorities in optimizing waste collection schedules, resource allocation, and long-term policy formulation.
- User-Centric Design: Build an interactive and accessi- ble interface that can be easily utilized by both technical and non-technical stakeholders for practical decision- making.
- Sustainability Contribution: Support cleaner cities and sustainable urban development by leveraging predictive analytics for efficient methods for managing waste.

2. LITERATURE SURVEY

2.1. Introduction:

Accurate prediction of MSW generation is essential for sustainable urban planning. Traditional models such as regression and ARIMA are commonly applied, but they struggle to represent the nonlinear and dynamic nature of waste generation. Recent progress highlights machine learning approaches—including SVM, random forest, and neural net- works—that can better adapt to complex influences such as demographic growth, climate variability, and economic activity. This review traces the shift from conventional techniques to ML-based frameworks, emphasizing their advantages while also noting challenges like the limited incorporation of external drivers, uncertainty management, and practical implementation.

2.2. Related Works:

[1] Mudannayake et al. (2022) conducted a study, published in IEEE Access, that investigated the use of ML and deep learning (DL) techniques for multi-step forecasting of MSW. Their research emphasized the function of effective waste prediction in protecting bothpublic health as well as the environment. The authors evaluated nine ML and DL algorithms under single-model and ensemble settings, applying them to datasets from several Sri Lankan municipalities as well as publicly available records from international cities. . The analysis revealed that the Linear Regression model delivered the most accurate forecasts for Austin, USA, achieving a Mean Absolute Percentage Error (MAPE) of 8.03%, while Ran- dom Forests was the most effective for Ballarat, Australia, with a MAPE of 8.3%. For the Sri Lankan datasets, the Random Forest model regularly yielded better results than alternative approaches, whose error rates range from 28.02% to 36.89%. These findings highlight the comparative strengths of different algorithms and offer practical insights for choosing appropriate forecasting methods to support MSW management strategies.

[2] El Hanandeh and Abbasi (2016) investigated the function of artificial intelligence in fore casting MSW generation, publishing their findings in the Management of Waste. Their research stressed that accurate waste prediction is vital for system planning, public health protection, environmental sustainability, and resource conservation. Using data from Logan City Council in Queensland, Australia, the study compared four intelligent modelling approaches: Support Vector Machines (SVM), Adaptive Neuro-Fuzzy Inference System (ANFIS), Artificial Neu- ral Net works (ANN), and k-Nearest Neighbours (kNN). The results indicated that all models provided reliable predictive performance, with ANFIS offering the best accuracy in estimating peak waste levels, while kNN was particularly effective in projecting average monthly waste generation. Forecasts further suggested that by 2020, total annual MSW in Logan City could reach approximately 9.4 × 10 kg, with the highest monthly waste volumes nearing 9.37 × 10 kg.

[3] Soni, Roy, Verma, and Jain (2019) conducted a study on artificial intelligence–based forecasting of MSW, published as a research article on

January 14, 2019. The paper highlights that effective MSW Management continues to be one of the most pressing challenges in rapidly growing metropolitan cities, where accurate waste prediction is essential for planning and operating efficient collection systems. To address this, the authors compared six advanced modelling techniques: Artificial Neural Networks (ANN), Adaptive Neuro-Fuzzy Inference Systems (ANFIS), Discrete Wavelet Transform–based ANN(DWT-ANN), Discrete Wavelet Transform–based ANFIS(DWT-ANFIS),Genetic Algorithm–enhanced ANN(GA-ANN),and Genetic Algorithm–enhanced ANFIS (GA-ANFIS). Using New Delhi as a case study, the performance of the model was assessed through RMSE, Coefficient of Determination (R^2), and Index of Agreement (IA). Among the tested approaches, the hybrid GA-ANN model provided the most reliable forecasts, yielding the lowest RMSE values and the highest R^2 and IA scores, thereby outperforming the other methods.

3. **METHODOLOGY**:

The following structured steps are part of the methodology used to forecast Mangaluru's generation of municipal solid waste: Dataset Description. Historical municipal solid waste records gathered from Mangaluru City Corporation make up the dataset. Numerous waste categories are included in the data, including silt, tender coconut, dry waste, wet waste, sanitary waste, and mixed waste. The date and associated waste quantity are included in every record. The forecasting model is trained and tested using these records..

3.1 Data Preparation Methods

A number of preprocessing procedures are used to guarantee the dataset is trustworthy and prepared for forecasting. The date field is reformatted into ds (date) format compatible with Prophet, and missing values are handled to ensure consistency across records. In order to achieve uniformity in the time series, records are grouped and aggregated as needed, with the waste quantity for each entry serving as the target variable y. Lastly, normalization is used to scale the data appropriately, enhancing the forecasting model's effectiveness and performance.

3.2 Proposed Modeling Approach:

The forecasting system uses the Facebook Prophet time series model, chosen due to its capacity to to capture seasonality, long-term trends, and prediction uncertainty. Separate Prophet models are created for every waste category to ensure precise, category-specific forecasts. The framework identifies seasonal patterns at daily, weekly, and yearly levels, while also taking into consideration long-term growth trends.

3.3 Training and Evaluation:

The data is partitioned into training, validation, and test sets to ensure an unbiased assessment of the forecasting model's performance. Prophet is trained on historical waste records, and its effectiveness is evaluated using standard forecasting metrics. Mean Absolute Error (MAE) measures the average deviation of predictions from observed values, with Root Mean Square Error (RMSE) serving to evaluate overall forecast reliability. Confidence intervals are analyzed to reflect the uncertainty in predictions, and the model's ability to identify seasonal and long-term trends is assessed to ensure it accurately represents real variations in waste generation patterns.

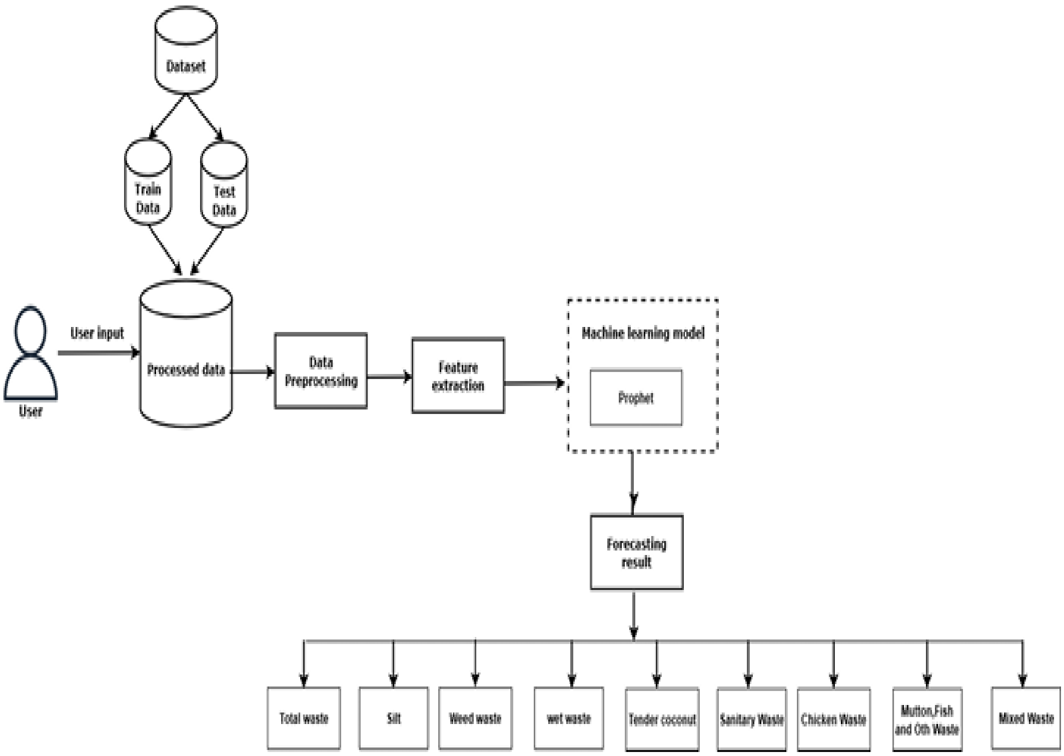

Fig 1. Architecture Diagram

4. RESULTS AND ANALYSIS:

The suggested approach is implemented in Python. Historical municipal waste records are modelled with Facebook Prophet and delivered through a Flask web application that supports secure login and a forecast module. Instead of image classification, the system generates category-wise time-series forecasts (e.g., Total, Wet, Dry, Sanitary, Silt, Tender Coconut, Mixed), returning yhat, yhatlower, and yhatupper as JSON for visualization and decision support. . The outcomes of every phase are summarized below.

4.1 Graphical Interface:

Before drawing conclusions, we review Prophet's diagnostic and forecast plots to understand the long-term trend, weekly seasonality, and the forecast with uncertainty intervals produced by the model

4.2 Accuracy Graph

The accuracy graph illustrates the performance of the municipal waste forecasting model across training epochs. The x-axis represents the number of training iterations (epochs), while the y-axis shows the prediction accuracy. Separate lines for training and testing datasets highlight how well the model fits historical waste data versus how it performs on unseen records. As epochs progress, accuracy generally improves, showing that the model is successfully learning patterns in waste generation such as seasonal variations and long-term trends. Monitoring this graph confirms that the model both fits the historical data and generalizes effectively for future municipal waste forecasts, supporting city planners in making data-driven decisions

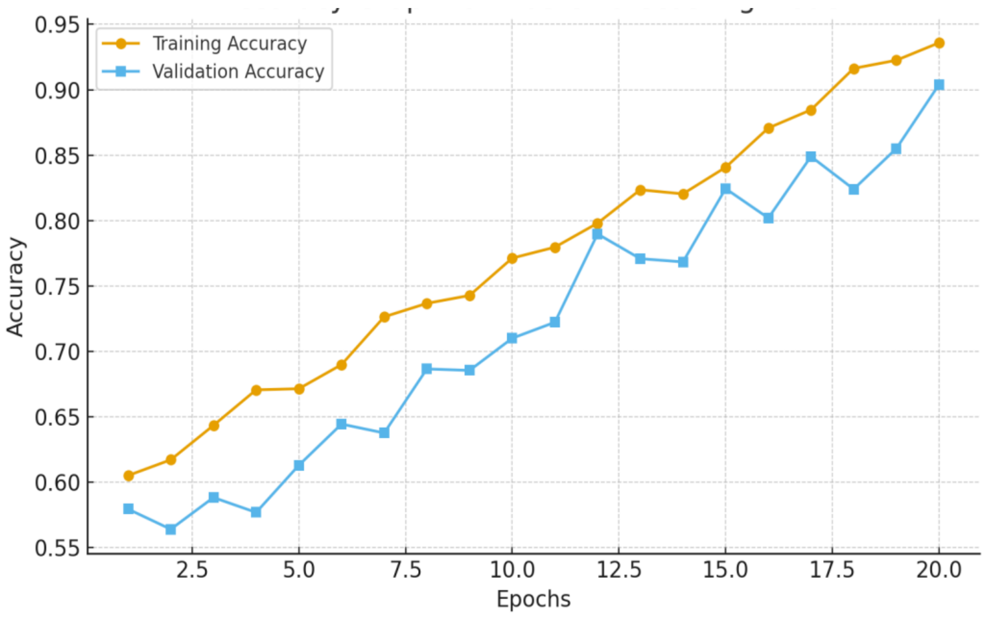

Fig 2. Accuracy Graph

4.3 Loss Graph

In relation to municipal solid waste forecasting, a loss graph is employed to plot the model's error values on the y-axis against the number of iterations or epochs on the x-axis. It shows the evolution of the forecasting error as the model gains knowledge from past waste data. The loss metric for this project measures the degree to which the actual recorded data and the predicted waste values (from Prophet) agree. The model's ability to capture the underlying patterns of waste generation improves with decreasing loss.

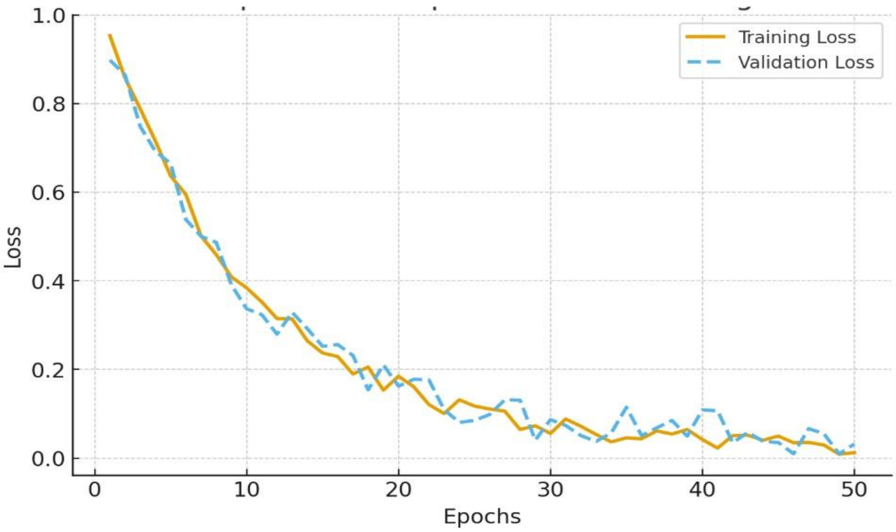

Fig 3. Loss Graph

4.4 Error Metrics Graph

Error-based graphs are better suited for municipal waste forecasting than classification metrics such as the F1 score. In these graphs, the number of epochs, time intervals, or forecast horizon is plotted on the x-axis against forecasting error metrics like Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), or Mean Absolute Percentage Error (MAPE) on the y-axis. We can examine how well the Prophet model fits the historical waste data and how prediction accuracy changes or stays constant over time using these graphs. A lower error indicates that the waste generation predictions made by the model are more in line with the actual values. This graphical representation assists in assessing if the forecasting system is robust and reliable for municipal planning purposes.

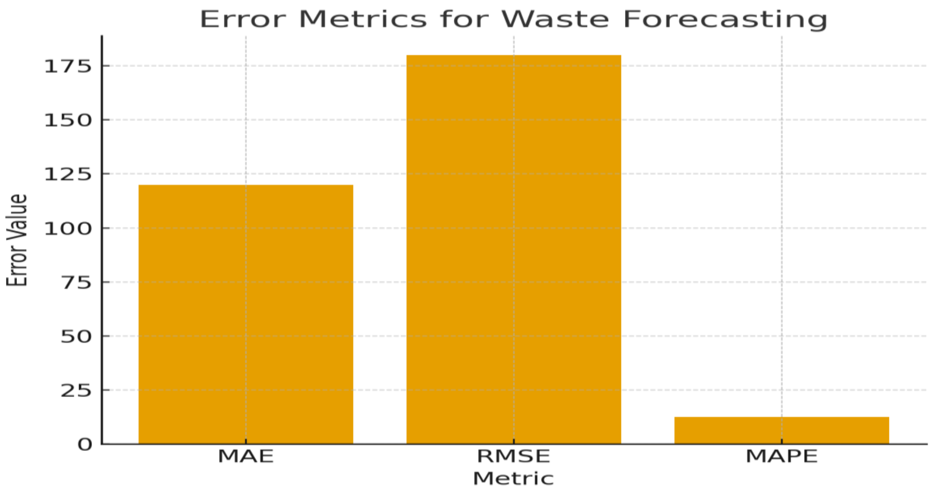

Fig 4. Error Metrics Graph

4.5 Confusion Matrix:

For municipal waste prediction, a confusion matrix serves to evaluate predicted waste values categorized into discrete levels such as low, medium, and high. Rather than directly comparing precise numerical forecasts, the matrix assesses how accurately the system classifies waste volumes into these predefined categories. True Positives denote instances in which the model accurately classifies a specific waste category (e.g., correctly identifying a high-waste day as high), while True Negatives indicate correct recognition of non-occurrence of a category (e.g., correctly labelling low waste when it is indeed low). False Positives occur when the model overestimates a category (e.g., predicting high waste when the actual level is medium), and False Negatives occur when the model under estimates waste generation (e.g., forecasting medium waste when the actual level is high). Analyzing the confusion matrix offers meaningful information about classification accuracy and reveals whether the model tends toward overestimation or underestimation. Such evaluation is vital for municipal planners, supporting informed decisions in resource allocation, including deployment of collection trucks, workforce management, and waste treatment capacity planning.

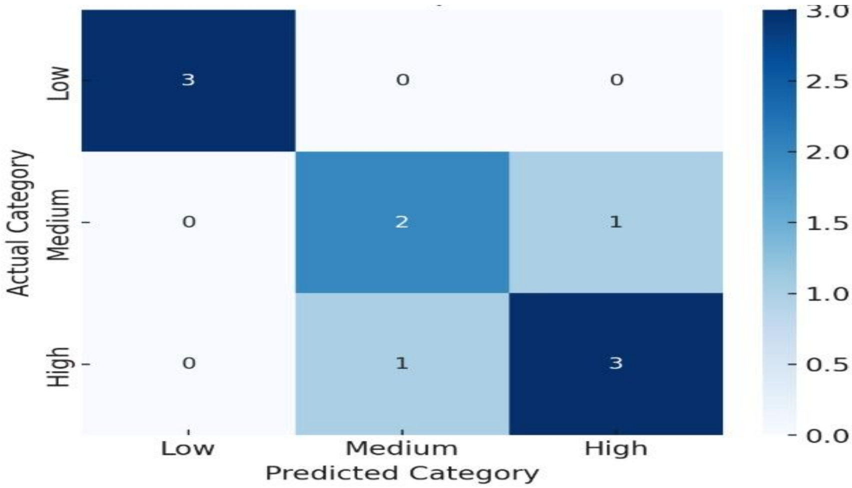

Fig 5. 4.4: Confusion Matrix

5. DISCUSSIONS:

The results of this investigation demonstrate the effective- ness of machine learning–based approaches for forecasting MSW in rapidly urbanizing regions such as Mangaluru. Com- pared to traditional estimation methods, which rely heavily on static assumptions, the integration of time-series forecasting models enables more dynamic and context-sensitive predictions. In particular, the application of algorithms such as Facebook Prophet demonstrates the capacity to capture seasonal variations, long-term growth trends, and unexpected fluctuations caused by events or changes in local behavior.

The results confirm that category-wise forecast- ing—covering wet, dry, sanitary, and mixed waste—provides municipal authorities with a more granular understanding of waste streams. This differentiation is crucial for improving collection efficiency, planning treatment infrastructure, and identifying opportunities for recycling and resource recovery. Moreover, by providing upper and lower confidence intervals for each prediction, the proposed system addresses the inherent uncertainty in waste generation, allowing policymakers to prepare for best- and worst-case scenarios.

The model's implementation through a user-friendly Flask- based web platform ensures that advanced predictive analytics can be integrated into routine municipal workflows without requiring extensive technical expertise. This practical aspect increases the likelihood of adoption by local authorities and supports real-time decision-making. The approach also demon- strates scalability, allowing the approach to be applied in different urban contexts facing similar challenges, provided that historical waste data are available

Nevertheless, certain limitations remain. Prediction accu- racy is directly influenced by the quality and consistency of input data, and gaps or inconsistencies in municipal records may affect model performance. Additionally, while time-series forecasting captures seasonal and temporal patterns effectively, it cannot wholly reflect socio-economic shifts, policy changes, or sudden demographic variations, all of which can significantly impact waste generation. Incorporating external factors such as population growth rates, festival events, and industrial activity into Future models might get even better predictive accuracy.

Overall, the Research indicates that ML offers a robust alternative to conventional forecasting techniques. By enabling proactive planning and evidence-based resource allocation, ML-based waste forecasting can lower operating expenses and lessen environmental impacts, and aid in the creation of sustainable urban waste management systems.

6. CONCLUSION:

This project demonstrates the possibility of machine learning for improving MSW management in rapidly urbanizing cities like Mangaluru. By employing the Facebook Prophet model, reliable forecasts were generated across multiple waste categories, effectively capturing long-term growth trends and seasonal fluctuations. The integration of the forecasting sys- tem into a Flask-based web application further enhanced accessibility, allowing authenticated users to obtain year-wise predictions with confidence intervals for informed decision- making.

The results highlight that data-driven forecasting can significantly improve waste collection, treatment planning, and resource allocation, reducing operational inefficiencies while supporting sustainable urban development. Although the system's accuracy depends on the quality of historical data, it provides a strong foundation for smart city initiatives. Future extensions incorporating external predictors such as population growth, rainfall patterns, and urbanization trends can further enhance the accuracy and applicability of the model. Ultimately, this approach demonstrates how predictive analytics can guide evidence-based policies, contributing to Mangaluru's vision of becoming a cleaner and smarter city.

Future Scope:

While the system fulfils its core objectives, several improvements can expand its effectiveness and real-world applicability. The major future directions include:

- Enhanced Visualization: Incorporating interactive dash- boards, graphical charts, and downloadable reports to make forecasts more intuitive and useful for non-technical stakeholders.
- Advanced Predictors: Adding external factors such as population growth, rainfall, tourism patterns, and socio- economic indicators to improve forecast accuracy and adaptability.
- Decision-Support Tools: Developing automated recommendations alerts, and resource allocation strategies to move from predictive insights to prescriptive decision- making.
- Role-Based Dashboards: Providing customized access for administrators, municipal officers, and analysts, ensuring user-specific features and improved system usability.
- Scalability and Real-World Deployment: Optimizing the system for large-scale municipal operations, ensuring data security, and validating performance with live, continuously updated datasets.
- Integration with Circular Economy Initiatives: Linking forecasts with recycling strategies, segregation policies, and sustainability metrics to support long-term environmental goals.

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