RESEARCH ARTICLE

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# A Robust Approach for Forecasting and Planning Municipal Solid Waste Generation: A SARIMA Model

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## Abstract

Under the smart city mission of government of India's ministry of urban development. Varanasi was selected under India's Smart Cities Mission (SCM) the ambitious goal of the smart city mission in Varanasi- aimed at improving quality of life, sustainability and urban efficiency which remain fundamentally unachievable without addressing the pervasive challenges in its municipal solid waste management. Current SWM practices, marked by issues such as insufficient source segregation, reliance on open dumping, and inadequate processing infrastructure (despite some progresses with door to door collection and the Karsada plant) present significant environmental and public health risk that directly counteract the "smart" and "clean" city vision. Varanasi being one of India's oldest and most densely populated cities, the municipal Solid Waste Management (MSW) system faces escalating challenges due to urbanization, population growth and tourism, making accurate forecasting essential for sustainable planning. This study presents a robust monthly MSW data from January 2020 to December 2024 collected from the Varanasi Nagar Nigam office. Using SARIMA (2,0,2) (1,0,0) [12], the research captures seasonal and non-seasonal trends in waste generation and projects future trends for 2025–2027. The analysis confirms that waste generation exhibits significant seasonality influenced by festivals and urban activities. Key findings suggest a consistent increase in waste generation over time with peaks during festival seasons. The results of this forecasting can aid in policy-making, budgeting, and strategic planning for sustainable waste management in Varanasi. The study recommends incorporating forecasting tools in municipal planning and highlights the importance of public participation and technological innovation in improving urban waste systems.

**Keywords:** Municipal solid waste, Waste forecasting, SARIMA, Urban sustainability. Seasonal Time series analysis

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## Introduction:

### *Historical Background:*

### *Waste Management Prior to Modern MSW system*

The administrative evolution of sanitation in Varanasi transitioned from the 19th-century Benares Municipal Board to the formal Nagar Mahapalika in 1959. This shift marked the end of purely community-led traditional disposal and the beginning of a state-managed public health framework. However, it was through the 74th Constitutional Amendment in the early 1990s that solid waste management was officially institutionalized as a core statutory function of the Varanasi Nagar Nigam.

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### *The Informal and Community-Led Era*

The traditional sanitation landscape of Varanasi was fundamentally sustained by the Safai Karamchari community, whose involvement in waste removal predates the modern municipal corporation. These individuals operated within a decentralized framework where waste management was not a mechanized industrial process, but a localized social function. Manual

Labor and the 'Gali' Constraint. The unique architectural heritage of Varanasi, characterized by an intricate network of narrow (i) Galis (alleys), historically dictated the methods of waste collection, (ii) Manual Dexterity-As many of these ancient pathways are inaccessible to motorized vehicles in galis, the city relied exclusively on manual labour for "at-source" collection, (iii) Primary Collection- Safai Karamcharis utilized hand held equipments and wicker baskets to navigate these narrow corridors, ensuring that refuse was moved from household doorsteps to secondary collection points and (iv) Physical Intensity-This era of waste management was defined by high physical demand, where the efficiency of the system was entirely dependent on the consistent presence and hereditary knowledge of the labor force.

*The Present Lag in Solid Waste Management*

Despite the city's inclusion in the Smart City Plan with the vision of becoming 'Nirmal Kashi', there remained a significant "lag" between waste generation and infrastructural response. Current management strategies often rely on static averages that fail to account for the extreme seasonality inherent to the city.

*The primary lags in the current system included:*

- Seasonal Inefficiency: Waste collection often falls behind during major cultural events because Varanasi is known for its cultural festive city which may generate more waste during these peak festive season where waste surges beyond the capacity of standard daily operations.

- Data-Planning Gap: There is a lack of integrated predictive tools within the Varanasi Nagar Nigam framework and there is also lack of data entry of MSW generation.. On record , they have only kept recent three to five years of waste collection data, leading to reactive rather than proactive waste handling .

- Logistical Overload: During the festive months of October and November, changing consumption patterns lead to an MSW spike that frequently exceeds existing transportation and processing capabilities and not enough vehicle for waste handling.

Thus, the Municipal Solid Waste (MSW) has emerged as a major environmental concern across urban India. In Varanasi, daily waste generation exceeds 600 metric tons, driven by rapid urbanization, population growth, tourism, and changing consumption patterns. Hence, accurate waste forecasting is essential for ensuring efficient infrastructure development, budget allocations, and policy-making.

## Literature Review

Solid waste management (SWM) has become a critical issue for urban areas across developing countries, particularly in rapidly expanding cities like Varanasi. Accurate forecasting of future waste generation is essential for effective planning, policy design, and sustainable waste management practices. Numerous studies have employed statistical and machine learning models to predict MSW generation. Prior studies such as. Sharma et al. (2021) emphasized the need for region-specific forecasting models, highlighting the heterogeneity in waste generation and composition across districts. Despite its importance, limited studies have focused on predictive analytics for Varanasi, underscoring the need for targeted models like SARIMA to improve waste management planning. Similarly, Waste Management & Research ARIMA models have been effectively used in urban contexts to model waste generation trends. However, they observed that incorporating seasonality improves forecast performance-this is where the SARIMA model becomes advantageous. (Sharma, P., Singh, A., & Bansal, R. 2021). Another study advocated integrating forecasting results with policy planning to enhance municipal preparedness and infrastructure development. It argues that forecasts alone are insufficient unless linked with capacity building and strategic interventions. (Ali and Gupta, 2020) .ARIMA models have been effectively used in urban contexts to model waste generation trends, as noted in studies (Ghosh, S., & Ghosh, S. K. 2018). Recent literature also emphasizes the importance of localized studies in SWM forecasting. Regional variability in municipal solid waste generation and composition in India Challenges and prospects. Environmental Science and Pollution Research and highlighted regional heterogeneity in waste composition and generation rates across Indian districts, underscoring the need for district-specific models. Despite its significance, Varanasi- being a major cultural and urban hub-has received limited attention in terms of predictive waste analytics.

## Research Gap

Although forecasting models such as ARIMA and SARIMA have been widely used to predict Municipal Solid Waste (MSW) generation, most existing studies focus on large metropolitan areas or national aggregates, overlooking the localized dynamics of mid-sized cities like Varanasi. Varanasi, a city of immense cultural, religious, and economic significance, experiences unique waste generation patterns influenced by seasonal tourism, population density, and infrastructure constraints. However, there is lack of empirical, district-level forecasting studies that account for these specific factors. Moreover, while many forecasting studies remain purely technical, they rarely integrate model outputs into actionable urban planning strategies. The present study addresses these gaps by using monthly municipal solid waste data from January 2020 to December 2024, sourced directly from the Varanasi Nagar Nigam office, to build a SARIMA-based forecast model. The research further extends beyond prediction by offering practical planning and policy recommendations tailored to the city's future waste management needs.

## Objective of Study

The primary objective of this study is to forecast municipal solid waste generation in the Varanasi district for the next ten years using SARIMA models.

*The specific objectives of the study are:*

- Explore the time series data of municipal solid waste generated in the Varanasi municipality to identify optimal parameters for accurate prediction

- Build an Seasonal Autoregressive Integrative Moving Average (SARIMA) model and use it to make predictions on the MSW generated in the municipality.

## Methodology

This study employs a quantitative time series approach using the SARIMA model to forecast monthly MSW generation. The area of study is Varanasi (as shown in Fig.1). Data was sourced from the Varanasi Nagar Nigam and spans from January 2020 to December 2024. The SARIMA configuration was selected based on diagnostic criteria such as AIC and RMSE. After comparing several model variants, SARIMA (2,0,2) (1,0,0) [12] was identified as the most suitable criteria. Seasonal and autoregressive components were assessed using ACF and PACF plots, and model stability was verified through the inverse root test.

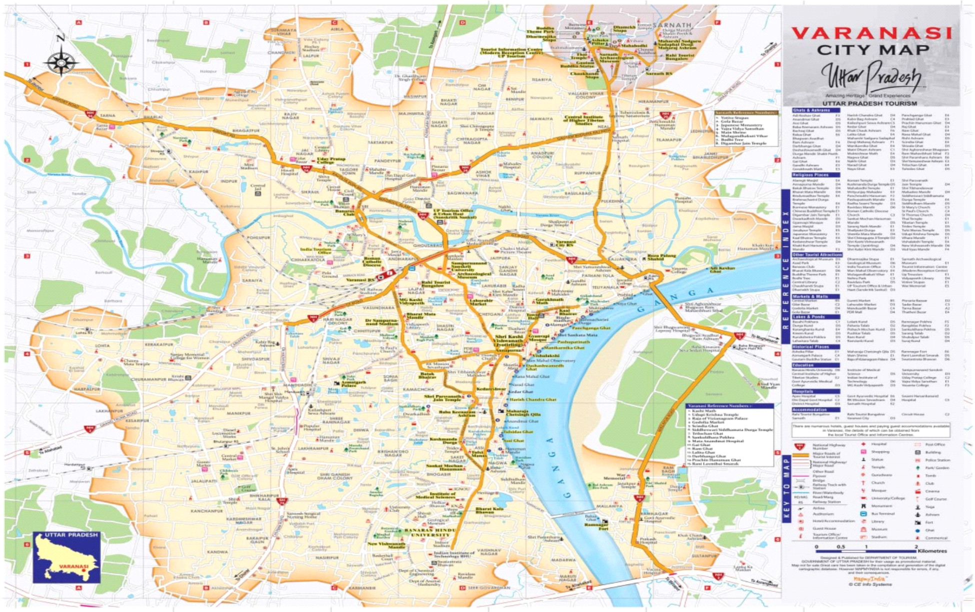



**Figure 1: Map of Varanasi District showing the Study Area**

## Data Analysis and Results

Descriptive analysis shows both seasonal and annual trends. Waste generation peaks during festivals like Diwali. The SARIMA model captured these fluctuations and predicted a steady increase in waste levels from 2025–2027, demanding adaptive waste management planning as in

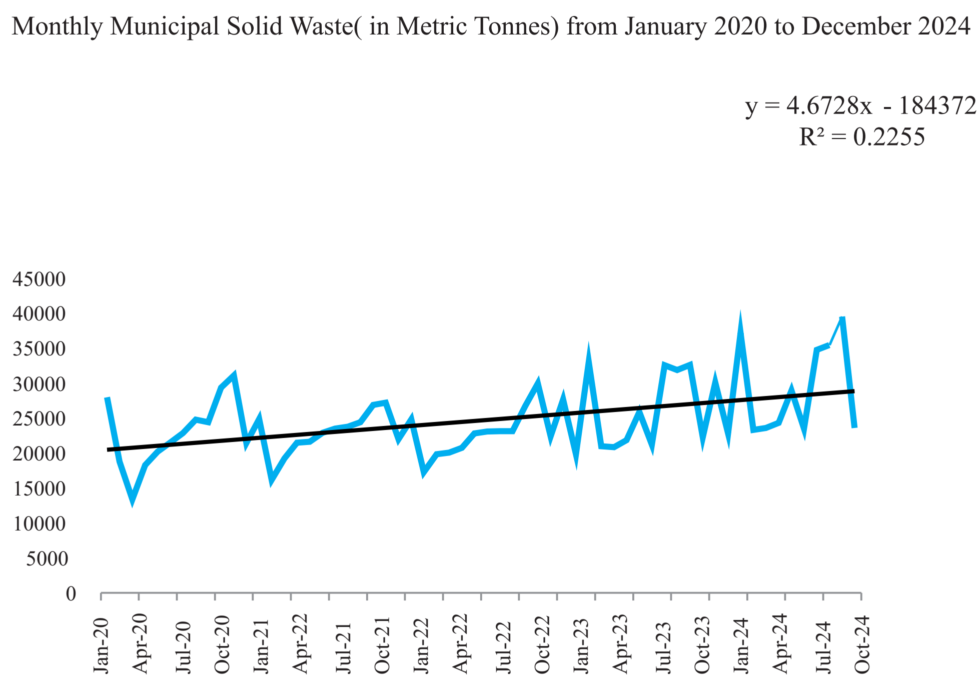



Figure 2: Trend line of MSW generation in Varanasi

*Time Series Analysis*

Time Series Analysis of Monthly Municipal Solid Waste Generation in Varanasi District

*Stationary and Time Series Diagnostics*

To ensure the appropriateness of time series modeling using SARIMA, it is essential to confirm the stationary of the municipal solid waste (MSW) data. To determine the suitability of applying the SARIMA model, it is essential to test whether the municipal solid waste (MSW) time series data is stationary. Two widely accepted unit root tests were applied: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test.

*Augmented Dickey-Fuller (ADF) Test*

The Augmented Dickey Fuller test (ADF Test) is a typical statistical test used to determine whether time series is stationary or not. It is one of the most widely used statistical tests for determining the stationary of a series. The ADF test belongs to a category of tests called 'Unit Root Test', which is the proper method for testing the stationarity of a time series. Further, the Unit Root' signifies a feature that distinguishes it from stationary data. In technical terms, a unit root is defined as the value of alpha = 1 in the following equation over time.

$$yt=\alpha yt-1+\beta xe+ \varepsilon$$

where, Yt is the value of the time series at time ‘t’ and xe is an exogenous variable

Fuller (1976) introduced an ADF test that may be used to evaluate the null hypothesis that time series data has a unit root. The general form of the ADF test is:

$$\Delta yt =\alpha+\beta t+\Upsilon yt-1+\sum_{i=1}^{p}\delta i\Delta yt-1+\varepsilon t$$

**Table 1: Descriptive analysis of results**

| Null Hypothesis: MSW has a unit root<br>Exogenous: Constant<br>Lag Length: 1 (Automatic - based on SIC, maxlag=10) | | | |
|---|---|---|---|
| | | t-Statistic | Prob.* |
| Augmented Dickey-Fuller test statistic | | -2.989233 | 0.0418 |
| Test critical values: | 1% level | -3.548208 | |
| | 5% level | -2.912631 | |
| | 10% level | -2.594027 | |

*MacKinnon (1996) one-sided p-values.

From *Table 1,* (The values are calculated by the author ) ADF test was conducted with a constant term to test the null hypothesis that the MSW time series has a unit root (i.e., is non-stationary). The test yielded a t-statistic of -2.989233 and a p-value of 0.0418. At the 5% significance level, the critical value is -2.912631. Since the test statistic is less than the critical value and the p-value is below 0.05, the null hypothesis of a unit root is rejected. This indicates that the MSW series is stationary at level according to the ADF test.

*Phillips-Perron (PP) Test*

The Phillips-Perron (PP) test is a statistical test used to check whether a time series is stationary or not. It is similar to the Augmented Dickey-Fuller (ADF) test but differs in how it corrects for autocorrelation and heteroskedasticity in the error term. The PP test does not add lagged difference terms as the ADF does, but instead uses a non-parametric correction to the test statistic, making it more flexible in some situations.

The PP test is based on the following basic regression model:

$$\Delta Yt = \alpha + \beta t + \gamma Yt{-}1 + \epsilon t$$

**Table 2: Descriptive analysis of result**

| Null Hypothesis: MSW has a unit root<br>Exogenous: Constant<br>Bandwidth: 1 (Newey-West automatic) using Bartlett kernel | | | |
|---|---|---|---|
| | | Adj. t-Stat | Prob. |
| Phillips-Perron test statistic | | -5.422161 | 0.0000 |
| Test critical values: | 1% level | -3.546099 | |
| | 5% level | -2.911730 | |
| | 10% level | -2.593551 | |

*MacKinnon (1996) one-sided p-values.

To confirm the robustness of the stationary result, the Phillips-Perron test was also applied. The PP test (Table 2) produced a test statistic of -5.42261 and a p-value of 0.0000, which is highly significant. This statistic is also lower than the 1%, 5%, and 10% critical values, leading to a clear rejection of the null hypothesis of non-stationary. Thus, the Phillips-Perron test also confirms that the MSW time series is stationary at level.

**Table 3: Descriptive Statistics result of MSW (Metric Tonnes)**

| | ADF Summary | | | Phillips-Perron | | |
|---|---|---|---|---|---|---|
| Level | Level | | | | | |
| variable | T stat | P-value | Result | T stat | p-value | Result |
| MSW | -3.5482 | 0.0418 | Stationary | -3.5460 | 0.0000 | Stationary |

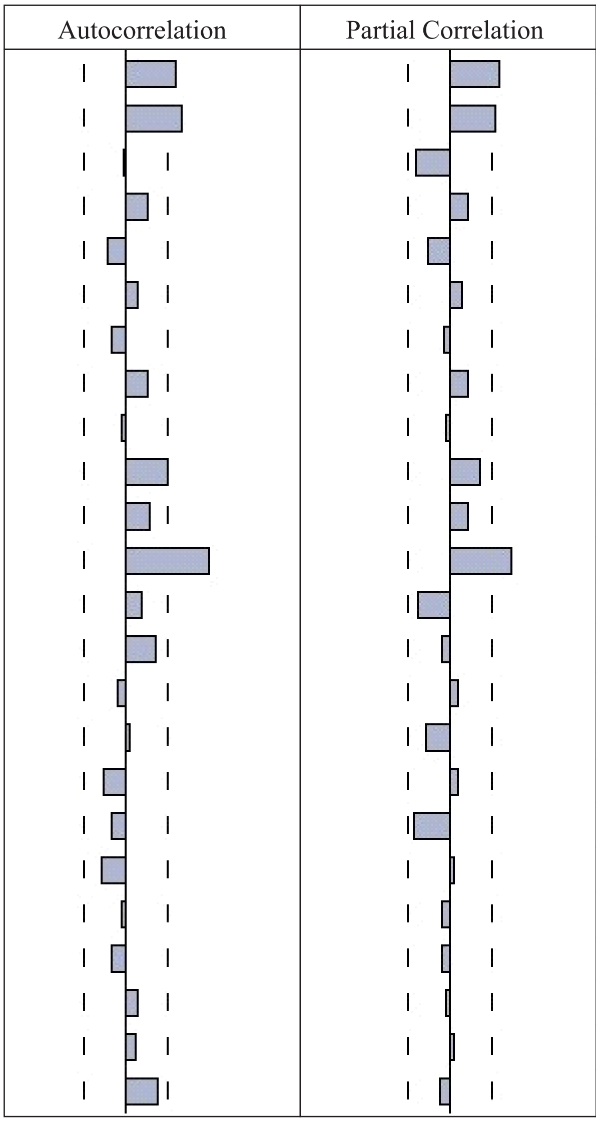
Values are calculated by the author

To evaluate the suitability of the SARIMA model, it is essential to check stationarity of the Municipal Solid Waste (MSW) time series data. For this purpose, two standard unit root tests were employed: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test.Augmented Dickey-Fuller (ADF) Test: The ADF test, conducted at level with a constant term, yielded a test statistic of -3.5482 and a p-value of 0.0418. Since the p-value is below the conventional alpha level of 0.05, the null hypothesis of a unit root is rejected. This indicates that the MSW series is stationary at level. To validate this result another test i.e Phillips-Perron (PP) test also applied to confirm the robustness of these findings. The results show a test statistic of -3.5460 with a highly significant p-value of 0.0000. These results provide strong evidence against the null hypothesis, confirming stationarity at the 1%, 5% significance levels. As both the ADF and PP tests consistently reject the null hypothesis of non-stationarity, it is concluded that the MSW time series is stationary at level. Consequently, no initial differencing is required (d = 0) before proceeding with the SARIMA modeling process.

### *Model: Identification and Selection*

To identify the appropriate SARIMA model, correlograms including Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots were examined using the time series data for monthly municipal solid waste generation from January 2020 to December 2024

Sample : 2020M01 2024M12
Included observations: ·60




| | AC | PAC | Q-Stat | Prob |
|---|---|---|---|---|
| 1 | 0 .312 | 0.312 | 6.1414 | 0.013 |
| 2 | 0.350 | 0.280 | 14.010 | 0.001 |
| 3 | -0.015 | -0.218 | 14.024 | 0.003 |
| 4 | 0.138 | 0.120 | 15.296 | 0.004 |
| 5 | -0.116 | -0.133 | 16.200 | 0.006 |
| 6 | -0.076 | 0.078 | 16.599 | 0.011 |
| 7 | -0 .089 | -0.035 | 17.157 | 0.016 |
| 8 | 0 .141 | 0.11 7 | 18.575 | 0.017 |
| 9 | -0 .021 | -0.018 | 18.606 | 0.029 |
| 10 | 0.256 | 0.195 | 23.494 | 0.009 |
| 11 | 0.155 | 0.123 | 25.318 | 0.008 |
| 12 | 0.526 | 0.388 | 46.729 | 0.000 |
| 13 | 0.106 | -0.201 | 47.614 | 0.000 |
| 14 | 0.196 | -0.055 | 50.709 | 0.000 |
| 15 | -0.047 | 0.056 | 50.890 | 0.000 |
| 16 | 0.017 | -0.150 | 50.916 | 0.000 |
| 17 | -0.132 | 0.050 | 52.416 | 0.000 |
| 18 | -0.098 | -0.229 | 53.265 | 0.000 |
| 19 | -0.153 | 0.017 | 55.401 | 0.000 |
| 20 | -0.018 | -0.057 | 55.432 | 0.000 |
| 21 | -0.090 | -0.052 | 56.21 1 | 0.000 |
| 22 | 0.072 | -0.023 | 56.7 18 | 0.000 |
| 23 | 0.058 | 0.023 | 57.057 | 0.000 |
| 24 | 0.199 | -0.062 | 6 1 .132 | 0.000 |

**Figure 3: Correlogram Plot (ACF and PACF) of MSW data**

The correlogram (**Fig. 3**) displays a prominent seasonal spike at lag 12, which indicates a yearly seasonal component with a seasonal period of 12 months. The ACF showed a slow decay, while the PACF exhibited significant spikes at lags 1 and 2, suggesting the presence of autoregressive (AR) terms. Additionally, strong spikes in both ACF and PACF at lag 12 imply seasonal components, likely involving both seasonal AR and MA terms. Based on this pattern, the preliminary SARIMA model identified is **SARIMA(2,0,2)(1,0,0)[12]** as shown in **Table 4**.

**Table 4: Model Results on Selection Using AIC, BIC, HQIC Criteria**

| Evaluation Criteria | $(1,0,1)(1,0,1)_{12}$ | $(1,0,2)(1,0,1)^{12}$ | (2,0,1)(1,0,1) | $(2,0,2)(1,0,1)_{12}$ | $(2,0,2)(1,0,0)_{12}$ | $(2,0,2)(0,0,1)_{12}$ |
|---|---|---|---|---|---|---|
| AIC | 19.800 | 19.949 | 19.800 | 19.808 | 19.776 | 19.784 |
| SBIC | 20.009 | 20.159 | 20.009 | 20.018 | 19.950 | 19.959 |
| HQIC | 19.881 | 20.031 | 19.881 | 19.844 | 19.890 | 19.853 |

*Note : Values as calculated by the author*

## Developing Sarima Model

To ensure the stability of the SARIMA (2,0,2) $(1,0,0)_{12}$ model, the inverse roots of the characteristic AR and MA polynomials were examined. A key requirement for a time series model to be stable and invertible is that all the roots of the autoregressive (AR) and moving average (MA) components must lie inside the unit circle in the complex plane. The inverse root plot confirmed that all AR and MA roots lie within the unit circle, indicating that the model is both stationary and invertible. Thus, the model meets the necessary conditions for reliability, and its forecasts can be considered statistically valid and robust as shown in ***Fig.5*** .

**MSW: Inverse Roots of AR/Ma Polynomial(s)**

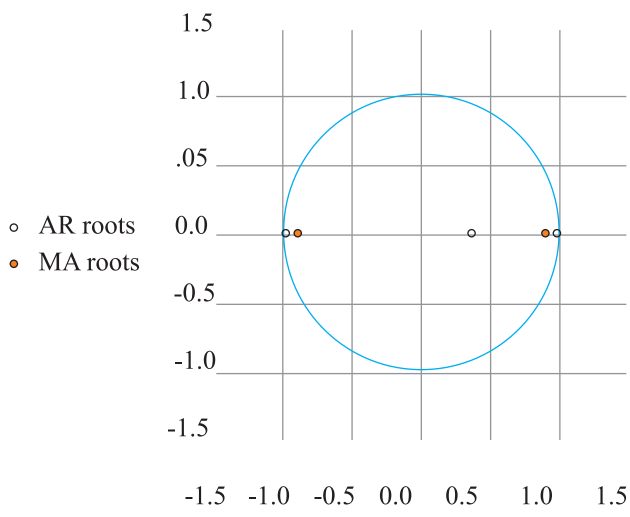
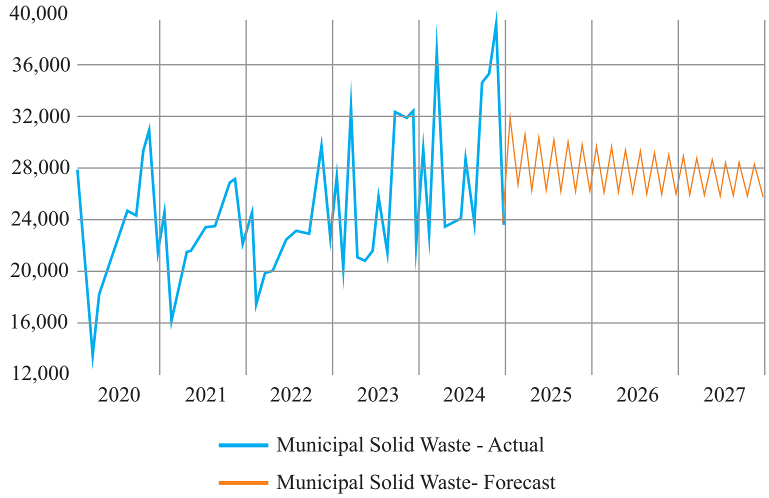



**Figure 5: Inverse Root of AR and MA Polynomials in a complex Unit Circle**

**Fig.5** also shows that diagnostic check was also done through inverse AR/MA root. The plot confirms the stationarity of the AR component and the invertibility of the MA component as all inverse roots for both polynomials lie inside the unit circle.




In Fig.6 forecasted solid waste values (in metric tones) are shown by the thicker red zig-zag curve, from my actual data from 2020 to 2024, However waste collection decreased in 2020 to 2023 and showing a constant pattern due to the pandemic effect or may be some other reason behind this. There was a significant increase in MSW with the highest point reached in 2024, before showing a pattern in 2025.

**Table 5: Forecasting for 2025 to 2027 of Monthly Wastage Weight (in metric tones)**

| Month | 2025 | 2026 | 2027 |
|---|---|---|---|
| January | 32061.718 | 29891.0149 | 29054.9191 |
| February | 26776.8982 | 26139.5039 | 25967.1378 |
| March | 30882.0895 | 29740.1159 | 28930.723 |
| April | 26369.8953 | 26108.3943 | 25941.5342 |
| May | 30567.7947 | 29594.0407 | 28810.4925 |
| June | 26282.6051 | 26078.2801 | 25916.7482 |
| July | 30377.1985 | 29452.6304 | 28694.1009 |
| August | 26240.2234 | 26049.1278 | 25892.7536 |
| September | 30208.2973 | 29315.7354 | 28581.4257 |
| October | 26204.9794 | 26020.9063 | 25869.5251 |
| November | 30046.9328 | 29183.2115 | 28472.3482 |
| December | 26171.6551 | 25993.5859 | 25847.0383 |

*Note: Forecasted Values are as per authors' calculation*

The data in *Table 5* implies a seasonal pattern, with specific period in each year data showing a peak waste generation. This seasonal trend tells us that waste generation is influenced by time specific factors. During Makar Sankranti, in the month of January we observe that waste generation is more than the previous month December and again on the occasion of Holi, 3rd month of the year ,waste generation again increase. There was an average pattern during April to September and again the MSW generation in Varanasi has significantly increased in the month of October and November due to the Hindu festive month may be people consumption pattern changes according to their festive season. To forecast MSW generation in Varanasi, SARIMA (2,0,2) $(1,0,0)_{12}$ model was selected based on its lowest AIC value, which indicates its suitability.

**Limitations of the Study**

Despite the statistical robustness of the SARIMA (2,0,2)(1,0,0)[12] model, this research is subject to several inherent limitations that provide context for the results:

*Temporal Data Constraints:*

The study is restricted by the availability of historical archives, as municipal records were only accessible for a five-year window (2020–2024), which may limit the model's ability to capture long-term decadal cycles.

*Anomalous Baseline Trends:*

The dataset include years (2020–2023) characterized by the global COVID-19 pandemic, which resulted in atypical, constant patterns in waste generation that may not fully reflect the rapid urban growth expected in the post-pandemic era.

*Infrastructure and Logistical Lags:*

While the model provides high-accuracy forecasting, there is a significant operational "lag" in the municipal response; the existing vehicle fleet and standard procedures are often overwhelmed during peak cultural surges, particularly in October and November.

*Data Entry and Technical Gaps:*

The absence of integrated, real-time predictive tools within the Varanasi Nagar Nigam framework and inconsistencies in manual data loggingmay introduce minor variations in the raw MSW figures used for time series diagnostics.

*Policy Implementation Efficiency:*

The model measures volume but cannot fully quantify the qualitative success of legislative interventions, such as the 2022 single-use plastic ban, which the study found had a negligible impact on bulk domestic and grocery-related waste streams.

*Morphological Constraints:*

The unique architectural layout of Varanasi's ancient *galis* (alleys) prevents the deployment of modern mechanized collection technology, meaning that forecasted surges remain heavily dependent on manual labor intensity regardless of technical accuracy.

*Exogenous Variables:*

This research utilizes a univariate SARIMA approach focusing on waste volume and does not explicitly integrate external factors such as fluctuating tourist footfall or specific economic shifts that might influence the per-capita waste generation rate.

*Conclusion and Suggestions*

The SARIMA model proves effective in modeling and forecasting urban waste patterns. The projections highlight the pressing need for improved infrastructure, better composting methods, and increased public awareness in Varanasi. This study reinforces the value of predictive modeling in municipal decision-making. Authorities are encouraged to regularly apply forecasting tools, integrate community participation, and emphasize sustainability to manage urban waste efficiently.

In India waste management is overseen by the Union Ministry of Environment Forests, and Climate Change (MOEFCC). In India, rules regarding the management of waste are based on the ideas of sustainable development, precaution, and polluters pay. The average waste generation in urban areas of India will be 0.7 kg per person per day in 2025. No doubt that it is approximately four to six times higher than in 1999. The vision beyond solid waste management strategy is to develop the oldest living city of Varanasi into a "clean, green and livable city by adopting sustainable integrated waste management practices thereby providing healthy and quality life to its citizens "Varanasi is one of the oldest cities with rich culture, spiritual depth and traditional components which gives it a status of religious capital of India. Under its Smart City Plan, the city aims to develop as 'Nirmal Kashi' which has improved scientific sustainable solid waste management in place. In order to achieve the vision of developing Varanasi into a clean, green and livable city, following strategies may be identified on the basis of the analysis of existing situation:

- To introduce and promote at source waste reduction and reuse initiatives by waste minimization, storage at source, actions to implement segregated waste collection etc

- Ensure 100% coverage of street sweeping, primary and secondary collection and transportation services to prevent open dumping and burning of waste The overall goal of the holistic waste management strategy should be to help "the city of Varanasi to develop into 'Nirmal Kashi' with an improved integrated solid waste management system that is financially and environmentally sustainable, socially inclusive and contributes to an improved quality of life".

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