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RESEARCH PAPER

Forecasting Municipal Solid Waste Management in DG Khan Using Time Series Analysis

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ABSTRACT

This study aims to forecast waste generation in Dera Ghazi Khan for 2025 by analyzing historical data from January 2021 to March 2024. The goal is to provide accurate waste predictions to assist local authorities in enhancing waste management and urban planning. As the region experiences population growth and urbanization, waste management becomes increasingly vital for public health and environmental sustainability. The ARIMA model was employed for this short-term forecast, leveraging time series data with seasonal patterns. The model was trained on historical data and analyzed using RStudio 6.1. Results indicate a consistent rise in waste generation, mirroring urbanization trends. The forecast underscores the need for improved waste management strategies, including adjusting collection frequencies, increasing resources during peak times, and implementing segregation programs. Additionally, expanding recycling facilities and adopting smart waste management systems are recommended to optimize operations and resource allocation. The study offers valuable insights for future waste management planning in Dera Ghazi Khan.

KEYWORDS Waste Management Strategies, ARIMA Model, Time Series Modeling

Introduction

Dera Ghazi Khan is the name of a district in the Punjab province of Pakistan. Dera Ghazi Khan Town used to be located on the western bank of the Indus River. Named after the son of a Baloch chieftain who had proclaimed independence from the Sultans of Multan of the Langah Dynasty, Nawab Ghazi Khan Mirani, the city was formed at the end of the 15th century (Aslam, et al., 2022).

A division within Pakistan's Punjab province, Dera Ghazi Khan Division is responsible for administrative matters. When the British were in power, the districts that had previously been a part of the Dera Ghazi Khan Division were merged into the Multan Division. The division of Dera Ghazi Khan was established after independence. In addition, it is now officially recognised as a Metropolitan Corporation. Four districts and fourteen tehsils make up D.G. Khan Division. It occupies around 20% of Punjab's overall landmass and is located in the province's far southwest corner. Muzaffargarh, Rajanpur, Layyah, and D.G. Khan are all part of it (Mohsin, et al., 2020). Before the establishment of a Waste Management Company or similar initiatives in Dera Ghazi Khan, the situation with garbage disposal and management might have been challenging.

According to Majeed et al. (2018), solid waste management is the process of managing garbage in a manner that takes into account public demand while also taking into account public health, the field of economics preservation, aesthetics, and the environment. Politics, laws, society, culture, the environment, the economy, and the availability of resources all play a role in solid waste management, in addition to technical considerations. In order to implement solid waste management in a sustainable manner, it is necessary to tackle all of these concerns (Menikpura, & Sang-Arun, 2013).

In light of the fast-paced social and economic growth, the paradox of rising garbage production rates and falling disposal capacity has taken on more significance. As a solution to this problem, we would really appreciate it if you could design MSW management systems that are both efficient and kind to the environment. It is important to think about how much money MSW will cost. In the early 1990s, Asian nations spent roughly $25 billion on solid waste management annually; by 2025, that number is predicted to climb to nearly $50 billion. 9 The approach that is most often used is land disposal. Local authorities in industrialized nations oversee the development and upkeep of well-managed landfills. Conversely, open dumps are used to dispose of rubbish in less regulated areas, which results in significant environmental damage and depletion of natural resources. The absence of well-structured waste management systems may have resulted in several problems (Pothirat, et al., 2019).

Dera Ghazi Khan City is a District headquarters as well as a Tehsil HQ of the District DGK. Prior to the establishment of Dera Ghazi Khan Waste Management Company (DGKWMC), Tehsil Municipal Administration (TMA) was responsible for Solid Waste Management (SWM) activities. Waste Management Company started its work in August 2020, The company inauguration ceremony held on ChowkChurhatta on 30 July 2020 that held by the Deputy Commissioner Sir TahirFarooq and the first CEO of WMC Captain Samiullah and the brother of Ex-Prime Minister Usman Khan Buzdar his brother Jaffar Khan Buzdar Participate in this ceremony. Muhammad Hanif Khan Pitafi, ZartajGul and the other MNA's and MPA's Participate in the Inauguration Ceremony.DGKWMC is carrying out the Solid Waste Management (SWM) activities. A very high demand scenario always existed specifically for improving rates of integrated waste reduction, reuse recycling and conversion systems for the entire metropolis while addressing health, environmental, climate change and safety concerns against the substantial probability of environmental disasters (Rolewicz-Kalińska, et al., 2020).

Research hypotheses

$\mathbf{H_0}$**:** The data is randomly distributed; no serial correlation exhibit in the residuals

$\mathbf{H_1}$**:** The data is not randomly distributed; serial correlation exhibit in the residuals

Litrature Review

An open-ended exploratory methodology was adopted for conducting the Waste Amount Characterization Research in DGK, Punjab. The existing information and documents on Solid Waste Management in Pakistan have been reviewed and analyzed, such as Solid Waste Management Strategy, Rules and Guidelines, Municipal Solid Waste Management Treatment and Disposal studies prepared by the Federal/Provincial Governments, International Donors, Public and Private Sector Organizations.

The literature review has provided a better understanding of solid waste management practices being adopted in DGK and facilitated preparing data collection tools for the Waste Amount Characterization Research. A number of previously conducted Waste Amount Characterization Research's in Pakistan were reviewed, particularly their methodology and sample size, which helped finalize a sample size and methodology applicable in Pakistan's context (Rodić, & Wilson, 2017).

The issue of polluted garbage has grown in importance in emerging nations. Environmental pollution resulting from non-disposal of solid waste was my primary factor in choosing Lahore. Successful waste management strategies in Oslo will be studied with the hope that they may be replicated in Lahore. Nevertheless, the scientific definition of solid waste management in Oslo encompasses three levels: production, collection, and treatment. Oslo has set the standard for other cities to follow when it comes to waste management, which has been in place for ten years. According to Waqas (2019), qualitative instruments form the basis of the study approach.

Oslo residents are willing to pay for garbage treatment facilities because they are well-informed and have better socioeconomic standards, but Lahore residents are hesitant to accept regulations owing to a lack of education and ineffective, corrupt government. When it comes to solid waste iv management, Lahore has a long way to go, but it may benefit from Oslo’s technological advancements. Municipal solid waste management and disposal in Pakistan are affected by a multitude of government legislation. However, the nation has a long way to go before these rules are really enforced. Progress in solid waste management has been hindered by the government’s and local authorities’ lack of interest. Meanwhile, in Norway, the federal government gives broad directives to the police, but it is up to the individual municipalities to determine how to make their communities safer, greener, and healthier for residents. The nation of Pakistan is now in the process of implementing solid waste management mechanisms, despite having the finest laws in place to do so. The city of Lahore should make environmental education a priority in the classroom so that future generations of citizens are environmentally conscious and able to make informed decisions at the state and federal levels (Muzaffar & Choudhary, 2017; Sohoo, et al., 2021).

Organic matter, plastics, and polythene bags made up the majority of household solid trash. Although the city’s solid waste management is the responsibility of Bahawalpur Waste Management Company (BWMC) and Tehsil Municipal Administration (TMA), the situation is far from good. Land deterioration, the establishment of breeding grounds for disease-carrying vectors like rats, mice, and mosquitoes, a drop in land values, and the spread of several serious illnesses are all consequences of ineffective solid waste management procedures. In addition, statistical research revealed a strong correlation between the community’s environmental and health issues and the ineffective solid waste management techniques (Shoaib, et al., 2006).

This article provides a status report on solid waste management in Lahore, Pakistan. The city's profile by UN-Habitat demonstrates that the current system primarily focusses on collecting waste, transit, and the production of 74,000 tones of natural compost annually. The profile also includes a systematic evaluation of the governance features of the system. The Lahore Waste Management Company (LWMC) has poor performance and a low level of market consultation when making decisions (governance characteristics). In complete opposition to modern waste management practices, the official system has regressed to the level of the informal system. Careful planning and organisation are suggested here to lessen the problem by merging the informal and official waste management systems for mutual benefit. In Lahore, the metrics used for integrated sustainable waste management (ISWM) vary by socioeconomic class. In order to bridge the gap in historical data and increase public awareness of recycling, Scarlat et al. (2019) suggest incorporating the informal sector into a sustainable system.

In Pakistan, solid waste management (SWM) contributes significantly to environmental deterioration. Residents are put at risk due to improper solid waste management. Through a literature assessment of current solid waste management (SWM) procedures in five large cities in Pakistan, this research intends to provide a comprehensive overview of these topics: amount, storage, collection, physiological composition, the transfer, processing, and disposal. In Pakistan, the SWM is often handled in a disjointed manner. The current method for collecting garbage is inadequate, as only 51–69 percent of the garbage produced in a handful of large cities is actually collected. Only places with high incomes have regular municipal trash pickup. Most landfills lack proper disposal infrastructure, including weighing facilities, and provide insufficient disposal service. As things are, no appropriate technique is being used for the disposal of hazardous waste, and the garbage is being poorly managed. A thorough and transparent set of rules addressing solid waste is required, according to the analysis of the legislative framework. Lawmaking, economic and financial analyses, public education initiatives, sanitary landfill development, and regulatory enforcement are major steps towards resolving environmental problems (Rupani, et al., 2019).

Like other developing nations, Pakistan's government only ranks the climate change agenda of the Sustainable Development Goals (SDGs) as a third priority, putting the Solid Waste Management (SWM) sector at a low level of importance. Efforts to improve SWM have been ongoing over the last decade, but thus far, these initiatives have only included garbage collection and manual sweeping, rather than waste treatment and disposal solutions. To that end, we looked at the country's present solid waste management model to see how we might improve it in the future so that it can meet the goals of the SDGs and the Nationally Determined Contributors (NDCs). Eleven of Pakistan's largest cities had their solid waste management (SWM) sectors evaluated using Waste-aware benchmarking metrics. Interventions to decrease GHG emission objectives by 2030 are discussed in this report, which also details the strengths and shortcomings of concerned local municipalities and WMCs. Achieving full sustainability in the solid waste management industry would be facilitated by proposed economic and environmental initiatives, which have the potential to produce enough money to cover as much as 29 percent of operating expenses (Ferronato, &Torretta, 2019).

The energy content of DGK is calculated as 3523.17 kcal/kg. In general, the average(year-wide) and recommended lower calorific value of waste should be at least 1,671 kcal/kg and must never fall below 1,433 kcal/kg. Without this value, there would be a need to constantly supply auxiliary fuel, which would decrease the viability of a MSW incineration facility. According to the findings of this research, DGK meets the recommended lower calorific value of waste. However, the mass incineration option is not suitable as GIZ Guidelines for Waste-to- Waste Amount Characterization Research in Dera Ghazi Khan, Energy state that to achieve optimal economies of scale, the plant capacity needs to be higher than 100,000 tons per year. Presently, DGK is producing 81,030 tons per year which does not fulfill GIZ criteria for waste to energy.

Material and Methods

Research Area

Dera Ghazi Khan is located in the southern part of Punjab, roughly between the latitudes of 30° 1 N and 70° 38 E. You will find the Waste Management Company (WACS) map office in Dera Ghazi Khan along with the Dera Ghazi Khan map. Fast urbanization, population expansion, and inadequate infrastructure pose serious problems for waste management in the famous city of Dera Ghazi Khan in Pakistan's Punjab province. The city's current waste management systems are overwhelmed by the massive volumes of solid garbage it produces, which include recyclables, hazardous items, and organic trash. Examining existing methods of waste management, pinpointing service gaps in collection and disposal, and investigating long-term solutions are the main goals of this field of study. Improving recycling procedures, assessing the efficacy of source-segregation, and launching community-based trash reduction programs are important focusses. Research in this area also intends to learn how ineffective waste management affects people's health and the environment, and to provide solutions to this problem by bringing together cutting-edge methods and technology in Dera Ghazi Khan.

Figure 1 Map of Dera Ghazi Khan on Google Earth.

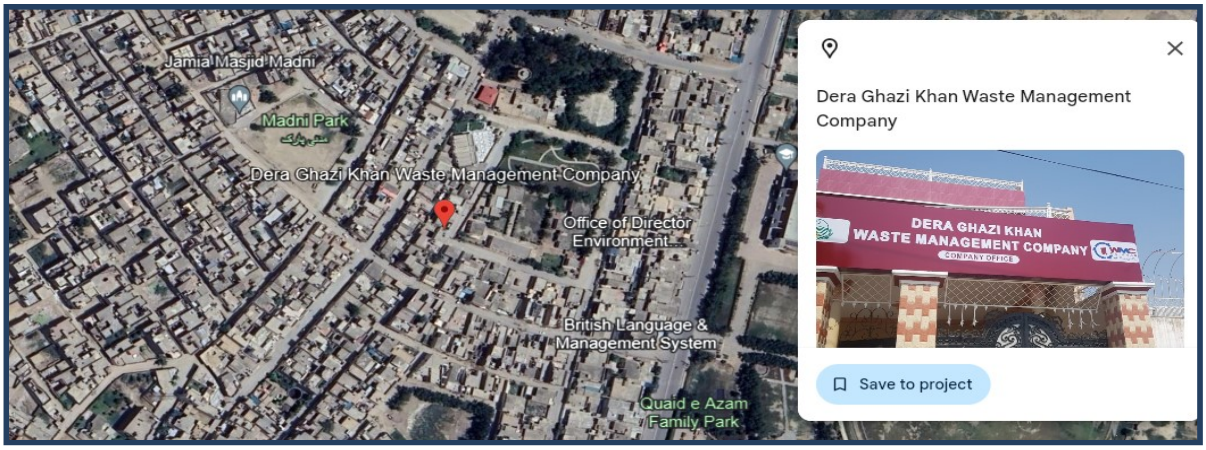

Figure 2 Map of Waste Management Company (WMC) office on Google Earth

Data Collection

Secondary data from January 2021 to March 2024 of Waste Weight (Tons) taken from the Waste Management Company (WMC) in Dera Ghazi Khan.

Time Series Analysis

Analyzing numerical data in a temporal-ordered format (list, graph, etc.) is called a time series analysis. Time series encompass methods for examining time series data in order to extract valuable statistics and other characteristics from the data (Imdadullah, 2013). According to Brockwell et al. (2002), a model of time series for the observed data {y_t } with t=1,2,…,T (where t is the time) is a requirement of the joint distributions of an ordered set of random variables {Y_t }. The mathematical properties of a stationary time series are as follows:

$$\text{mean} = E(Y_t) = \mu,$$

variance $= E(Y_t - \mu_t)^2 = \partial^2$ and

covariance $= E(Y_t - \mu_t)(Y_{t-1} - \mu_{t-1}) = \gamma(s)$ is independent of t.

The lag-terms are denoted by the letter "s." respectively. A non-stationary time series is one that does not exhibit the aforementioned characteristics.

Stationary Diagnostic Tests

If the average value of the random variable {Y_t } fluctuates over time, meaning the variable is not stationary, then the approach is called a non-stationary time series, as stated by Brockwell and Davis (2016). Transforming a non-stationary time series to a stationary one using different transformations (e.g., the log modification, the differencing transformation, etc.) is the first step in any investigation using such a series. These checks are referred to as unit root tests as well.

Auto correlation Function (ACF)

According to Gujrati (2003), the autocorrelation function (ACF) measures the degree of correlation between several time- or space-ordered series of data. To rephrase, ACF may alternatively be seen as a correlation between the series {Y_t } and the sum of the series' prior lag values for lags s=1,2,...,t or Y_(t-1),Y_(t-2),...,Y_(t-s). With the help of ACF, we can find the connection between Y_t and Y_(t-1), Y_t and Y_(t-2), and so on. It is possible to define ACF mathematically as the time series percentage of autocorrelation with s^thlag order, and its variance is represented by ϱ_k. This is further stated as;

$$\varrho_k = \frac{cov(Y_t - Y_{t-s})}{\sqrt{var(Y_t)var(Y_{t-k})}}$$

$$\varrho_k = \frac{E(Y_t - \mu_t)(Y_{t-1} - \mu_{t-s})}{\sqrt{E(Y_t - \mu_t)^2 E(Y_{t-s} - \mu_{t-s})^2}}$$

$$\varrho_k = \frac{r(s)}{r_0} \qquad \text{with} \qquad -1 \leq \varrho_k \leq +1$$

Where;

$$r_k = \frac{E(Y_t - \mu_t)(Y_{t-1} - \mu_{t-s})}{N}$$

$$r_0 = \frac{\sqrt{E(Y_t - \mu_t)^2 E(Y_{t-s} - \mu_{t-s})^2}}{N}$$

Partial Autocorrelation Function (PACF)

A conditional correlation is the partial autocorrelation function (PACF). According to Box (2015), when it comes to time series analysis, PACF provides a partial correlation with both its own lag values and monitoring data at all reduced delays. The partial autocorrelation function (PACF) between two variables is defined as the conditional correlation between two variables, with respect to the set of dataset observations that fall between time points t and t-h, and the variables Y_(t-s+1), Y_(t-s+2),..., Y_(t-1). When describing PACF, the first order is the same as when describing ACF, while the second order is as follows:

$$\varphi_2 = \frac{cov(Y_t, Y_{t-2}|Y_{t-1})}{\sqrt{var(Y_t|Y_{t-1})\, var(Y_{t-2}|Y_{t-1})}}$$

Values at two different times are correlated. In addition, knowing the third value that exists between them is a prerequisite. In PACF, the third order is;

$$\varphi_2 = \frac{cov(Y_t, Y_{t-3}|Y_{t-1}, Y_{t-3})}{\sqrt{var(Y_t|Y_{t-1}, Y_{t-2})\ var(Y_{t-3}|Y_{t-1}, Y_{t-2})}}$$

And so on for higher lag terms.

Augmented Dickey Fuller test

As a unit root test, the Augmented-Dickey Fuller (ADF) is used in statistics to determine whether time series data is stationary. Fuller (1976) introduced an ADF test that may be used to evaluate the null hypothesis that time series data has a unit root. Here is the ADF test hypothesis:

$\boldsymbol{H}_0$**:** The stationary is not exist in the data

$\boldsymbol{H}_1$**:** The stationary is exist in the data

Finding the right regression model to use with time series data is the first step. Means (μ_t) that are not zero suggest that the regression will include constant components, as an example. This is a list of four standard regression models:

No constant, no trend $= YY_{t-1} + \mu_t$

Constant, no trend $= \gamma + YY_{t-1} + \mu_t$

No constant, trend = $YY_{t-1} + \pi_t + \mu_t$

Constant and trend $= \gamma + YY_{t-1} + \pi_t + \mu_t$

The ADF test adds lagged differences to these models:

No constant, no trend $\Delta Y_t = YY_{t-1} + \sum_{i=1}^{n} a_i \Delta Y_{t-i} + \mu_t$

Constant, no trend $\Delta Y_t = \gamma + YY_{t-1} + \sum_{i=1}^{n} a_i \Delta Y_{t-i} + \mu_t$

No constant, trend $\Delta Y_t = YY_{t-1} + \pi_t + \sum_{i=1}^{n} a_i \Delta Y_{t-i} + \mu_t$

Constant, trend$\Delta Y_t = \gamma + YY_{t-1} + \pi_t + \sum_{i=1}^{n} a_i \Delta Y_{t-i} + \mu_t$

The constant γ and the trend π_t at time t are denoted by these variables, respectively. To account for higher-order auto-regressive processes, the ADF formulation incorporates lags of order 'i.' To find the lag length 'i,' one may use selection criteria like AIC or BIC, or run a t-test on the coefficients.

Here is the algebraic version of the ADF test statistic:

$$DF_T = {}^{\hat{\rho}}\!\big/_{S.E(\hat{\rho})} \qquad (3.1)$$

Where $\hat{\rho}$ is the correlation

Phillips Perron test

The Phillips Perron (PP) test is also a unit root test, used in the analysis of time series to test the null hypothesis that the time series integrated into order 1.

Time Series Models

This research contains the following time series models: Arima (Auto Regressive Integrated Moving Average) Model, Here is an overview of the model and its mathematical representation:

Autoregressive Integrated Moving Average Process

Here, non-stationary time series cannot be well characterized by the ARMA approach. This is where the ARIMA model comes in handy; it's an expanded version of the ARMA procedure that can handle non-stationary data as well. Applying finite differencing to non-stationary time series datasets in the ARIMA model makes them stationary. The following is the statistical representation of the ARIMA (p, d, q) model;

$$\emptyset(B)(1-B)^d y_t = \theta(B)z_t; i.e.$$

$$\left[1-\sum_{i=1}^{p}\emptyset_i B^2\right](1-B)^d y_t = \left[1+\sum_{j=1}^{q}\theta_j B^2\right] z_t \qquad (3.2)$$

In this context, the numbers p, d, and q not equal to zero denote the order of the AR and MA components of the models, accordingly. The degree of differentiation is controlled by the number d. The model degrades to an ARMA (p,q) model when d=0 (Adhikari, 2013).

3.6 Model Selection Criteria

Prior to making a model selection, it is necessary to determine which parameters would produce optimal outcomes. The AIC, the Schwarz criteria, and the coefficient of determination

Akike information criteria and Schwarz Criteria

Most widely used measures for model identification are Akike information criteria (AIC), Schwarz criteria (SC) or Bayesian information criteria (BIC) suggested by Schwarz and Gideon (1978)

$$AIC(P) = nln\left(\frac{\hat{\partial}_e^2}{n}\right) + 2P \qquad (3.3)$$

$$\text{SIC or BIC(p)} = \text{AIC} + \text{P} + \text{Pln(n)} \qquad (3.4)$$

In this case, 'n' denotes the quantity of effective observations used for model fitting, P denotes the quantity of model parameters, and \ Б_e^2 denotes the sample square residuals. The best order for the model parameters is determined by how many parameters minimized AIC or SC. SC consistently estimates the order if the actual 'p' is smaller than the 'p' maximum, whereas AIC asymptotically overestimates the order with a positive probability.

Coefficient of determination

The total variation, which is the variability among the values of the dependent variable y, is provided by the sum of all the variances, or (y-ȳ)^2. Both the variation that can be described by the regression line (i.e., ∑(〖ŷ-y ƀ)〗 ^2) and the variation that the a regression line cannot explain (i.e., ∑(〖y-y Б)〗 ^2) make up total variation.

$$\text{total variation} = \text{explained varitaion} - \text{unexplained variation}$$

$$\sum(y-\bar{y})^2 = \sum(\hat{y}-\bar{y})^2 + \sum(y-\hat{y})^2$$

The statistical metric known as the coefficient of determination, abbreviated as R^2, indicates the extent to which the explanatory variables account for the variance in a response variable (Draper and Smith, 1998).

$$R^2 = \frac{\sum(y-\bar{y})^2}{\sum(y-\hat{y})^2} \qquad 0 \le R^2 \le 1 \qquad (3.5)$$

If R2=1, then the regression line explains all of the variation.

R^2 is not a credible metric for choosing a better-fitting model if the MLR has a significant number of variables that predict in the model. If you want to choose the best model, modified R^2 is a preferable metric to use. This is how the adjusted R^2 is defined:

$$\overline{R^2} = 1 - (1 - R^2)\frac{(n-1)}{(n-k-1)} \qquad (3.6)$$

The output is a regression line with a sample size of 'n' and a number of predictor variables of 'k'.

Model Accuracy Measures

Mean absolute errors (MAE), Root Mean Square Error (RMSE), and Mean Error (ME) are several ways to measure the accuracy of the model. Square of the mean square error after compensating for the degree of freedom of the error is known as root-mean-squared error (RMSE), standard error (SE) of the regression, or estimated white noise standard error in the ARIMA model. The parameter procedure minimizes the RMSE statistic value to provide the confidence interval.

$$SE = \sum_{i=1}^{n}(y_i - \hat{y_i})$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y_i})^2} \qquad (3.7)$$

Because of its extensive usage in climatic and environmental literature, RMSE is of special importance. But that average error metric is ill-suited and easily misunderstood. The root-mean-squared error (RMSE) is a function of three error characteristics rather than the average error, hence it is inappropriate to use it here. A variety of factors affect RMSE, including the size of the mean absolute error (MAE), the dispersion of the error values, and the square root of the error count. According to Willmott and Matsurra (2005), MAE is a clearer and more intuitive way to calculate the average error than RMSE. The mean absolute error (MAE) is a statistical measure. Although it is less sensitive to big mistakes, the MAE is otherwise rather comparable to the RMSE.

$$MAE = \sum_{i=1}^{n}|y_i - \hat{y_i}| \qquad (3.8)$$

A signed metric that shows whether the prediction is biased or not is the mean error (ME) that is reported in several statistical procedures. Commonly used colloquially, "ME" denotes the mean of all the set's faults. When there is a discrepancy between the expected and actual values in a dataset, this is known as an error.

$$ME = \sum_{i=1}^{n}(y_i - \hat{y_i}) \qquad (3.9)$$

Data Analysis

Data preliminary analysis is what this is all about. To comprehend the data's behavior, Descriptive Analysis is useful. The Weight of Wastage was predicted using the ARIMA model. Here are the variables that were utilized for the analysis:

1. Weeks: The number of weeks in a month.

2. Tons: The unit used for the weight of wastage that is collected in a day of a week. The metric tone is used interchangeably with the more common 1000 kg in many parts of the world. You may calculate the weight in tones by dividing the mass in kilogram's by 1000.

Summary of Wastage Weight

In the section on preliminary analysis, table 4.1 illustrates the behaviour of the Wastage Weight data for Dera Ghazi Khan (City) from January 2021 to March 2024.

Table 1
Statistics of Wastage Weight (Tons) 2021-2024

Years	Total Weight (Tons)	Monthly Averages
2021	68975	1189.24
2022	74699	1336.01
2023	64841	1117.95
2024 (Three Months)	5365	357.69
Total	213881	4000.89

The year 2022 is shown by Figure 4.1 as the year with the highest rate of wasted weight in Dera Ghazi Khan. There was a very high amount of waste weight in 2022 (74,699) and a relatively low amount recorded in 2024 (5,365). Waste weight follows a seasonal pattern from 2021–2024, as seen in the graph. A tiny peak of waste weight occurs in 2024, after peaks in 2021, 2022, and 2023.

Time series plot

The typical use of time series is to gain insight into the data's behavior. For non-stationary data, missing information, or outliers such trends, seasonality, cyclist, or irregular changes, it is employed (Ganapragasam, 2016).

Table 2
Stationary test for Wastage Weight (Tons)

ADF test	Phillip Perron test
DF=-2.1816	Z = -153.07
(P=0.500***)	(P=0.01***)

Note: *** Statistically Significant at 1% level, ** Statistical Significant at 5% level, * statistically significance at 10% According to Polwiang (2016), models may be made more predictive by taking seasonality into account. We used the Phillip Perron test and the Augmented Dickey Fuller (ADF) test (3.7) to make sure the Wastage Weight data was stationary. Table 4.1 displays the results of the ADF and PP tests, which show that the data is seasonal.

Developing SARIMA Model

The dataset Wastage Weight is divided into two parts. The data from January 2021 to December 2023 used as the train data to develop the model and monthly Wastage Weight from January 2024 to March 2024 used as test data for cross-validate the model. The models are develop by using the auto.arima( ) function in R software on the basis of Akike Information Criteria (AIC).

Table 3
Models results on selection criteria using Akike Information Criteria (AIC).

S.No	Models	AIC	Rank
1	**ARIMA(1,1,1)(0,0,1)^{52}**	**2480.97**	**1**
2	ARIMA(0,1,1)(1,0,1)^{52}	2499.241	2
3	ARIMA(0,1,1)(1,0,0)$^{52}_{wd}$	2501.768	3
4	ARIMA(1,1,0)(0,0,1)$^{52}_{wd}$	2518.836	4
5	ARIMA(0,1,0)(0,0,1)$^{52}_{wd}$	2551.826	5
6	ARIMA(0,1,0)^{52}	2557.927	6
7	ARIMA(1,1,0)(1,0,0)$^{52}_{wd}$	2564.798	7

According to Table the ARIMA model with the lowest AIC value and the estimated variance for the dataset by utilizing equation (3.2) was found for the Dera Ghazi Khan District to be (1, 1, 1) (0, 0, 1)52. The estimated values of the autoregressive parameter ϕ_1 and the seasonal component ϕ_52,1 are 0.0044 and 0.2757, respectively, with a standard error (SE) of 0.0922 and 0.1124, in the ARIMA model (2, 0, 0) (1, 1, 0)12. As a result, it is the most appropriate model for predicting the weekly waste weight in tones for the next year.

Residuals Diagnostic

If the residuals exhibit dependence after the model's parameters have been estimated, the model is unfit for prediction or may provide inaccurate predictions (Mertinez et al., 2011). Functions for autocorrelation (ACF), partial autocorrelation (PACF), the Box-Pierce (BP) test (3.10), and the Ljung-Box (LB) test (3.11) which are used to assess the independence of residuals.

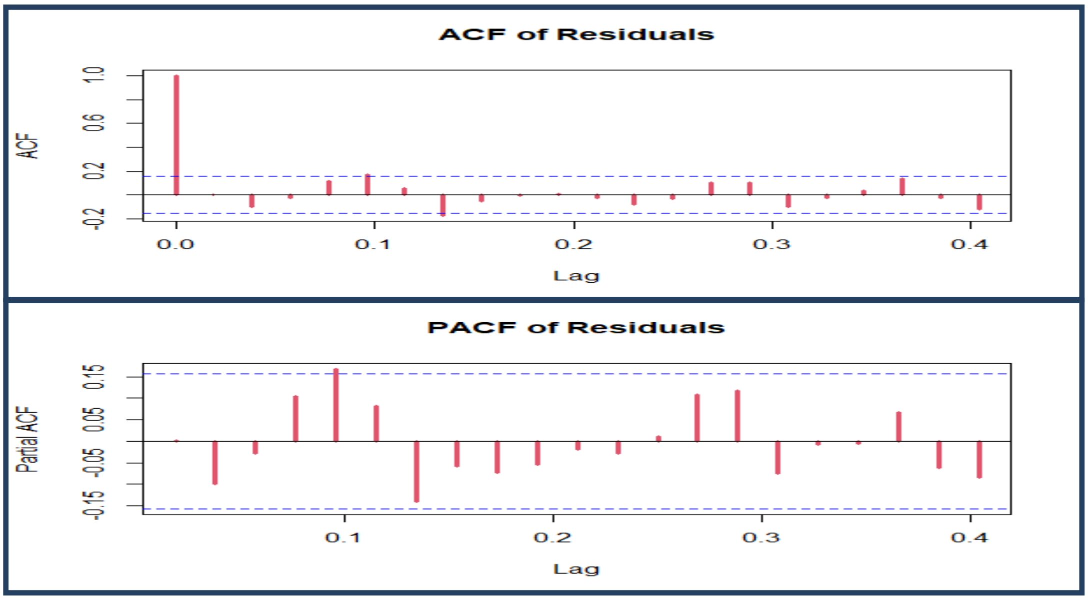

Figure 2 Plot of ACF and PACF of residuals of ARIMA model

Table 4
Diagnostic checking results

Box-pierce test	Ljung-Box test
0.1462	0.1298

Note: *** Statistically Significant at 1% level, ** Statistical Significant at 5% level, * statistically significance at 10%

According to the p-value for the Ljung-Box (LB) and Box-pierce (BP) as shown in table 4.4. Suggesting that there is insignificant autocorrelation amongst residuals at different lag terms and the residuals are randomly distributed or the null hypothesis of independence of residuals unable to reject. The figure 4.2 shows ACF and PACF of ARIMA (1, 1, 1) (0, 0, 1)[52] model for Wastage Weight explained that the residuals are independent at lag time. Therefore, the model is good for forecast the data of districts Dera Ghazi Khan for 2025, respectively.

Forecast of Wastage Weight

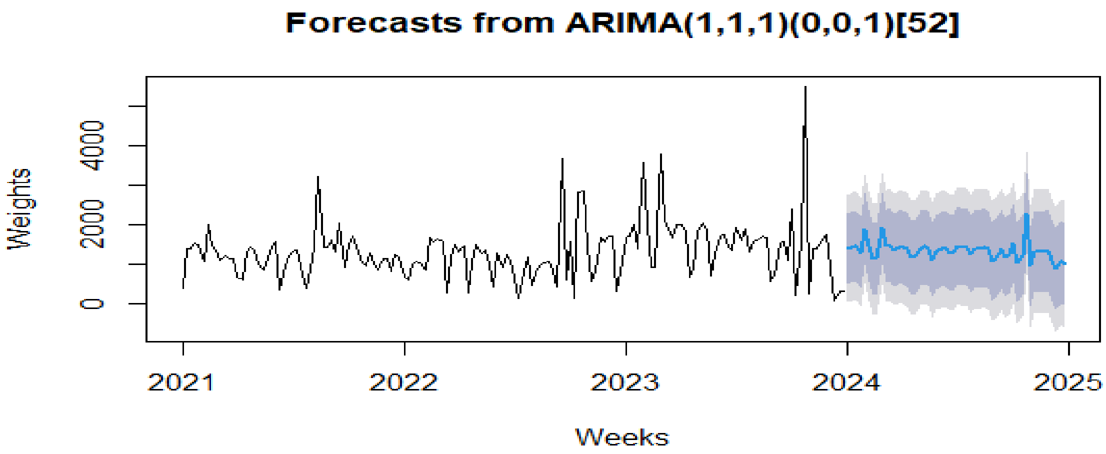

Figure 3: Forecasting graph for 2025 of Weekly Wastage Weight

Figure 3 Illustrate that the forecasted graph for Dera Ghazi Khan District. The graphs shows variation pattern of forecasted data cycle of weekly wastage weight (tons) for Dera Ghazi Khan District. Figure 3 shows the weekly waste weight (in tonnes) as observed in the Dera Ghazi Khan District, with the original data shown by the black dotted lines and the observed value by the blue lines. Confidence intervals of 80% and 95% are shown by the darker and lighter shades, respectively. In terms of waste weight (in tonnes), both the predicted and observed values fall within the confidence interval.

Table 5
Forecasted Values for the year 2025

Weeks	Forecasted Values
1	1379.15
2	1413.56
3	1461.16
4	1296.01
5	1898.70
6	1472.14
7	1128.01
8	1123.29
9	1909.62
10	1444.53
11	1493.11
12	1358.04

13	1421.21
14	1431.37
15	1368.69
16	1159.54
17	1157.14
18	1390.78
19	1446.01
20	1399.91
21	1107.84
22	1302.14
23	1368.95
24	1381.82
25	1283.04
26	1278.92
27	1470.71
28	1425.02
29	1435.66
30	1248.38
31	1375.26
32	375.15
33	1427.37
34	1371.39
35	1068.24
36	1129.55
37	1381.12
38	1161.18
39	1244.34
40	1530.95
41	1041.19
42	1212.22
43	2285.19
44	939.90
45	1331.22
46	1306.44
47	1297.96
48	1345.51
49	1108.43
50	874.55
51	1048.03
52	991.62

Conclusion

From 2021 to 2022, there was a significant increase in waste weight, with the highest point reached in 2022. However, the waste weight decreased in 2023 and 2024, before showing a marked rise again in 2025. The data indicates a seasonal pattern, with specific periods in each year experiencing peak waste generation. This seasonal trend suggests that waste weight is influenced by time-specific factors, such as seasonal activities or fluctuations in population behavior. To forecast waste weight in Dera Ghazi Khan, the ARIMA(1, 1, 1)(0, 0, 1)52 model was selected based on its lowest AIC value, which indicated its suitability for the task. The residual diagnostic tests, including the Box-Pierce and Ljung-Box tests, confirmed that the residuals from the ARIMA model were independent and randomly distributed, supporting the model's validity for forecasting purposes. The forecast for weekly waste weight in 2025 shows variability, with some weeks exhibiting higher forecasted values while others show lower values. These forecasted values fall within the 95% confidence interval, indicating a high level of reliability. Notably, the forecast highlights peaks in waste weight, particularly in week 43, where the forecasted value is 2285.19 tons, signaling periods of high waste production that will require special attention in waste management planning.

Recommendations

Following were the recommendations of the study

- To improve the efficiency of waste management, it is recommended to increase waste collection frequencies during peak periods, particularly in weeks when high waste volumes are forecasted. This proactive approach prevents waste overflow, ensuring that waste is removed in a timely manner and preventing the accumulation of waste in public spaces.
- During periods of high waste generation, DGKWMC should allocate additional resources, including extra waste collection vehicles and staff. This will help manage the increased waste volumes more effectively, ensuring that the system operates efficiently and that there is no backlog or delay in waste removal.
- One of the most effective ways to manage waste is through source segregation. It is crucial to encourage residents and businesses to sort their waste at the point of disposal. By separating recyclables, organic waste, and non-recyclables, the waste management process becomes more streamlined, and valuable materials can be diverted from landfills for recycling and composting.
- To accommodate the growing volumes of recyclables, it is important to invest in or improve recycling facilities. Enhancing recycling capabilities will reduce the reliance on landfills and promote resource recovery. Upgrading existing facilities will also help in processing a wider variety of materials, further contributing to environmental sustainability.
- Educating the community about the importance of waste reduction, recycling, and composting is critical. Public awareness campaigns can lead to behavioral changes, encouraging individuals and businesses to reduce waste generation and participate actively in recycling initiatives. This can foster a culture of sustainability and support waste minimization efforts.
- Ensuring compliance with waste management regulations is crucial for maintaining effective waste systems. It is recommended to implement penalties for non-compliance with waste disposal practices to encourage adherence to the standards and promote responsible waste management within the community.
- Investing in the modernization of recycling facilities is key to improving waste processing efficiency. Upgraded facilities, with state-of-the-art sorting technology and processing equipment, will ensure that a variety of materials can be efficiently handled, resulting in higher-quality and greater quantities of recyclables being processed.
- Increasing the accessibility of recycling bins and drop-off centers for both residents and businesses is essential to improve participation in recycling programs. Ensuring that these facilities are conveniently located, clearly marked, and easy to use will help encourage more people to actively engage in recycling efforts and contribute to waste reduction.

References

Ali, M., Geng, Y., Robins, D., Cooper, D., Roberts, W., & Vogtländer, J. (2019). Improvement of waste management practices in a fast-expanding sub-megacity in Pakistan, on the basis of qualitative and quantitative indicators. *Waste Management, 85*.

Aslam, B., Maqsoom, A., Tahir, M. D., Ullah, F., Rehman, M. S. U., & Albattah, M. (2022). Identifying and ranking landfill sites for municipal solid waste management: An integrated remote sensing and GIS approach. *Buildings, 12*(605). https://doi.org/10.3390/buildings12050605

Aye, L., & Widjaya, E. R. (2006). Environmental and economic analyses of waste disposal options for traditional markets in Indonesia. *Waste Management, 26*(1180–1191). https://doi.org/10.1016/j.wasman.2005.08.022

Babar, A. R., Khalid, Q. S., Rashid Nawaz, I. A., & Azim, S. (2021). Capacity analysis of solid waste in Peshawar, Pakistan. *International Journal of Scientific Research, 10*(22–26).

Debrah, J. K., Vidal, D. G., & Dinis, M. A. (2021). Raising awareness on solid waste management through formal education for sustainability: A developing countries evidence review. *Recycling, 6*(6). https://doi.org/10.3390/recycling6020006

Dlamini, S., Simatele, M. D., & Serge Kubanza, N. (2019). Municipal solid waste management in South Africa: From waste to energy recovery through waste-to-energy technologies in Johannesburg. *Local Environment, 24*(249–257). https://doi.org/10.1080/13549839.2019.1579360

Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Health Research, 16*. https://doi.org/10.1080/09603123.2019.1637301

Ferronato, N., D'Avino, C., Ragazzi, M., Torretta, V., & De Feo, G. (2017). Social surveys about solid waste management within higher education institutes: A comparison. *Sustainability, 9*(391). https://doi.org/10.3390/su9030391

Ferronato, N., Pasinetti, R., Valencia Vargas, D., Calle Mendoza, I. J., Guisbert Lizarazu, E. G., Gorritty Portillo, M. A., Conti, F., & Torretta, V. (2022). Circular economy, international cooperation, and solid waste management: A development project in La Paz (Bolivia). *Sustainability, 14*(1412). https://doi.org/10.3390/su14031412

Ilmas, B., Mir, K. A., & Khalid, S. (2018). Greenhouse gas emissions from the waste sector: A case study of Rawalpindi in Pakistan. *Carbon Management, 9*(645–654). https://doi.org/10.1080/17583004.2018.1496400

Jerin, D. T., Sara, H. H., Radia, M. A., Hema, P. S., Hasan, S., Urme, S. A., Audia, C., Hasan, M. T., & Quayyum, Z. (2022). An overview of progress towards implementation of solid waste management policies in Dhaka, Bangladesh. *Heliyon, 8*(e08918). https://doi.org/10.1016/j.heliyon.2022.e08918

Kabera, T., Wilson, D. C., & Nishimwe, H. (2019). Benchmarking performance of solid waste management and recycling systems in East Africa: Comparing Kigali Rwanda with other major cities. *Waste Management Research, 37*(58–72). https://doi.org/10.1177/0734242X18823491

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. *World Bank Publications*. https://doi.org/10.1596/978-1-4648-1347-7

Maasakkers, J. D., Varon, D. J., Elfarsdóttir, A., McKeever, J., Jervis, D., Mahapatra, G., Pandey, S., Lorente, A., Borsdorff, T., Foorthuis, L. R., et al. (2022). Using satellites to uncover large methane emissions from landfills. *Science Advances, 8*(eabn9683). https://doi.org/10.1126/sciadv.abn9683

Majeed, A., Batool, S. A., & Chaudhry, M. N. (2018). Environmental quantification of the existing waste management system in a developing world municipality using EaseTech: The case of Bahawalpur, Pakistan. *Sustainability, 10*(2424). https://doi.org/10.3390/su10072424

Menikpura, N., & Sang-Arun, J. (2013). *User Manual: Estimation Tool for Greenhouse Gas (GHG) Emissions from Municipal Solid Waste (MSW) Management in a Life Cycle Perspective.* Institute for Global Environmental Strategies.

Mohsin, M., Khan, A. A., Nasar-u-Minallah, M., & Barkat, T. (2020). Assessment of municipal solid waste management practices in Bahawalpur city, Pakistan. *International Journal of Economics and Environment, 11*(1–5).

Muzaffar, M. & Choudhary, S. (2017). Human Development and Democratic Governance: An Analysis, *Orient Research Journal of Social Sciences, 2*(I), 71-94

Park, Y. K., Kim, W., & Jo, Y. M. (2013). Release of harmful air pollutants from open burning of domestic municipal solid wastes in a metropolitan area of Korea. *Aerosol and Air Quality Research, 13*(1365–1372). https://doi.org/10.4209/aaqr.2012.12.0346

Permana, A. S., Towolioe, S., Abd Aziz, N., & Ho, C. S. (2015). Sustainable solid waste management practices and perceived cleanliness in a low-income city. *Habitat International, 49*, 197–205. https://doi.org/10.1016/j.habitatint.2015.05.004

Pothirat, C., Chaiwong, W., Liwsrisakun, C., Bumroongkit, C., Deesomchok, A., Theerakittikul, T., Limsukon, A., Tajaroenmuang, P., Phetsuk, N. (2019). Influence of particulate matter during seasonal smog on quality of life and lung function in patients with chronic obstructive pulmonary disease. *International Journal of Environmental Health Research, 16*(106). https://doi.org/10.1080/09603123.2019.1618991

Rodić, L., & Wilson, D. C. (2017). Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. *Sustainability, 9*(404). https://doi.org/10.3390/su9030404

Rolewicz-Kalińska, A., Lelicińska-Serafin, K., & Manczarski, P. (2020). The circular economy and organic fraction of municipal solid waste recycling strategies. *Energies, 13*(4366). https://doi.org/10.3390/en13174366

Rupani, P. F., Delarestaghi, R. M., Abbaspour, M., Rupani, M. M., El-Mesery, H. S., Shao, W. (2019). Current status and future perspectives of solid waste management in Iran: A critical overview of Iranian metropolitan cities. *Environmental Science and Pollution Research, 26*(32777–32789). https://doi.org/10.1007/s11356-019-05163-1

Scarlat, N., Fahl, F., & Dallemand, J. F. (2019). Status and opportunities for energy recovery from municipal solid waste in Europe. *Waste and Biomass Valorization, 10*(2425–2444). https://doi.org/10.1007/s12649-018-0174-0

Shoaib, M., Mirza, U. K., & Sarwar, M. A. (2006). Review and status of solid waste management practices in Multan, Pakistan. *Electronic Green Journal, 1*.

Sohoo, I., Ritzkowski, M., Sohu, Z. A., Cinar, S. Ö., Chong, Z. K., Kuchta, K. (2021). Estimation of methane production and electrical energy generation from municipal solid waste disposal sites in Pakistan. *Energies, 14*(2444). https://doi.org/10.3390/en14082444

Vaccari, M., Torretta, V., & Collivignarelli, C. (2012). Effect of improving environmental sustainability in developing countries by upgrading solid waste management techniques: A case study. *Sustainability, 4*(2852–2861). https://doi.org/10.3390/su4112852

Waqas, M. (2019). The current status and steps towards sustainable waste management in the developing countries: A case study of Peshawar-Pakistan. *Indonesian Journal of Urban and Environmental Technology, 3*(47–66).

Wilson, D. C., Rodic, L., Cowing, M. J., Velis, C. A., Whiteman, A. D., Scheinberg, A., Vilches, R., Masterson, D., Stretz, J., Oelz, B. (2015). 'Wasteaware' benchmark indicators for integrated sustainable waste management in cities. *Waste Management, 35*(329–342). https://doi.org/10.1016/j.wasman.2014.10.027

Yasin, H., Usman, M., Rashid, H., Nasir, A., & Randhawa, I. A. (2017). Alternative approaches for solid waste management: A case study in Faisalabad Pakistan. *Earth Science Pakistan, 7–9*.