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ORIGINAL ARTICLE

Development of a Waste Generation Prediction Model Using Independent Macro Variables in Various Sectors (Case Study: Tehran)

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ABSTRACT
According to statistics from the Ministry of Interior of Iran, more than 75% of the waste produced in the country is landfilled. Many of the programs proposed by waste management organizations and municipalities have not been effective due to the failure to consider the impacts of various economic and non-economic variables on waste generation. Therefore, this study aims to increase the effectiveness of proposed waste management programs for Tehran in line with sustainable development. An empirical modeling approach was used, utilizing 120 months of data (April 2011 to March 2021) to develop models for predicting different types of waste generation. Additionally, the statistical relationship between 32 macroeconomic variables, including industry and mining, agriculture, urban management, population, and climate, and five waste generation variables was examined at a 90% confidence level. The results indicate that 79% of the variations in the total waste generation tonnage, 73.4% of the variations in the mixed waste tonnage at the source, 80.3% of the variations in the separated dry waste tonnage at the source, and 81.4% of the variations in the construction and demolition waste tonnage in Tehran can be predicted using the models developed in this study.

KEYWORDS
Construction and Demolition Waste, Source Separation of Waste, Open Space Waste, Regression Model, Economic Variables.

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آموزش محیط‌زیست و توسعه پایدار

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«مقاله پژوهشی»

توسعه یک مدل پیش بینی تولید پسماند با استفاده از متغیرهای کلان مستقل در حوزه های مختلف (مطالعه موردی: شهر تهران)

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چکیده

بر اساس آمار وزارت کشور بیش از ۷۵ درصد از پسماندهای تولیدی در کشور دفن شده و بسیاری از برنامه‌های ارایه شده توسط سازمان‌های مدیریت پسماند و شهرداری‌ها به دلیل عدم در نظر گرفتن تاثیرات متغیرهای مختلف اقتصادی و غیر اقتصادی بر تولید پسماندها از اثربخشی مناسب برخوردار نبوده‌اند. لذا در این پژوهش با هدف افزایش اثربخشی برنامه‌های پیشنهادی برای مدیریت پسماند شهر تهران در راستای توسعه پایدار، از روش مدلسازی تجربی و بهره‌گیری از داده‌های ۱۲۰ ماه (فروردین ۱۳۹۰ الی اسفند ۱۳۹۹) جهت توسعه مدل‌هایی جهت پیش‌بینی تولید انواع پسماند استفاده شد. همچنین ارتباط آماری میان ۳۲ متغیر کلان اقتصادی، صنعت و معدن، کشاورزی، مدیریت شهری، جمعیت و آب و هوایی و ۵ متغیر تولید پسماندها در سطح اطمینان ۹۰ درصد نیز مورد بررسی قرار گرفت. بر اساس نتایج ۷۹ درصد از تغییرات تناژ تولید کل پسماندها، ۷۳/۴ درصد از تغییرات تناژ تولید پسماندهای مخلوط تفکیک نشده در مبداء، ۸۰/۳ درصد از تغییرات تناژ پسماندهای خشک تفکیک شده در مبداء و ۸۱/۴ درصد از تغییرات تناژ پسماندهای ساختمانی و عمرانی شهر تهران را می توان‌با استفاده از مدل‌های ایجاد شده در این پژوهش پیش‌بینی نمود.

واژه‌های کلیدی

پسماندهای ساختمانی و عمرانی، تفکیک پسماند از مبداء، پسماندهای فضای باز، مدل رگرسیونی، متغیرهای اقتصادی.

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این مقاله تحت گواهی زیر منتشرشده و هر نوع استفاده غیرتجاری از آن مشروط بر استناد صحیح به مقاله و با رعایت شرایط مندرج در آدرس زیر مجاز است.

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Introduction

In recent decades, the increase in population and global economic growth has led to a significant rise in the generation of municipal solid waste. This increase directly impacts quality of life, public health, and the environment (Al-Salem et al., 2018), making solid waste management one of the most critical environmental challenges in developing countries (Khan et al., 2022; Darban Astane & Hajilo, 2016; Muheirwe et al., 2017). These environmental issues have posed significant challenges for many planners and decision-makers in solid waste management. Moreover, these problems have become more complex with the rapid socio-economic development of communities and cities (Biswas & De, 2016). This situation has prompted urban managers to develop effective models for predicting solid waste generation using different regressor variables, including social and demographic dimensions (Darban Astane & Hajilo, 2017).

Solid waste management in developing countries is more complex than in developed countries due to limited recycling and inefficient policies and planning (Budihardjo et al., 2022). In these countries, inappropriate policymaking has led to the mismanagement of 75% of all generated solid waste (Aparcana, 2017). Predictions indicate that global solid waste generation, mainly due to population growth, urbanization, and socio-economic issues in low-income (and also middle-income) countries, will increase from 1.3 billion tons in 1990 to 2.7 billion tons by 2050. This increase is particularly significant for Asia and Africa (Wilson & Velis, 2015). It is evident that this increase in waste generation and the pollution resulting from its collection and disposal can cause severe damage to the environment and human health (Darban Astane & Hajilo, 2016; Ghinea et al., 2017). It is noteworthy that managing such a large amount of waste consumes a significant portion of a city's or municipality's operational revenue (Ahmadia et al., 2013). Therefore, developing and implementing global and national policies for optimal solid waste management is crucial (Muheirwe et al., 2022).

The rapid growth of solid waste generation, the lack of sufficient information and data, and the impact of various and uncontrollable factors on waste quantity have made the development of waste generation prediction models, and consequently, policy-making, a complex engineering problem, especially in developing countries (Abbasi et al., 2013). Moreover, population growth, changes in consumption patterns, economic growth, advances in science and technology, and various social and cultural factors have altered not only the quantity but also the quality of solid waste (Darban Astane & Hajilo, 2015; Oribe-Garcia et al., 2017). Additionally, to develop and implement an optimal solid waste management system in cities, it is essential to predict waste generation (Wu et al., 2020). Therefore, developing a reliable model to assess the impact of various factors such as economic factors, population changes, and climatic changes on solid waste generation prediction would be a significant advancement in managing this waste. It is crucial to note that accurately determining the quantities of generated solid waste provides municipalities with the opportunity to make informed decisions regarding the necessary investment in machinery, transfer stations, disposal capacity, and land required for future waste landfilling (Abdoli et al., 2011). These decisions will directly impact the quality of services and the operational costs of the solid waste management system (Cubillos et al., 2021).

Researchers have conducted various studies to develop models for predicting the quantity of solid waste (Araiza-Aguilar et al., 2020). These studies have employed different methods to predict the rate of solid waste generation and the impact of various factors on it, each differing in methodology and data sources used. Descriptive statistics, regression analysis, material flow models, time series analysis, and artificial intelligence are some of the main methods used. The necessary data for these methods are typically obtained from municipalities or questionnaire data (Cubillos et al., 2021).

Factorial or regression models are statistical models that provide a clear understanding of the reasons behind urban waste generation. They allow the identification of the interrelationships between various socio-economic factors and waste generation. Due to their theoretical simplicity and straightforward algorithms, these models have been used to predict and examine the impact of various factors on daily or annual urban waste generation at household, city, or regional levels (Oribe-Garcia et al., 2015). Additionally, many cities currently lack complete and long-term historical data on solid waste generation, which are essential for creating and developing time series models. Therefore, in these conditions, regression models are a viable option, enabling the development of an equation linking solid waste generation with other independent variables (Wu et al., 2020).

For instance, Sun and Changpeeboolpatana (2017) used regression and time series analysis to predict the generation and composition of municipal solid waste in Iasi, Romania. Dyson and Chang (2005) incorporated the effects of population, income level, and housing unit size into a linear regression model. Benitez and colleagues (2008) predicted residential solid waste generation by developing a linear model using variables such as household income, and number of residents. It is also shown that income is an influential factor in urban solid waste generation (Buenrostro et al., 2001; Benitez et al., 2008; Hackett & Lober, 2004). Dayal and his colleagues also used linear regression to assess the impact of climatic conditions and socio-economic status on the characteristics of solid waste (Dayal et al., 1993).

However, achieving the predicted accuracy given the current and future trends in solid waste production is highly challenging (Abdoli et al., 2011). On the other hand, the lack of recorded data and information, especially in developing countries, has posed limitations on creating models for predicting urban waste production (Kolekar et al., 2016). From a practical standpoint, incorrect predictions of the amount of waste produced can lead to inefficient decision-making regarding infrastructure, equipment capacity, or collection plans (Cubillos et al., 2021). Moreover, due to the social, economic, and geographical heterogeneity of different regions of the world, inference or prediction using proposed models is difficult, and thus, the models and their variables need to be adapted to the conditions of other areas (Araiza-Aguilar et al., 2020). Some researchers have used four statistical indicators—Mean Absolute Error (MAE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE), and the Coefficient of determination (R^2)—to select the best model for predicting waste production (Ghinea et al., 2016).

The amount and composition of solid waste vary depending on various social, environmental, and demographic factors (Araiza-Aguilar et al., 2020). It is also important to note that the factors influencing waste production differ due to local conditions such as climate, standard of living, technology, customs and culture, economic issues, and other factors specific to each region. According to the results of studies by Keser and her colleagues, the amount of waste produced is influenced by various factors, including geographical location, season, kitchen waste utilization cycles, collection frequency, regional service characteristics, on-site processing, people's diets, habits, economic conditions, recycling and reuse practices, waste management laws, local culture and beliefs, population growth, climatic conditions, and household size (Keser et al., 2012). Therefore, various articles have used input data related to variables such as population, income level, and education to develop models for predicting solid waste production (Adeleke et al., 2020).

Although various influencing factors have been identified in this regard, studies have identified the economic status as a main driver, showing a positive correlation (Vieira & Matheus, 2018). While the impact of economic crises on the amount of solid waste produced has not been sufficiently studied, it can be hypothesized that economic changes have influenced solid waste production. Many economic theories accept that significant events such as political or economic crises, natural disasters, wars, etc., can create major changes in the economy. These changes, by altering various socio-economic parameters, can cause fluctuations in the amount of urban solid waste compared to the periods before such changes (Adamović et al., 2017).

Tehran is the most developed city and the capital of Iran, and it is also the 21st largest city in the world (Zand & Heir, 2020). According to the latest census conducted in 2016 by the National Statistical Center of Iran, the population of Tehran was 8,693,706, with 2,911,065 households (SCOI, 2016). Tehran covers an area of over 700 square kilometers and is divided into 22 municipal districts, 1,233 neighborhoods, and 354 localities (Farzi et al., 2021; Gholampour & Gitipour, 2020). The climate of Tehran is hot and dry, with an average temperature of 18 degrees Celsius and an average minimum and maximum temperature of -7.4 and 38.7 degrees Celsius, respectively (SCOI, 2020). The annual rainfall in Tehran ranges from 245 to 316 millimeters. Based on studies conducted in the second comprehensive waste management plan of Tehran in September and October 2019, the per capita waste production in Tehran was 694 grams per person per day, of which 492 grams were from residential sources and 202 grams from non-residential sources (administrative, commercial, educational, etc.) (TUPRC, 2021). Figure 1 illustrates the waste management process for household and non-household sources in Tehran, from collection to final disposal.

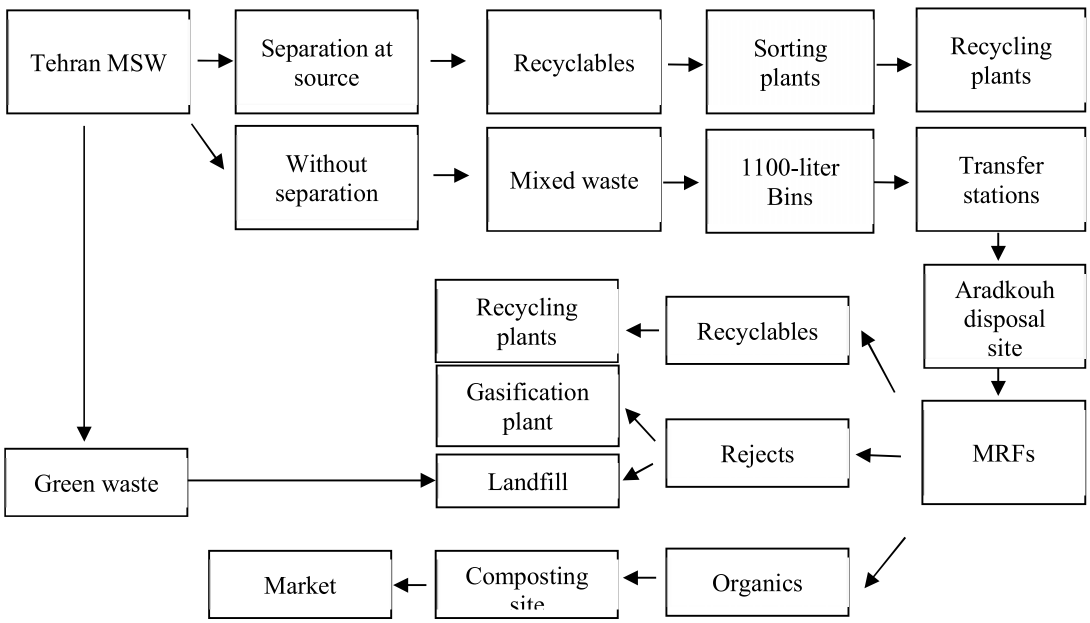

Figure 1. Tehran MSW Management Flowchat (Rupani et al., 2019)

Figure 2 shows the amount of urban waste production (total segregated waste and unsegregated mixed waste at the source), construction and demolition waste, and open space waste in Tehran from 2011 to 2020. It is noteworthy that the amount of urban waste produced in Tehran in 2020 decreased by 30.4% compared to the base year (2011).

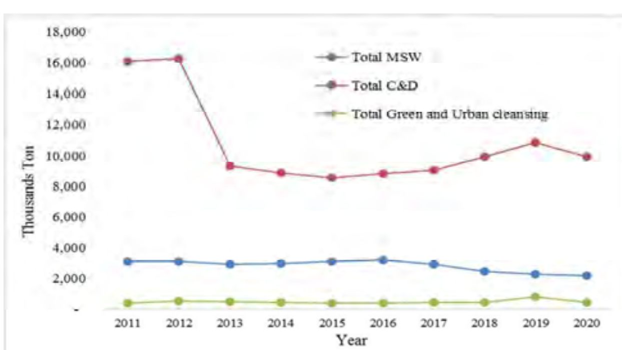

Figure 2. Generation Amount of Different Types of Waste in Tehran (2011-2020) (TWMO, 2021)

Figure 3 illustrates the amount of urban waste produced in Tehran from the beginning of 2017 to the end of 2020. According to available statistics, the amount of waste produced in Tehran decreased following the United States' withdrawal from the Joint Comprehensive Plan of Action (JCPOA) in May 2018 (point a) and the start of U.S. sanctions in November 2018 (point b). For example, the amount of urban waste produced in Tehran decreased by 16%, from 2,949,958 tons in 2017 to 2,474,958 tons in 2018 (TWMO, 2021). As another example, the amount of urban waste produced in Tehran in December 2018, after the start of the sanctions (200,580 tons), decreased by 13.6% compared to December 2017 (232,275 tons).

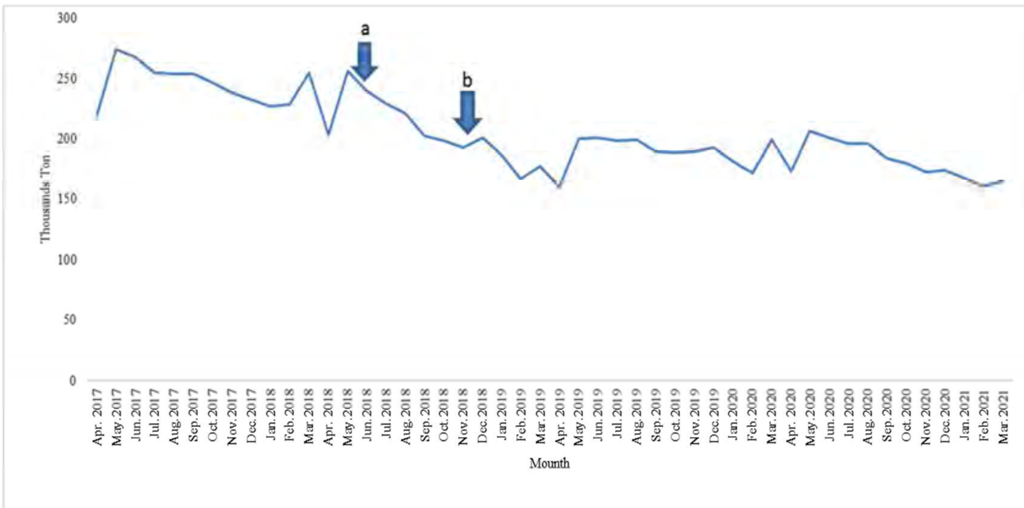

Figure 3. The Amount of MSW Generation in Tehran from 2016 to 2019 (TWMO, 2021)
a: May, 8th, 2018- the withdrawal of the USA from the nuclear agreement of the member countries of the 5+1 group
b: Nov,5th,2018- beginning of the USA sanctions against Iran

Limited studies have been conducted on the impact of various economic, social, and cultural factors on the quality and quantity of ordinary waste in Tehran. Moradi Kia and his colleagues, in their studies on Tehran's waste, concluded that 74% of the variations in the tonnage of construction and demolition waste can be explained by the economic variable of the Consumer Price Index (CPI), and 69% of the variations in the tonnage of source-separated dry waste can be explained by two economic variables: the Consumer Price Index and the US dollar exchange rate announced by the Central Bank (Moradikia et al., 2021). Peivastehgar and Ansari (2018) also investigated the factors influencing the reduction of per capita household waste generation in districts 3 and 10 of Tehran Municipality. Their findings indicated that many social factors, such as age, gender, marital status, household size, duration of residence in Tehran and the district, type of residential unit, and adherence to source separation of waste, have direct effects on per capita household waste generation. Fami and colleagues, in a study on identifying factors influencing food waste generation behavior in Tehran, found that families with greater economic power had a higher capability to reduce food waste due to greater knowledge and skills. Conversely, economic power had a negative impact on food waste management, primarily due to spending less time cooking at home and more time eating out (Fami et al., 2019).

Fathidokht and Parizanganeh (2011) conducted a study on the quantitative and qualitative changes in household waste in Tehran and concluded that the most significant factor in the quantitative growth of waste is the increase in the population of Tehran and the per capita waste generation. On the other hand, this research identified the most important factors affecting the quality of waste in Tehran as the enhancement of public awareness, changes in the economic conditions of society, and waste separation at the source by a segment of the city's population. Additionally, a study conducted by Salehi and colleagues in 2018 on the impact of the economic and social conditions of households on waste management in Tehran modeled the impact of economic and social factors on household waste management using a system dynamics approach. This proposed model examined the effects of economic variables such as inflation, per capita income, purchasing power, and per capita consumption in Tehran. The validation and sensitivity analysis of the model indicated that the model's results closely match the existing data (Salehi et al., 2018).

Various studies have investigated the parameters and factors involved in the amount of waste generated. According to the studies by Dehvari and colleagues, the inflation index has a significant impact on the production of urban waste (Dehvari et al., 2016). Gómez and colleagues found a strong dependency between waste generation and economic well-being (Gómez et al., 2009). Considering the negative impact of inflation on the Consumer Price Index (CPI) as the average price of goods and services consumed by a household (Barkachian et al., 2015) and the annual non-food expenditures of households (Rezaei et al., 2013), it can be concluded that with the increase in the Euro exchange rate and inflation, the CPI and non-food household expenditures rise, leading to reduced purchasing power and consequently a decrease in the generation of urban waste. Given the negative impact of the inflation rate on agricultural development (Khalilian et al., 2006; Kamijani & Naghdi, 2008), it can be inferred that with the increase in the inflation rate, the final prices of agricultural products rise, resulting in reduced purchasing power and, subsequently, a decrease in urban waste generation. According to the studies by Fallahi and Peighambari (2007) and Emami and colleagues (2011), an increase in the selling price of oil and the resulting shock has a positive impact on the economic growth of oil-exporting countries (Fallahi & Izadi, 2007; Emami et al., 2011). Studies by Soltan Tooyeh and colleagues, using the ARDL (Autoregressive Distributed Lag) model and linear regression, indicate an inverse relationship between the inflation rate and economic growth in Iran during the period 1979-2011 (Soltan Tooyeh et al., 2013). Studies conducted by Najafi and colleagues (2021), Rafiei and colleagues (2019), and Dehvari and colleagues (2016) have shown that an increase in population leads to an increase in urban waste (both wet and dry). The population growth in cities is also accompanied by increased construction of residential buildings. Moreover, the tonnage of waste collected in residential areas of Tehran is higher compared to commercial areas (Peivastehgar & Ansari, 2017; Abdoli et al., 2015). Kheiri and Azad Aramaki have shown that under unfavorable economic conditions, there is a reduction in the participation of Tehran citizens in optimal waste management and source separation (Kheiri & Azad Aramaki, 2014). It leads to a decrease in the percentage of dry waste generated (Hoang et al., 2017).

Moradikia and colleagues (2021) developed a model to predict the tonnage of source-separated dry waste in Tehran over a 56-month period (April 2014 to November 2018). With the increase in the price of the OPEC reference basket, the economic growth of the country improves (Soltan Tooyeh et al., 2012). Models for predicting waste generation in Tehran (Sarv Aghaji et al., 2016) and various parts of the world (Denafas et al., 2014) exist. The use of meteorological data in this context has not been significantly considered. It is predicted that, given the impact of the reopening of schools and universities on the quality and quantity of waste (Zeng et al., 2005) and the maximum increase in the percentage of paper waste in winter (Adeleke et al., 2020), the purchase and generation of dry waste will increase before Nowruz (the new year ceremony of Iranians). The tonnage and percentage of wet waste in autumn and winter (with higher relative humidity) decrease compared to spring and summer (Gómez et al., 2009; Kamran et al., 2015; Zia et al., 2017). According to studies by Ghafarzadeh and colleagues, with the increase in the number of recycling booths, the tonnage of source-separated dry waste and citizen participation also increased (Ghafarzadeh et al., 2021). According to the results of studies by Zazouli and colleagues, in developing countries, government policy instability can affect the level of recycling through its impact on the market for recycled products and the household economy. (Zazouli et al. 2020).

Therefore, although the increase in the purchase price of source-separated dry waste might initially be seen as an incentive for citizens to separate and present dry waste to municipalities and the private sector, it indirectly indicates an increase in the exchange rate and inflation rate, as well as a reduction in the import of raw materials into the country. This issue, in addition to reducing the purchasing power of citizens and the generation of dry waste, also causes changes in the costs of the waste management system and its economic efficiency (Walery, 2017).

The price of materials directly affects the price of housing (Ghaderi & Izadi, 2015), and with the increase in housing prices, the demand for the production of mineral materials decreases due to the reduced demand for housing, consequently reducing the tonnage of construction waste and associated waste (Goodarzi & Arman Mehr, 2018). Kaghazian and colleagues (2015) investigated the impact of exchange rate fluctuations on the level of investment in the housing sector in Iran over a 22-year period (1992-2013). According to the studies by Abbasinejad and Yari (2009), the impact of shocks resulting from changes in oil prices on the growth of housing prices in Iran during the period 1973-2005 has been significant. Studies by Bigdelo and colleagues (2011) on construction and demolition waste in the city of Karaj indicate the impact of precipitation and maximum relative humidity on the tonnage of waste. According to the studies by Kaghazian and collegues (2015), as well as Shah Abadi and Ganji (2013), an increase in industrial production leads to a decrease in the inflation rate, which in turn stimulates the construction industry and subsequently increases the tonnage of construction and demolition waste.

In the present article, for the first time, by collecting data related to independent and macro variables in the fields of economy, industry and mining, urban management, agriculture, climate, demography, and population, and by examining the relationship between these independent variables and the dependent variables of various types of waste production in Tehran over a long-term period of 120 months (beginning of 2011 to the end of 2020), a series of models were developed using linear regression to predict waste production in Tehran. The examination of the relationship between waste production in Tehran and some of the aforementioned macro variables over a 10-year period, which has been less addressed previously, may be considered one of the most important innovations of this research.

Research Methodology

In this research, to develop a model for predicting the amount of waste produced in Tehran, the relationship between 32 different independent variables in the fields of economy, agriculture, industry and mining, urban management, population, and climate, as well as 5 response variables of waste production in Tehran, was examined using data related to each of the variables over a 120-month period (April 2011 - March 2021). Although, based on the results of the review of international articles, it is possible to use more independent variables in addition to the 32 independent variables considered in this article to increase the accuracy of the expected models, existing limitations led to the use of only 32 independent variables in this article. These limitations include:

1. Lack of continuous annual data for some independent variables from the Iranian Statistics Center and the Central Bank.
2. Significant discrepancies between the data provided by the Iranian Statistics Center and the Central Bank regarding the same independent variable (especially concerning economic variables).
3. Statistical reviews indicating inaccuracies in the data provided for some variables.

In preparing the models, the principle of using the minimum number of input variables and examining the adequacy of the model to achieve the simplest adequate and significant model based on itterative analyses and tests was observed. Additionally, due to specific limitations caused by international sanctions on

Iran, obtaining real and accurate statistics for some economic independent variables was not possible for the authors. The initial independent variables considered are presented in Table 1.

Table 1. Primary Independent Variables Considered in Research

Independent variables	Classification
1. US dollar currency price announced by Central Bank 2. US dollar currency price in market 3. Euro currency price announced by Central Bank 4. Euro currency price in the market 5. Bahar Azadi gold coin price (new design) 6. Avalable Liquidity & the volume of banknotes in circulation 7. Average purchase price of one kilogram of separated recyclables 8. Inflation rate of urban households in Tehran Province, announced by Iran Statistics Center 9. Average total income of an urban household 10. Consumer price index of urban households in Tehran Province, announced by Iran Statistics Center 11. The average annual food cost of an urban household 12. The average annual non-food cost of an urban household 13. The average price of one kilogram of selected food items in urban areas, announced by the Iran Statistics Center 14. The selling price of one square meter of residential footage in Tehran, announced by the Iran Statistics Center 15. Average monthly rent plus three percent of the deposit paid for renting one square meter of residential footage in Tehran, announced by the Iran Statistics Center 16. OPEC reference basket price	Economy
17. Production quantity index of the country's mining sector (except oil and natural gas extraction) 18. Production quantity index of the industrial sector	Industry and Mining
19. The number of transactions of land or the land of demolished residential building in Tehran, announced by Iran Statistics Center 20. The number of sales transactions of residential lands in Tehran, announced by the Iran Statistics Center 21. The number of rental transactions of residential lands in Tehran, announced by the Iran Statistics Center 22. The number of issued construction licenses of residential buildings in Tehran 23. Area of green space in Tehran 24. Area of Tehran city 25. The number of 1100 liters of mixed waste bins 26. Number of recycling buyback centers 27. Number of recyclables pickup vans	Urban Management
28. Production quantity index of the agricultural sector of the country	Agriculture
29. Population of Tehran	Population
30. Average temperature of Tehran 31. Maximum relative humidity of Tehran 32. Average amount of rainfall in Tehran	Weather

It is worth mentioning that in this article, the annual average food expenditure of an urban household, based on the weekly report of the average retail price of certain food items in Tehran as announced by the Central Bank of the Islamic Republic of Iran, refers to the average price of one kilogram items of Iranian rice, beef or veal, chicken, pasteurized milk, pasteurized yogurt, Iranian pasteurized cheese, pasteurized butter, eggs, vegetable oil, apples, oranges, cucumbers, tomatoes, potatoes, onions, pinto beans, lentils, sugar, and foreign tea. Additionally, the five response variables of waste production in Tehran examined in this research are as follows:

1. Total tonnage of municipal waste in Tehran (Y1)
2. Tonnage of unsorted mixed waste at the source (Y2)
3. Tonnage of sorted dry waste at the source (Y3)
4. Tonnage of construction and demolition waste (Y4)
5. Tonnage of open space waste in Tehran (Y5)

In this study, the Shapiro-Wilk test was used to examine the normality of the initial data (Pourzamani et al., 2018; Steen et al., 2019). Additionally, the multicollinearity among the initial data was assessed using the R software. The results indicated that there is multicollinearity among some of the variables. Therefore, to eliminate the independent variables with multicollinearity, the Variance Inflation Factor (VIF) criterion was employed (Montgomery et al., 2009). The VIF for the independent variable is defined as follows:

$$VIF_j = \frac{1}{1 - R_j^2}$$

where in:

$j = 1,2,3,\Lambda\ , p$

Where R_j is the coefficient of determination of the j-th variable based on the other independent variables.

As a rule of thumb, if the VIF value is less than 10, there is no need to further investigate the multicollinearity of the independent variables (Montgomery et al., 2009). However, if the VIF value is greater than 10, there is severe multicollinearity among the independent variables, and thus, the independent variables with a VIF greater than 10 should be removed (Araiza-Aguilar et al. 2020; Popli et al., 2021). Therefore, using the exploratory analysis method and examining VIF values greater than 10, 17 independent variables were removed, and 14 independent variables with VIF values less than 10 remained. Subsequently, using the linear regression method and the remaining 14 independent variables, a model between the independent and dependent variables was developed. Additionally, the statistical relationship between the independent variables and the dependent variables related to waste production was examined at a 95% confidence level. Table 2 shows the independent variables with VIF values less than 10.

Table 2. Independent Variables with a VIF Value of Less than 10

Row	Independent variable	Unit	VIF
1	Euro exchange rate announced by the Central Bank (X_3)	Rial	6.175
2	Consumer price index of urban households in Tehran province, announced by Iran Statistics Center (X_5)	-	3.951
3	The average annual non-food expenditure of an urban household (X_8)	Rial	4.077
4	The number of permits for the construction of residential buildings in Tehran (X_{16})	Number	/5.976
5	Population of Tehran (X_{17})	Person	3.588
6	OPEC reference basket price (X_{18})	US Dollar	3.078
7	Maximum relative humidity of Tehran (X_{23})	Percent	6.669
8	Average rainfall in Tehran (X_{24})	Millimeter	2.799
9	Production quantity index of the country's agricultural sector (X_{25})	-	3.838
10	Production quantity index of the country's mining sector (except oil and natural gas extraction) (X_{26})	-	2.65
11	Production quantity index of the industrial sector (X_{27})	-	2.01
12	The number of 1100 liters of mixed waste bins (X_{28})	Number	2.331
13	Number of recycling buyback centers (X29)	Number	2.617
14	Average purchase price of one kilogram of separated recyclables (X_{32})	Rial	3.225

In order to investigate the relationship between independent variables and dependent variables of waste production, the backward elimination linear regression method was used (Buenrostro et al., 2001; Hoang et al., 2017; Araiza-Aguilar, 2020):

$$Y_i=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\epsilon$$

where in:

Yi = dependent variable

β_0= Y axis intercept

β_i= coefficient of influence of independent variables (model parameters)

X_i= independent variable

ϵ = random error

Research Findings

In this article, taking into account the outputs of R and SPSS software, the linear regression method was used to develop prediction models for the production of all types of municipal solid waste in the Tehran metropolis. Table 3 shows the fitted models for five dependent variables of waste production in Tehran and also the values of R^2_{adj}, MAE, RMSE, and MARE coefficients. These indices are often used for comparison, adequacy tests, and error measurement of regression models. The most common index in fitting regression models is the coefficient of determination (R^2). The coefficient of determination shows how many percent of changes in the dependent variable are explained by the considered independent variables. However, the coefficient of determination alone is not a suitable criterion for this explanation because with the increase in observations and also with the increase in the number of independent variables, its rate will increase in multiple regression analysis, which may lead to a false interpretation in this case. Therefore, it is necessary to calculate the value of the adjusted coefficient of determination (R^2_{adj}) when there are multiple independent variables. The smallness of the error criteria for each model indicates that the values predicted by the models are closer to the observed values and the presented model has a higher predictive power (Montgomery et al., 2009). In general, the lower the value of the error measurement indices and the higher the R^2_{adj} index, the more accurate and suitable the corresponding model is. According to the obtained results, model number 3 has the lowest RMSE value and the highest R^2_{adj} value.

Table 3. Five Final Models Based on the Linear Regression Method

Response Variable	Fitted Model	R^2_{adj}	MAE	MARE	RMSE
Y_1	Y_1=305239.646 – 1.42 X_3 – 0.0003951 X_5 – 792.663 X_8 + 1.711 X_{18} – 293.197 X_{25}	0.790	0.3410	0.4583	0.0163
Y_2	Y_2 = 26603.851 – 1.354 X_3 – 0.0002625 X_{25} – 428.557 X_8 – 40.758 X_{17} + 1.83 X_{18}	0.734	0.3772	0.5159	0.0160
Y_3	Y_3 = -131542.395 – 0.256 X_3 – 0.0001585 X_5 – 97.899 X_8 +0.307 X_{18} + 958.519 X_{23} + 473.666 X_{29} – 13.447 X_{32}	0.803	0.3385	0.4434	0.0171
Y_4	Y_4 = -325725.382 – 17.077 X_3 + 0.003 X_5 – 25.048 X_{18} + 36843.561 X_{23} + 3714.841 X_{24} – 1300.453 X_{26} + 832.482 X_{27}	0.814	0.3354	0.4312	0.0162
Y_5	Y_5 = -525979.586 + 0.0003141 X_5 + 1253.454 X_8 + 4371.950 X_{23}	0.074	0.7838	0.9623	0.1443

Based on the results, 79% of the variations in the total tonnage of municipal waste production in Tehran (Y_1) can be explained using the variables: the Euro exchange rate announced by the Central Bank (X_3), the Consumer Price Index for urban households in Tehran province announced by the Iranian Statistical Center (X_5), the average annual non-food expenditure of an urban household (X_8), the OPEC reference basket price (X_{18}), and the agricultural production index of the country (X_{25}). Additionally, 73.4% of the variations in the tonnage of unsorted mixed waste at the source (Y_2) can be explained by the variables: the Euro exchange rate announced by the Central Bank (X_3), the Consumer Price Index for urban households in Tehran province announced by the Iranian Statistical Center (X_5), the average annual non-food expenditure of an urban household (X_8), the number of building permits issued for residential buildings in Tehran (x_{16}), the population of Tehran (X_{17}), and the OPEC reference basket price (X_{18}).

Furthermore, using the variables: the Euro exchange rate announced by the Central Bank (X_3), the Consumer Price Index for urban households in Tehran province announced by the Iranian Statistical Center (X_5), the average annual non-food expenditure of an urban household (X_8), the OPEC reference basket price (X_{18}), the maximum relative humidity in Tehran (X_{23}), the number of recycling stations (X_{29}), and the average purchase price of one kilogram of various sorted dry waste (X_{32}), 80.3% of the variations in the tonnage of sorted dry waste at the source (Y_3) can be predicted. Additionally, 81.4% of the variations in the tonnage of construction and demolition waste (Y_4) can be explained by the variables: the Euro exchange rate announced by the Central Bank (X_3), the Consumer Price Index for urban households in Tehran province announced by the Iranian Statistical Center (X_5), the OPEC reference basket price (X_{18}), the area cleaned in Tehran (X_{21}), the maximum relative humidity in Tehran (X_{23}), the average rainfall in Tehran (X_{24}), the mining production index excluding oil and natural gas extraction (X_{26}), and the industrial production index (X_{27}).

However, only 7.4% of the variations in the tonnage of open space waste in Tehran (Y_5) can be explained by the variables: the Consumer Price Index for urban households in Tehran province announced by the Iranian Statistical Center (X_5), the average annual non-food expenditure of an urban household (X_8), and the maximum relative humidity in Tehran (X_{23}).

The results of the significance test of the model on independent economic variables, taking into account dependent variables from Y_1 to Y_5, are also presented in Table No. 4. It is worth mentioning that there is a statistical significance between all independent variables and dependent variables in the fitted models at the 95% confidence level (P-value is less than 5%).

Table 4. The Results of the Model Running on the Data, Considering Y1 to Y5 as the Response Variable

Dependent Variable	Independent Variable	Coefficient Estimation	Standard Deviation	t-value	P-value
Y_1	intercept	0.0000	0.0419	0	1
	X_3	-0.4699	0.0600	-7.829	0.0000
	X_5	-0.3227	0.0685	-4.786	0.0000
	X_8	-0.2994	0.0504	-5.937	0.0000
	X_{18}	0.2056	0.0481	4.271	0.0000
	X_{25}	-0.1153	0.0456	-2.527	0.0129
	F-statistic value: 90.51 (Degree of Freedom: 4 and 114)				$< 2\times 10^{-16}$
Y_2	intercept	0.0000	0.4709	0	1
	X_3	-0.6286	0.0792	-7.927	0.0000
	X_5	-0.2269	0.0735	-3.086	0.0026
	X_8	-0.1955	0.0615	-3.177	0.0019
	X_{16}	-0.2031	0.0875	-2.322	0.0220
	X_{17}	0.1497	0.0754	1.985	0.0496
	X_{18}	0.2730	0.0517	5.282	0.0000
	F-statistic value: 55.69 (Degree of Freedom: 6 and 113)				$< 2\times 10^{-16}$
Y_3	intercept	0.0000	0.0405	0	1
	X_3	0.3983	0.0844	-4.721	0.0000
	X_5	-0.603	0.0674	-8.946	0.0000
	X_8	-0.1319	0.0649	-2.03	0.0447
	X_{18}	0.1894	0.0577	3.28	0.0014
	X_{23}	0.2426	0.9081	2.672	0.0087
	X_{29}	0.3012	0.5999	5.02	٠/٠٠٠٠
	X_{32}	0.2315	0.0665	3.481	0.0007
	F-statistic value: 70.45 (Degree of Freedom: 7 and 112)				$< 2\times 10^{-16}$
Y_4	intercept	-1.09×10^{-17}	0.03937	0	1
	X_3	-0.8053	0.080	-10.066	0.0000
	X_5	0.3068	0.0547	5.604	0.0000
	X_{18}	-0.3853	0.0533	-7.231	0.0000
	X_{23}	0.2903	0.0733	3.96	0.0001
	X_{24}	0.1766	0.0458	3.854	0.0002
	X_{26}	-0.1473	0.0438	-3.363	0.0011
	X_{27}	0.1117	0.0486	2.297	0.0235
	F-statistic value: 66.12 (Degree of Freedom: 8 and 111)				$< 2\times 10^{-16}$
Y_5	intercept	-1.85×10^{-17}	0.0878	0	1
	X_5	-0.2706	0.1356	-1.996	0.2704
	X_8	0.3882	0.1144	3.394	0.0094
	X_{23}	0.2575	0.1179	2.185	0.0031
	F-statistic value: 14.17(Degree of Freedom: 3 and 116)				0.0076

Discussion and results analysis

The first fitted model showed that model adequacy is reached by using independent variables X_3, X_5, X_8, X_{18} and X_{25}. It is possible to predict 79% of the variations in the total tonnage of municipal waste production in Tehran using these five regressors. According to the studies by Dehvari et al. (2016) and Gómez et al. (2009), as it was mentioned above, it can be concluded that with the increase in the Euro exchange rate and consequently the inflation rate, the welfare and purchasing power of citizens decrease, which in turn it leads to a reduction in municipal waste production. The results are compatible with the studies of Barakchian et al. (2016) and Rezaei Ghahroodi et al. (2013) which indicated that inflation negatively affects the consumer price index, which is the average price of goods and services consumed by households, and the annual non-food expenditure of households. Therefore, it can be concluded that with the increase in the Euro exchange rate and inflation, the consumer price index and non-food household expenditure increase, resulting in a decrease in purchasing power and, consequently, a reduction in municipal waste production. On the other hand, with the increase in inflation, the final prices of agricultural products rise, leading to a decrease in purchasing power, as indicated above based on the results of Khalilian et al. (2006) and Kimijani and Naghdi (2008). Consequently, it results in a reduction in municipal waste production. Moreover, it can be inferred that with the increase in the OPEC reference basket price, the economic growth of the country improves, and thus, with the reduction in inflation, the purchasing power of citizens and the production of municipal waste will increase.

In the second fitted model, 73.4% of the changes in the tonnage of unseparated mixed waste at the origin can be predicted using the fluctuations of X_3, X_5, X_8, X_{16}, X_{17} and X_{18} variables. According to the above-mentioned studies of Najafi et al. (2021), Rafiei et al. (2019), Dehvari et al. (2016) on the impact of population on the amount of municipal waste production, as well as the studies of Pivastegar and Ansari (2017) and Abdoli et al. (2015), Kheiri and Azad Aramaki (2014) and Huang et al. (2017), it can be concluded that under unfavorable economic conditions such as an increase in the Euro exchange rate and inflation rate, the increase in population and the number of residential constructions will lead to an increase in the amount of unsorted mixed waste produced at the source in the city of Tehran which is consistent with the results of the second regression model.

Based on the results of the third fitted model, 80.3% of the changes in the dry waste tonnage separated at the source can be described using independent variables X_3, X_5, X_8, X_{18}, X_{23}, X_{29} and X_{32}. In the third fitted model, the tonnage of source-separated dry waste in Tehran over a 120-month period decreases with an increase in the Euro exchange rate announced by the Central Bank, the consumer price index of urban households in Tehran province, and the average annual non-food expenditure of an urban family. The result of this fitted model is consistent with the findings of studies by Moradikia et al. (2021), Dehvari et al. (2016), Sarv Aghaji et al. (2016), Denafas et al. (2014), Zeng et al. (2005), Adeleke et al. (2020), Gómez et al. (2017), Kamran et al. (2015), and Zia et al. (2017) which was mentioned in the introduction section. According to the fitted model, an increase in the number of recycling stations leads to an increase in the tonnage of source-separated dry waste and citizen participation, which aligns with the results of studies by Ghafarzadeh and colleagues (2021). On the other hand, according to the fitted model, an increase in the average purchase price of source-separated dry waste from citizens by Tehran municipality contractors leads to a decrease in the tonnage of this waste. This result is consistent with the discussions of Zazouli et al. (2020) and Walery et al. (2017).

Based on the results of the fourth fitted model, 81.4% of the changes in the tonnage of construction and demolition waste in Tehran can be described using variables X_3, X_5, X_{18}, X_{23}, X_{24}, X_{26} and X_{27}. According to the model, an increase in the exchange rate of the Euro announced by the Central Bank of Iran will reduce the amount of construction and demolition waste in Tehran, which is consistent with the findings of Kaghdzian et al. (2015). Additionally, an increase in the household consumer price index will increase the amount of this type of waste in Tehran, which is consistent with the findings of Moradikia and colleagues (2021). Furthermore, the results of the model regarding the relationship between construction and demolition waste generation and the factors of oil price changes, weather factors, housing prices, and inflation rates are consistent with the findings of Abbasinezhad and Yari (2018), Goodarzi and Arman Mehr (2018), and Shah Abbadi and Ganji (2013), respectively.

Considering the fifth model, only 7.4% of the changes in the tonnage of green waste in Tehran city (Y_5) can be related to the variables of the consumer price index of urban households in Tehran province announced by the Iran Statistics Center (X_5), the average annual non-food cost of an urban household (X8) and the maximum relative humidity of The city of Tehran (X_{23}) in the linear regression model. It should be noted that open space waste in Tehran is a mixture of waste from green spaces, bulky waste, and sludge from dredging in the 22 districts of Tehran Municipality. More work on the last model would be necessary to increase its adequacy. This may include using other independent variables and variable transformation, including interaction and higher order terms in the model and nonlinear models.

Conclusion

In this study, linear regression methods and 120 months of data (April 2011 - March 2021) related to 14 independent variables from economic, agricultural, industrial and mining, urban management, demographic, and climatic categories, as well as 5 response variables related to waste production in Tehran, were used to fit five new waste prediction models. Although the use of more independent variables could have increased the accuracy of the first four presented models, existing limitations in providing continuous and accurate annual data by institutions and organizations such as the Central Bank of the Islamic Republic of Iran and the Iranian Statistical Center resulted in the number of independent variables in this article being restricted to only 32 initial variables and ultimately 14 final variables with a variance inflation factor (VIF) of less than 10.

Additionally, the lack of provision of some economic data due to existing restrictions, and some discrepancies between the available data provided on some of the economic independent variables, also contributed to the limitation in the number of independent variables**.**

The models' adequacy and meaningfulness were checked and according to the results, 79% of the changes in the tonnage of total waste generation, 73.4% of the changes in the tonnage of mixed waste not separated at source, 80.3% of the changes in the tonnage of dry waste separated at source, and 81.4% of the changes in the tonnage of construction and demolition waste in Tehran can be predicted using the models developed in this study. The results were analysed and compared with the available literature and studies which confirmed the models.

Based on the fitted models and the analysis of their results, the following scientific and managerial suggestions can be made for the use of waste management executives (subject of articles 2 and 7 of the Waste Management Law) with an approach to increasing the effectiveness of decision-making and macro-level decisions on municipal solid waste management at the national and regional levels:

1. Preparation and completion of a database of data related to the dependent variables of waste management in the country by the Ministry of Interior and municipalities
2. Preparation of statistics on independent economic, agricultural, industrial and mining, urban management, population, and climatic settlements by municipalities to develop models for predicting the dependent variables of municipal waste management with an approach to maximizing source separation and recycling and minimizing landfilling.
3. Development and operation of a municipal waste management dashboard by the Ministry of Interior (at the national level) and municipalities (at the regional level) using regression models and dynamic systems using accurate and reliable time-series data of independent economic, agricultural, industrial and mining, urban management, population and climatic variables, as well as real statistics provided

on the production and separation of various types of municipal waste by municipalities and village councils.

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