ISSN:2782-8492

FEDPOLAD Journal of Engineering & Environmental Studies (FEDPOLADJEES); Vol. 4, ISSUE 1. OCTOBER, 2024 Edition
Website: *https://seemjournals.fedpolyado.edu.ng/index.php/fedpoladjees*

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DEVELOPMENT OF AN EFFICIENT WASTE DISPOSAL AND CONVERSION MODEL FOR NIGERIA: A CASE STUDY OF EKITI-STATE

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Abstract
In developing countries such as Nigeria, indiscriminate waste disposal poses serious environmental threat as well as public health menace. An efficient waste disposal and conversion model for Ado-Ekiti, Ekiti State was developed through the application of cubic polynomial regression analysis to predict weekly waste generation. Structured questionnaires, interviews with stakeholders, site visits to waste management facilities and an experimental collaboration with local scavengers were carried out to collect data on the amount of waste generated on a daily basis. When the actual and predicted waste data were both included in the cubic polynomial regression model, 54.2% of the variance in waste generation was accounted for, with a 31.3% discrepancy between predicted and actual values. The inefficiencies in the existing waste management system were identified as improper waste collection, limited recycling efforts, and lack of public participation in waste separation. The use of three colour waste bins, buy back centres and centralised waste collection were proposed as a new waste management model. This research extends the application of advanced cubic polynomial modelling to waste generation prediction, enabling a more nuanced understanding of waste trends in a developing urban context. Although further refinement is necessary, the results exhibit good potential as a valuable tool for waste management planning. With the identified gaps in Ado Ekiti's waste management system addressed, and the predictive model optimised, the city can enhance its waste collection efficiency, recycling rates, and general environmental sustainability. The potential contribution of this study is both to the academic and to the practical solutions of waste management in developing countries cities.

Keywords*: Waste Management, Waste Prediction, Cubic Polynomial Regression, Waste Conversion, Recycling, Solid Waste Management.*

Introduction

With waste management still a key concern for the world at large, and developing countries particularly, having little or no adequate infrastructure or the appropriate policies in place, the waste disposal chain is inefficient. These challenges are made more pronounced as urbanisation accelerates and populations expand. Poor waste management systems, insufficient recycling, lack of public awareness and environmental degradation are endemic problems in Nigeria. The struggles inherent in the sustainable management of waste, given the increasing population of many cities and their limited resources, are a complicated but legitimate problem that calls for serious attention.

Waste is commonly defined as any material that is no longer useful or desirable, requiring disposal (Ugwu, et al., 2020; Lange, 2021). Adler et al., (2022) points out that waste is often without future financial value, and can be fraught with environmental and social risk if not handled properly. Recycling and waste to energy technologies have already advanced

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the reductions of landfill contributions, especially in developed nations, yet such efforts fail to be realised in developing countries. Municipal solid waste in developing countries is primarily organic (Nanda and Berruti, 2021), comprising little waste that is treated because of budget constraint and technical hurdles (Khan, et al., 2022).

With an estimated 32 million tonnes of solid waste generated yearly, out of which the huge bulk is not managed properly. Nigeria has a population of over 170 million people, making it one of the megacities of the world (Mama et al., 2021; Nubi et al., 2022). In Ekiti State, waste collection, separation and recycling remain a challenge. Waste indiscriminately disposed cause pollution, health hazards and ecosystem degradation especially in urban centres like Ado-Ekiti. Owing to paucity of infrastructure, lack of consciousness of the masses and inefficient waste collection practises, the current system under Ekiti State Waste Management Board, coupled with the National Environmental Standards and Regulation Enforcement Agency (NESREA), has failed to tackle these problems effectively.

Several other studies cited the difficulties involved in waste management in developing countries: Ogwueleka (2009) stated that inefficiencies arise in urban centres due to inadequate infrastructure and improper practise. Yu and Maclaren (1995), emphasised that statistical tools may help to improve waste collection processes. Based on their work, this study further explores a cubic polynomial regression model to enhance the treatment of non-linear patterns in waste generation. Dauda and Osita (2003) argued that unstructured systems with regards to waste collection and the definition of roles result in environmental degradation justifying the need for the proposed waste management model outlined in this study. It is also important to involve the public as a means of facilitating waste separation at the source, as necessitated by Martin (2011). Hence, an affair of recommending public awareness campaigns to achieve effective waste separation. Suttibak and Nitivattananon (2008) found that recycling in developing countries is hindered not only by lack of infrastructure and incentives, but also by poor social structure. Consequently, we have proposed buy back centres in this work to encourage recycling.

The predictive modelling for waste management systems has been backed by empirical study. More accurate forecasting of waste generation is enabled by predictive models that are essential to optimising collection processes and resource allocation. Saini and Simon (2013) further arrived at the use of statistical methods in waste management by proving how regression models help to estimate waste generation. To improve predictions further, this current study advances this by using a cubic polynomial regression. Troschinetz and Mihelcic (2009) further showed that improved waste separation programmes result in increased recycling rates and reduced environmental impact and that the proposed three colour bin system in Ado Ekiti is likely to be successful. Recycling has important economic incentives recommended by UN-ESCAP (1993). In this study, buy back centres is also incorporated to encourage participation. According to Abila and Kantola (2013), organic waste is a large component of municipal waste in Nigeria and this is confirmed in this study where we found that 63% of the waste generated in Ado-Ekiti is organic, showing the need for composting. To attenuate these risks, Rhyner and Green (1988) finally demonstrated that poor waste management poses environmental and health risks, which this study attempts to address with the suggestion of improved collection, separation and recycling systems.

This research is founded on a framework to apply comparable predictive modelling techniques to Nigeria, taking Ado Ekiti as a

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case study as a result of its rapidly growing population and urbanisation that require more efficient waste management systems. Waste composition in Ekiti State is consistent with other developing regions. UN-ESCAP (1993) studies of municipal solid waste classified waste as organic waste, plastic waste, metal waste and agricultural waste. For instance, organic composition of about 63% exists in Ekiti and this composition is similarly found in other developing countries due to relatively high level of agricultural activity and food consumption. The large share of organic waste means we could be better converting waste, for example, into compost; however, the current system for managing waste is not so efficient.

The waste disposal system in Ado-Ekiti today has an infrastructure that enables inadequate waste separation, suboptimal management of public waste bins, and low recycling rates. This is seen from previous studies that such inefficiencies produce high environmental hazards such as air and water pollution (Festus and Omoboye, 2015). NESREA's waste bins, which are quite large in public, are not properly used and residents do not undertake waste separation practises hence, waste spillage and to some extent their accumulation in public place occurs. Additionally, Saini and Simon (2013) put forward the role of public education and government regulation as crucial in encouraging an adequate waste separation and recycling practise.

Considering these difficulties, the present study attempts to create a more viable waste disposal and waste conversion model for Ekiti State based on cubic polynomial regression to estimate the generation rate of waste. Demographic and socioeconomic variables are incorporated to improve modelling of waste generation for more efficient planning of waste collection and disposal. The study develops from the empirical work of Yu and Maclaren (1995), and Rhyner and Green (1988) by applying their findings to the Nigerian context. This research addresses the inefficiencies of current waste management system and proposes a centralised approach with emphasis on recycling and education for the larger purpose of improving waste management practises in developing nations.

2. Methodology

The approach employed here uses both qualitative and quantitative methods to provide a comprehensive analysis of waste generation, collection, and disposal practises in the study area. The study design, data collection methods, analytical techniques and model development are used to accomplish the study objectives.

2.1 Study Area

This study was carried out in Ado-Ekiti, Ekiti state, South-West Nigeria. It is a city with a mixed population comprising of civil servants and farmers as well as purveyors and business persons, traders and students and professionals. Assessment of Ado-Ekiti reveals challenges associated with working population, urbanisation and poor infrastructure of waste collection and recycling. Typically, like many developing regions where agricultural activity and food consumption patterns dominate waste generation, the waste composition in Ado Ekiti is mainly organic (63%).

2.2 Data Collection

The period of data collection for this study was six months and included both surveys and interviews, site visits, and collaborative experiments as the data collection process, to ensuring comprehensive insights into waste generation and management practises in Ado-Ekiti, Ekiti State. The study designed and distributed structured questionnaires across the metropolis to a number of stakeholders, including: a) households, b) businesses, c) public employees and d) private organisations. The objective was to gather information regarding generation and disposal habits of the

residents and their viewpoints as regards waste management.

In addition, interviews were carried out with key officials in Ekiti State Ministry of Environment and Ekiti State Waste Management Board. The interviews, however, did offer a critical information on waste management system policies, challenges, and even the actual effectiveness of the system. In order to complement the survey and interview data, the research team visited several waste disposal and processing sites, including the Ilokun Dumping Site, where there are equipment for waste recycling and conversion. The on-site data obtained, gave a practical look at the way the people usually handle waste, and the way the waste management system functioned. Lastly, an experiment was carried out in collaboration with scavengers in various districts of Ado-Ekiti. The experiment measured the daily waste generation rates over a week in five key areas: Ajilosun, Omolayo, Gbajumo, Oke-Bola, and Ekute. This hands-on approach allowed the researchers to collect primary data on the quantity of waste generated and fed into the model's prediction and validation processes.

2.3 Model Development

The waste prediction model was developed using a cubic polynomial regression analysis to estimate waste generation based on collected data. Computer generated predictions of this model were compared with manually collected data from Oke-Bola Ado-Ekiti to assess the accuracy of the model. The cubic polynomial regression model is effective in understanding the non-linear trends in the dataset and make a more refined sense of waste generation pattern. This study therefore applied this model to enable a more accurate forecast of weekly waste volumes, useful for planning waste collection and disposal strategies.

The waste generation data collected from households and business centres in Ado-Ekiti was used to construct the cubic polynomial regression model. The quantity of the waste generated per week is independent variable (x) and the estimated amount of the waste is dependent variable (y). It took into account factors like population density, economic activity and waste composition.

The regression equation was structured as follows:

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3$$

…………………………………. (1)

Where: y is predicted amount of waste generated per week (in kilograms), x is actual waste per week (in kilograms), β_0, β_1, β_2, and β_3, are the coefficients of the model, determined from the regression analysis.

2.4 Data Analysis

Analysis of data involved comparing the amounts of weekly generated waste to what was predicted by the regression model and an individual calculation. The cubic polynomial model showed a moderate fit for predicting waste values, and hence the analysis was done to understand discrepancies in actual collection and predicted amount of waste. The study also divided the waste types and analysed their composition, finding that the total waste in Ado-Ekiti consisted of 63% of organic waste. In addition, the study analysed patterns of occupational waste generation in the region and discovered that traders and farmers were the major sources of waste generation.

The study then further evaluated the model by examining the residuals (i.e. the difference between observed and predicted waste amounts). The results of the regression analysis showed that the model performed reasonably and reliably in predicting. The resulting findings highlight the importance of continuing to refine data as well as model adjustments to increase waste prediction accuracy in future applications.

3. Results

The data collected from Ado-Ekiti was analysed using a cubic polynomial regression

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model to predict weekly waste generation based on actual observed values. The study also explored the potential of a reverse interpretation of the results, emphasizing the gaps between model predictions and actual waste collected. This reverse analysis highlights inefficiencies in the current waste management system, offering insights for refining future waste prediction models.

The research revealed that over 170 waste bins have been strategically placed in various locations, including market areas across Ado-Ekiti, such as Ijigbo Junction and along Ikere Road. The city has been divided into four operational axes—Odo Ado, Adebayo, Bashiri, and Ilawe Road—to streamline waste management processes. The dumping sites in these areas play a crucial role in both waste disposal and potential recycling operations. However, the study emphasizes that a more detailed understanding of the practices, equipment, and methods at these sites would improve waste management efforts in Ado-Ekiti.

3.1 Polynomial Regression Analysis of Waste Data

Table 1 presents the polynomial regression analysis of waste items collected in Ado-Ekiti, categorized by waste type and amount generated per week. The analysis used the cubic polynomial regression model to predict the weekly amount of waste generated based on the amount of waste collected.

Table 1. Polynomial Regression Analysis on Waste Items Data at Ado-Ekiti

Waste Type	Per Day (kg)	Waste Per Week (kg)	Amount Per Week (Naira)
Paper	20	405.15	8103
Plastic	20	301.64	6032.8
Iron	50	174.65	8732.5
Rod	100	110.2	11020
Aluminium	80	79.8	6384
Metal	50	90	2700
Tins And Cans	35	401.3	14045.5
Stainless Steel	40	50.02	2000.8
Rubber	20	287.2	5744
Cement Sack	10	87.45	874.5

3.2 Polynomial Regression Analysis on the amount of sales per week (Naira) versus Waste Collected per week (kg)

The cubic polynomial regression model is represented by the following equation:

$$Amount\ per\ week(y) = -9429 + 259.7x - 1.196x^2 + 0.001680x^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Figure 1 shows the scatter plot of waste amounts generated, with a cubic model fitted line plot using the polynomial regression analysis.

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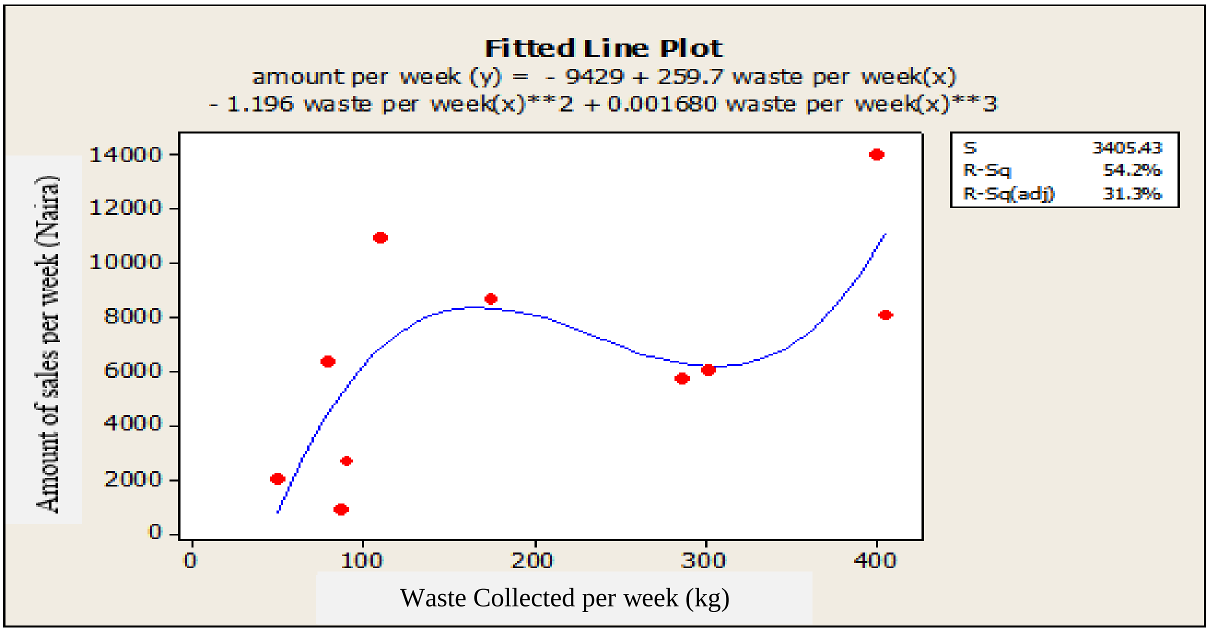

Fig: 1: Amount of sales per week (Naira) versus Waste Collected per week (kg)

Table 2 provides a comparison between the actual waste amounts collected per week and those predicted by the model.

Table 2: Predicting Amount of Sales from the Model

Amount per week (Naira)	Residual	Predicted	Coefficient
8103	-3048.4826	11151.4826	-9428.9140
6032.8	-132.9071	6165.7071	259.6878
8732.5	348.2675	8384.2325	-1.1964
11020	4111.5815	6908.4185	0.0017
6384	1854.6019	4529.3981	
2700	-2777.1841	5477.1841	
14045.5	3334.8524	10710.6476	
2000.8	1223.2118	777.5882	
5744	-533.2975	6277.2975	
874.5	-4380.6437	5255.1437	

3.3 Analysis of the Polynomial Regression Model

The cubic polynomial regression model was applied to estimate waste generation per week. The model takes into account various waste types, such as paper, plastic, iron, and other materials. The quadratic term creates a curve resembling a "U" or inverted "U" shape, while the cubic term adds a second curve that shifts direction, providing a more nuanced prediction.

Where the Amount of sales per week (Naira)

$$y = -9429+259.7(x) - 1.196(x)^2 + 0.001680(x)^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

For Paper, When x = 405.15, y = 11195.8729
For Plastic, When x = 301.64, y = 6194.8053
For Iron, When x = 174.65, y = 8396.304
For Rod, When x = 110.2, y = 6913.9672
For Aluminium, When x = 79.8, y = 4532.6089
For Metal, When x = 54, y = 1371.8035
For Tins and Cans, When x = 401.3, y = 10754.47946

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For Stainless Steel, When x = 50.02, y = 779.0536

For Rubber, When x = 287.2, y = 6307.2903

For Cement Sack, When x = 87.45, y = 5258.8925

The calculated values obtained from the model closely align with the manually computed values, confirming the acceptability of the polynomial regression model for predicting waste generation in Ado-Ekiti.

3.4 Comparison of Predicted and Actual Waste Data

Table 3 compares the waste amounts predicted by the model with the actual amounts manually calculated. This comparison highlights both the accuracy of the model and the residual discrepancies that suggest areas for improvement. The results obtained were derived through the use of the Cubic Polynomial Regression Model. The coefficients for the model were calculated as 9428.9140, 259.6878, 1.1968, and 0.0017. These coefficients contribute to the statistical significance and acceptability of the chosen method for analysis

Table 3: Predicting amount of sales from the model and the manual calculation.

Waste Type	Amount Per Week (Naira)	Predicted by the Model (Naira)	Predicted By The Manual (Naira)
Paper	8103	11151.483	11195.873
Plastic	6032.8	6165.7071	6194.8053
Iron	8732.5	8384.2325	8396.304
Rod	11020	6908.4185	6913.9672
Aluminium	6384	4529.3981	4532.6089
Metal	2700	1370.5654	1371.8035
Tins and Cans	14045.5	10710.648	10754.48
Stainless Steel	2000.8	777.5882	779.0536
Rubber	5744	6277.2975	6307.2903
Cement Sack	874.5	5255.1437	5258.8925

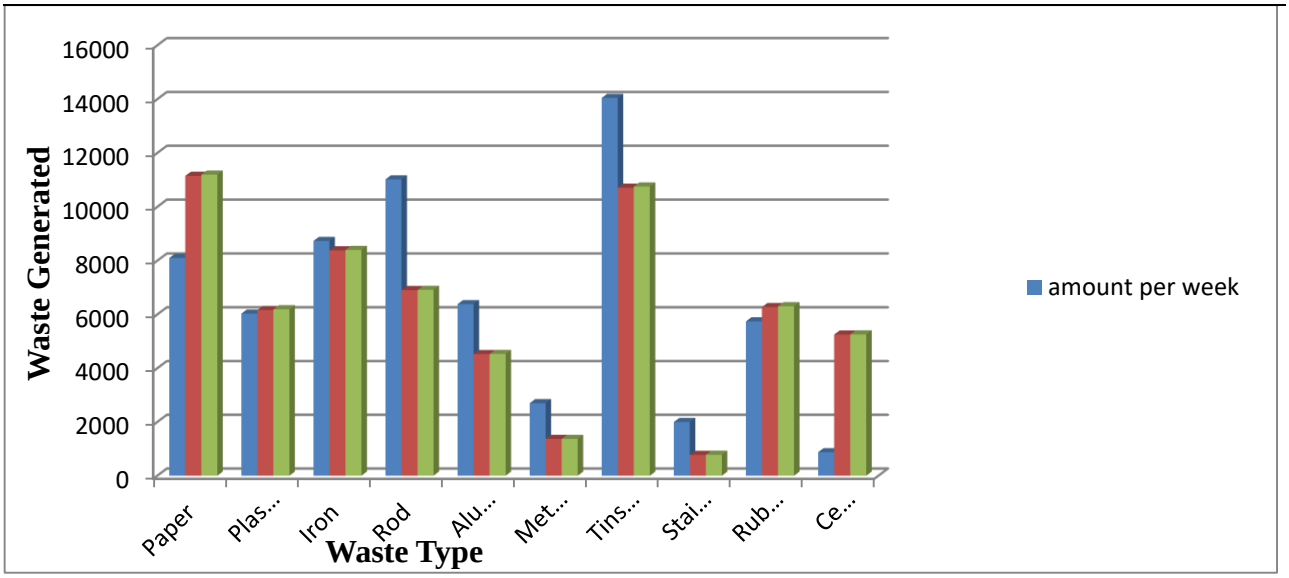

Fig. 2: Comparison between the waste amounts per week, waste amounts predicted (predictive model) and waste predicted (manual calculation)

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4. CONCLUSION

A cubic polynomial regression analysis was applied to develop an efficient waste disposal and conversion model specific to the peculiar conditions of Ado-Ekiti, Ekiti State, Nigeria, with the aim of using the above to predict weekly waste generation. The novelty of this work is in how it tackles the specific waste management constraints from such a developing urban setting by leveraging the application of advanced statistical modelling to the development of practical waste management strategies. In contrast to previous studies that focused mostly on linear or the most basic predictive models, this study employed a cubic polynomial regression model which more accurately captures the trends of waste generation in a dynamic and growing city.

The cubic polynomial regression model achieved a moderately good fit (54.2% of variance explained) in the waste generation, thus providing a useful planning tool for waste management. However, the model had a 31.3% deviation between the predicted and actual waste amounts, suggesting further refinement. A novel aspect of the study is that this advanced model has been applied in a local Nigerian context to provide deeper insights into waste trends when compared with conventional models. Despite the discrepancies, the model offers a promising starting point for more accurate future waste predictions that should aid future waste management strategies in the region.

Apart from the unconventional modelling technique, this research also pointed out the numerous shortcomings of the existing waste management infrastructure like the underutilization of recycling centres, the inefficiency of the waste collection process, and inappropriate waste segregation as compared to the actual requirement. Improvement of environmental sustainability and public health is dependent addressing these gaps. In addition, the study suggested practical interventions like public education on waste separation and government sponsored recycling incentives which, when coupled with better predictive modelling could revolutionise waste management practises in Ado Ekiti. This research is novel both in its scope, employing a combination of advanced statistical techniques and on the ground data collection and analysis, and in its focus on integrating perspectives from almost every aspect of these systems, from user hands, to sensing, to datasets, to hardware. The result of this study is a combination of both qualitative and quantitative data which produces a more holistic view of waste generation and management which is a pioneering effort of using cubic regression in waste management in Nigeria. This is an avenue of future research and a model served as other urban areas dealing with the same waste management issues.

Consequently, the cubic polynomial regression model constitutes a new and promising way to predict waste generation, however, further optimization and real time data updates are required. Solutions to the gaps identified in this study, via exploitation of the model's predictive capabilities, will assist Ado-Ekiti in a transition toward a more efficient and environmentally sensitive waste management system.

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