Poll Res. 44 (3–4) : 139-149 (2025)

ISSN 0257–8050

DOI No.: http://doi.org/10.53550/PR.2025.v44i03-04.001
Journal Home Page: www.envirobiotechjournals.com

TIME SERIES ANALYSIS AND REGRESSION MODELLING OF FLOOD-INDUCED MACRO-PLASTIC POLLUTION IN MASVINGO URBAN, ZIMBABWE

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(Received 7 March, 2025; Accepted 25 March, 2025)

ABSTRACT

This study analyses macro-plastic pollution in Masvingo Urban, focusing on the role of flood events, water levels, and rainfall in influencing pollution levels, using time series analysis and regression modelling. A linear regression model demonstrated a strong relationship between macro plastic pollution and these environmental variables, with an R^2 value of 0.858, indicating that the model explains 85.8% of the variation in macro plastic pollution. The statistically significant relationship revealed a p-value < 0.001, confirming that flood events, water levels and rainfall is critical in determining pollution levels. The stationarity of the macro plastic pollution data using the Augmented Dickey-Fuller (ADF) test enables accurate forecasting. An ARIMAX (1,1,1) model captures the relationship between past pollution levels, water level fluctuations, rainfall, and flood events. The model revealed that water level (coefficient = 331.88), rainfall (coefficient = 0.766), and flood events (coefficient = 31.81) are significant predictors of macro plastic pollution. The most decisive influence on pollution transport was water levels. Based on the analysis, the study recommends improved waste management infrastructure, flood control measures, and community engagement initiatives to reduce flood-induced macro plastic pollution.

KEY WORDS : Macroplastic pollution, Flood events, Water level, Rainfall, Time series analysis, Regression modelling

INTRODUCTION

In recent years, floods have become more frequent and severe, particularly in urban areas, due to climate change, urbanization and inadequate infrastructure. One of the lesser-knownbut significant impacts of flooding is the rise of macro plastic pollution. Macro plastics are plastic debris larger than 5 mm. Macro plastics refer to large plastic items like bottles, bags, and containers, significantly threatening urban environments and ecosystems (Andrady, 2019).

It is believed that plastic may take up to 500 years to degrade due to its lethal additives. Despite this challenge, plastic consumption increases annually by at least 5%, with an annual global production hitting 150 million tons. Indonesia is estimated to be one of the largest plastic-emitting countries in the world, mainly due to its densely populated areas with high amounts of mismanaged plastic waste (Lebreton and Andrady, 2019; Gundogdu *et al.*, 2022). Van Emmerick *et al.* (2019a) estimated the annual riverine plastic emission of the Jakarta rivers and waterways into the ocean to be 2100 tonnes yearly. Flood-induced macroplastic pollution poses significant risks to aquatic ecosystems, human health and the economy.

In many urban areas, including Masvingo, Zimbabwe, improper disposal of solid waste and sewage can contaminate water sources during

(Mathematics and Statistics Lecturer)

floods. Informal settlements and older neighbourhoods may lack adequate waste collection systems, worsening the problem. Studies show that poor urban drainage systems escalated by plastic waste contribute to seasonal flooding in Masvingo Urban during the rainy season (Chanza and Musakwa, 2020). Masvingo Urban, Zimbabwe, is particularly vulnerable to flood-induced macroplastic pollution due to its location in a flood-prone area, inadequate waste management infrastructure and rapid urbanization. The city experiences frequent flooding events escalated by macro-plastic pollution in the environment. Despite the growing concern about flood-induced macro-plastic pollution, there is a lack of quantitative research on this topic, particularly in the context of Masvingo Urban. This knowledge gap hinders the development of effective (Eshete *et al.*, 2025) strategies to mitigate the impacts of flood-induced macroplastic pollution. This study uses time series analysis and regression modelling of flood-induced macroplastic pollution to address the knowledge gap in Masvingo Urban, Zimbabwe. It helps clarify flood-induced macro-plastic pollution and inform sustainable urban development strategies in Masvingo Urban and other cities.

Flood-induced macro-plastic pollution is an escalating environmental challenge in Masvingo Urban, Zimbabwe, where poor waste management systems and increasing flood events contribute to severe pollution in waterways and drainage systems. Again, illegal vendors in the area are a major contributor to the macro plastic pollution problem as they often dispose of plastic packaging and products irresponsibly. For instance, illegal vendors selling food and drinks use single-use plastic containers, bags and straws thrown on the streets, contributing to the macro plastic pollution problem. During floods, plastic waste from households, markets, and industrial areas is transported across the urban landscape, accumulating in rivers, wetlands and public spaces. Plastic waste poses significant risks to aquatic ecosystems, public health, and urban infrastructure. Masvingo faces a growing problem of flood-induced macro-plastic pollution. However, there is limited empirical data on the correlation between rainfall intensity, flood events and plastic accumulation. This study employs time series analysis and regression modelling to investigate the relationship between flood events and macro-plastic pollution in Masvingo Urban. The research aims to identify trends, seasonal variations, and key drivers of plastic pollution by examining historical flood occurrences, rainfall data and observed plastic waste accumulation from 2020 to 2023. The results will provide valuable insights for urban planners and environmental agencies in developing evidence-based strategies for flood resilience and plastic waste management in Masvingo Urban.

The study aims to examine time series trends and model the relationship between rainfall intensity, water levels, flood events, and macro plastic pollution in Masvingo Urban, Zimbabwe. This study uses time series analysis to analyse temporal trends and seasonal variations in flood-induced macro-plastic pollution. The other goal is to investigate the relationship between flood events, rainfall intensity, water levels and macro plastic pollution in urban drainage systems, waterways and the environment. It uses regression modelling to predict future pollution and its impact on urban areas. Hence, management strategies should be developed to mitigate flood-induced macro plastic pollution.

Furthermore, it aims to raise community awareness about the impact of flood-induced plastic pollution and promote better waste disposal behaviours, ultimately leading to improved urban sanitation and public health. UNEP (2024) and Yaacob *et al.* (2022) states that over 460 million metric tons of plastic are produced yearly. Almost all consumer and industrial activities, from construction and vehicles to electronics and agriculture, use plastic. Plastic waste pollutes and harms the environment if dumped improperly, becoming a widespread driver of biodiversity loss and ecosystem degradation. It threatens human health, affects food and water safety, burdens economic activities and contributes to climate change. Much plastic pollution is generated by single-use products such as bottles, caps, cigarettes, shopping bags, cups and straws. Pollution sources are mainly land-based, from urban and stormwater runoff, littering, industrial activities, tyre abrasion, construction, and agriculture. In the marine environment, plastic pollution originates primarily from land runoff, including paint sheds from shipping, discarded fishing gear, and more (UNEP, 2018).

Acot *et al.* (2022) and Navarro *et al.* (2022) studied the status of plastic litter on urban and rural beaches in Mindanao, Philippines. They observed that plastic litter is more prevalent in urban areas than in

rural areas in terms of density. The collection patterns of plastic litter suggest that the number of plastics in any area may either increase or decrease but is never zero, which means that plastic waste is constantly being deposited in coastal areas, possibly aided by wind and wave actions. Again, Adeniran et al. (2022) and Bangura and Azizi (2024) examined the literature to highlight the impact of plastic waste pollution on environmental and health impacts in sub-Saharan Africa. They discovered that the population in sub-Saharan Africa is growing; hence, managing waste generally and plastic waste represents a continuous challenge. With only 15-25% of its plastic waste recycled, the more significant proportion of waste was either burnt openly or disposed of in open spaces or landfills, where the additives pollute the environment. Moreover, some of the waste finds its way into waterways through estuaries into global water networks and continues to cause harm to man through the food chain (Adeniran, 2022; Bangura and Azizi, 2024).

Plastic-aggravated flooding caused by plastic pollution blocks drainage systems (and waterways), thus making flooding events more severe, as flood water cannot drain away as usual. Plastic waste doubled globally between 2000 and 2019, coupled with poor solid waste management. Densely populated slums in South Asia, East Asia, the Pacific, and sub-Saharan Africa will likely experience the worst effects of plastic-aggravated flooding due to rapid, poorly planned development and limited flood mitigation infrastructure. Flooding events pose both immediate and long-term dangers to human health. (OECD, 2022)

Honingh *et al.* (2020) and Gundogdu *et al.* (2022) studied the relationship between the abundance of plastic debris in rivers and increased flood risk by estimating the water level increase in response to plastic waste accumulation in the Cikapundung River, which runs through Bandung, Indonesia. They used a combination of flume experiments and field observations to quantify the effect of plastic debris accumulation on water levels in the Cikapundung River. Flume experiments determined the accumulation rate of debris at a trash rack as a function of flow velocity, plastic type, and total debris' plastic/organic content. Field observations obtained typical values for plastic mass transport and debris composition in a densely populated urban area with poor waste management infrastructure. They concluded that, besides adverse effects on the marine environment, plastic debris was one of the leading causes of increased flood risk in cities such as Jakarta and Bandung.

Plastic pollution in aquatic environments is an emerging hazard because of its direct and indirect harmful effects on ecosystem health and human livelihood (van Emmerick and Schwarz, 2020). Land-based plastic waste may enter rivers and urban drainage systems through natural drivers, such as wind and surface runoff (Bruge *et al.*, 2018; Schneider, 2021) or direct dumping (Mihai, 2018; Gundogdu *et al.*, 2022). Once in the water system, plastic pollution accumulates in hydraulic infrastructures (such as rack structures), leading to the urban drainage system clogging. It may increase flood risk in urban areas (Windsor *et al*., 2019; Senese *et al.*, 2023).

Mapfumo and Madesha (2014) evaluated the river health using the macro-invertebrates found within the Mucheke and Shagashe rivers of Masvingo City as water quality monitors. The South African Scoring System (SASS 5) was used to score using the macro-invertebrate's sensitivity to pollution levels in the two river systems. They concluded that specific types of macro-invertebrates can assess pollution levels in the Mucheke and Shagashe rivers of Masvingo City. According to Chigwenya and Simbanegavi (2022), informal settlements in Masvingo Urban are out of the city's waste management system. They live without important services such as waste collection, which is not sustainable. The informal traders dump waste in open spaces, roadsides and riverbanks, polluting the environment. The water bodies can no longer sustain aquatic life as they are heavily polluted. People live in unhealthy environments characterized by rudimental waste management practices.

The city has a population of approximately 100,000 (ZIMSTAT 2022), indicating a growth rate of about 1.3% per annum. Chireshe, (2020) states that the growth rate has implications for municipal solid waste management because an increase in urban population is associated with an increase in the Municipal Solid Waste generation rate, which makes it difficult for local authorities to collect and dispose of waste sustainably. Masvingo is associated with high informal traders, increasing daily due to high unemployment rates (Gambe *et al*., 2023). However, too much informal trading is associated with poor waste disposal, which exposes humans to risks. Given the high unemployment rate in Masvingo City, most waste generators fail to pay rates

(Chitongo *et al.*, 2023). In Zimbabwe, rapid urbanization has led to higher plastic waste generation, escalated by inadequate waste management systems (Makoni and Makurira, 2021). Flood events, especially in flood-prone regions like Masvingo urban, have been recognized as a major driver of macro plastic pollution, as floodwaters carry plastics into urban areas and drainage systems. Plastic pollution is a global concern, with urban centres increasingly dealing with plastic waste, mainly macro plastics such as plastic bags and bottles, to mention a few, in water bodies. In Zimbabwe, the situation has worsened due to urbanization and inadequate waste management systems (Chikozho *et al.*, 2017)

Mbue and Dieudonne (2022) used the ARIMA (Autoregressive Integrated Moving Average) model to simulate plastic wastes generated in the Bonaberi industrial zone of Cameron for operational planning and management. Their ARIMA (1,1,1) model showed that production and waste management trends would increase in the following years.

MATERIALS AND METHODS

The analyses of the relationship and impact of rainfall, water level and flood events on macroplastic pollution in Masvingo Urban is carried out using a structured research approach, integrating study area, data collection, statistical modelling and predictive analysis. The study will use primary and secondary data to establish the relationships between flooding, rainfall, water levels, and macroplastic accumulation. For data processing and visualization, Microsoft Excel was used to facilitate the organization of raw data. It enabled preliminary trend analysis, and JASP (version 0.19.3) software will produce statistical analysis, including time series modelling, stationarity testing, and multiple regression analysis.

Study Area

Masvingo Urban is one of the oldest towns in Zimbabwe, serving as the administrative and commercial centre of Masvingo Province. It is in the southeastern part of the country. It covers an area of approximately 2260 km^2 with a population of approximately 90 286 people and a population density of 39.9 people per km^2, as of 2022 census records. Masvingo Urban is in a semi-arid region characterized by low and erratic rainfall. The town is bordered by the Mucheke and Shagashe rivers., which play an essential role in drainage and water supply. It has a growing population driven by rural-to-urban migration, economic activities and its role as an education hub. The town comprises several suburbs (as shown in Figure 1 below), each with distinct characteristics. Figure 1 below shows the map of Masvingo Urban, itssuburbs and the rivers.

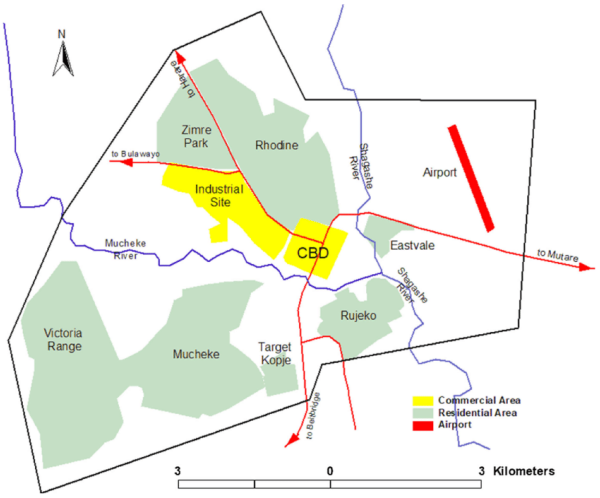

Fig. 1. Masvingo City and itssuburbs

Data Collection and Analysis

Primary data included monthly plastic waste collection records obtained from the Masvingo Urban Recycling Club for 48 months from 2020–2023, providing insights into temporal variations in plastic pollution. Secondary data was collected from the Zimbabwe Meteorological Services Department, covering historical rainfall and flood event records from 2020 to 2023. This data will allow for the analysis of patterns between rainfall intensity, water levels, flood occurrences, and the movement of microplastic waste. The study employed time series analysis and regression modelling (Haq, 2018) to examine the relationship between macro plastic pollution, water levels, rainfall, and flood events in Masvingo Urban. The JASP (version 0.19.3) software will use statistical techniques such as ARIMA modelling, stationarity testing, and multiple regression modelling to obtain trends, relationships, and predictive patterns.

Time series analysis examined the temporal behaviour of macroplastic pollution over 48 months from 2020 to 2023. A time series dataset consists of monthly observations, allowing for identifying trends, seasonality and cyclic patterns. The first step in time series analysis was checking for stationarity, a critical assumption for effective modelling.

A stationary time series has statistical properties, such as mean and variance, that remain constant over time. Stationarity is essential for reliable forecasting, as non-stationary data can lead to misleading model estimates. The Augmented Dickey-Fuller (ADF) test (Slade *et al.*, 2021; Dickey and Fuller, 1979) determined whether the macroplastic pollution time series was stationary. The null hypothesis (H_0) of the ADF test states that the series is non-stationary, while the alternative hypothesis (H_1) indicates that the series is stationary.

In this study, the ADF test produced a test statistic of -4.396 with a p-value of 0.01, below the 0.05 threshold. Hence, we reject the null hypothesis, confirming that the macroplastic pollution data was stationary after differencing. Stationarity was necessary before fitting an ARIMA model for forecasting.

An AutoRegressive Integrated Moving Average (ARIMA) model predicted future macro-plastic pollution levels. ARIMA is a widely used forecasting technique that accounts for autoregressive (AR), differencing (I), and moving average (MA) components (Box *et al.*, 2015). The general ARIMA (p, d, q) model is mathematically expressed as:

$$\Delta^d Y_t = c + \sum_{i=1}^{p} \emptyset_i \, Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t$$

Where:

- Y_t = the time series value at time t.
- $\Delta^d Y_t$ = the differenced time series to achieve stationarity, where d is the order of differencing.
- c = Constant term (intercept).
- p = Order of the autoregressive (AR) component.
- Φ_i = Coefficients of the autoregressive terms.
- Y_{t-i} = Lagged values of the time series.
- q = Order of the moving average (MA) component.
- θ_j = Coefficients of the moving average terms.
- ε_t = White noise (random error term) at time t.
- ε_{t-j} = Lagged error terms from previous time steps.

This study incorporates **exogenous variables**, rainfall, water level and flood events. The model extends to an **ARIMAX** (p, d, q) (Autoregressive Integrated Moving Average with Exogenous Variables) model:

$$\Delta^d Y_t = c + \sum_{i=1}^{p} \emptyset_i \, Y_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j+} \sum_{k=1}^{m} \beta_k X_{k,t} + \varepsilon_t$$

Where:

- $X_{k,t}$ represents the exogenous variables (e.g., rainfall, water level, flood events).
- B_k are the corresponding coefficients of the exogenous variables.
- The rest of the terms follow the same definitions as in the ARIMA model.

The ARIMAX model allows external factors to influence the forecast, making it useful when environmental or economic variables significantly impact the time series data.

Based on this study analysing flood-induced macroplastic pollution in Masvingo Urban, the ARIMAX model incorporates water level, rainfall, and flood events as exogenous variables. The ARIMAX (1,1,1) equation for this study is:

$$Y_t = 0.642 + 0.189Y_{t-1} - 1\varepsilon_{t-1} + 331.88W_t + 0.766R_t + 95.427F_t + \varepsilon_t$$

Where:

- Y_t = Macroplastic pollution (kg) at time t.
- Intercept (0.642): The baseline level of macroplastic pollution when all predictors (previous pollution, water level, and flood events) are zero.
- AR (1) Term: $0.189Y_{t-1}$ represents the contribution of the previous macroplastic pollution value.
- MA (1) Term: "1accounts for the past error impact.
- Exogenous Variables (X_t):
- W_t = Water level at time t (coefficient = 331.88).
- R_t = Rainfall (mm) at time t (coefficient = 0.766).
- F_t =Flood event (Yes/No) at time t (coefficient=95.427)
- = error term – captures random fluctuations or unexplained variability in pollution levels.

The ARIMA model was used to generate a five-month forecast of macroplastic pollution, predicting values of 251, 255, 257, 261, and 264 kg for the subsequent months.

A multiple linear regression model was developed to quantify the relationship (Wei, 2011) between macroplastic pollution and its influencing factors: water level, rainfall, and flood events. The general regression equation was:

The general linear regression model is expressed as:

$$Y=\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...\beta_p X_p + \varepsilon$$

Where:

- Y is the dependent variable,
- β_0 is the intercept,
- β_1, β_2,…, β_p are the coefficients for each independent variable X_1, X_2,…, X_p,

- ε represents the error term that captures the variation in Y not explained by the predictors.

This study produced the following model:

Y_t =20.47 + 175.5 Water Level + 0.645 Rainfall + 31.81 Flood Event + ε

where:

- Y_t represents macroplastic pollution (kg),
- Water level and rainfall are continuous predictor variables,
- Flood event is a categorical variable (1 = Flood, 0 = No Flood),
- ε is the error term.

Model diagnostics assess the reliability and goodness-of-fit of the model using R^2 (Coefficient of Determination). The R^2 value of the regression model measured how well the independent variables explained variations in macroplastic pollution. A high R^2 value of 0.858 obtained in this study indicated that water level, rainfall and flood events explained a significant proportion of macro plastic pollution variability. The p-value assesses the model's statistical significance. The p-value for all the predictors was less than 0.001, indicating their statistical significance in explaining macroplastic pollution variations. These findings can inform urban waste management and flood mitigation strategies to reduce microplastic pollution in flood-prone areas.

RESULTS AND DISCUSSION

The descriptive results of macroplastic pollution (kg) from Table 1 above provide key insights into its distribution and temporal patterns. The average amount of macroplastic contamination is 79.6 kg. The dataset's middle value, 47.5 kg, is less than the average. Some observations were significantly higher or lower than the mean, there is a significant amount of variability (standard deviation of 64.4 kg)

Table 1. The Descriptive Statistics

Statistic	Plastic Pollution (kg)	Water Level (m)	Rainfall (mm)
Mean	79.6	0.058	55.53
Median	47.5	0.03	28.75
Standard Deviation	64.37	0.056	54.18
Minimum	10.0	0.002	1.9
Maximum	250.0	0.16	163.7
Range	240		
Variance			
Lag 1 Autocorrelation	0.672		

in the levels of macro plastic contamination. The wide range of macroplastic contamination (10 kg to 250 kg) further supports the notion of a right-skewed distribution. A Lag-1 Autocorrelation of 0.672 suggests a substantial positive autocorrelation, indicating that the prior time step significantly influences the amount of microplastic pollution. The water level is 0.058 metres on average. The median is 0.03m, less than the mean, indicating that a few higher values raise the average water level. The standard deviation of the water level is 0.056 metres, exhibiting a moderate amount of fluctuation around the mean. There is a moderate degree of fluctuation in the water level data from 0.002m to 0.16m. The average rainfall is 55.53 mm. The median is 28.75 mm. There is a 54.18 mm standard deviation. There is much variationbecause the amount of rainfall varies greatly. Rainfall varied widely from 1.9 mm to 163.7 mm, indicating that some months had much rain and others had very little. The rainfall data is somewhat inconsistent, with sporadic periods of intense precipitation. Rainfall is far more variable than water levels, which makes sense since water levels respond gradually to precipitation rather than fluctuating abruptly.

Rainfall and macro- plastics are related in that significant rainfall events may escalate plastic pollution by relocating debris from drainage systems, urban areas, and riverbanks into water bodies. The pollution has a high lag-1 autocorrelation of 0.672, suggesting that the accumulation of waste will continue downstream by several severe rainfall events. Again, the possible impact of water levels on pollution is that higher water levels might increase pollution transport by eroding plastic debris from riverbanks and floodplains. A series of intense rainstorms may raise water levels, thereby facilitating the movement of macro plastics. When there is much rainfall but low water levels, plastics could accumulate locally instead of travelling beyond. Macroplastic transport is increased by the interplay between rainfall and water level changes, with extreme occurrences (high rainfall and peak water levels) causing notable increases in pollution. The descriptive statistics of microplastic pollution, water level, and rainfall suggest possible relationships between these environmental factors. Their interactions can help assess pollution dynamics and identify key macroplastic accumulation drivers.

The flood event data from Table 2 above, shows that 58.3% of the time, there was no flooding

(NO),while 41.7% of the time there was flooding (YES).Flood events increase macroplasticpollution by transporting waste.Non-flood periods allow plastic accumulation, which is transported duringfloods.Management strategies should focus on preventing plastic accumulation before floods occur to reduce pollution surges.

Table 2. Frequencies for Flood Event (Yes/No)

Flood Event (Yes/No)	Frequency	Per cent
NO	28	58.3
YES	20	41.7

Figure 2 above shows the time series plot of macro-plastic pollution in 48 months from 2020 to 2023, whenMasvingo Urban experienced flooding. It shows that macro-plastic pollution is high in the rainy season from November to March when floods occur and moderate in the dry season.

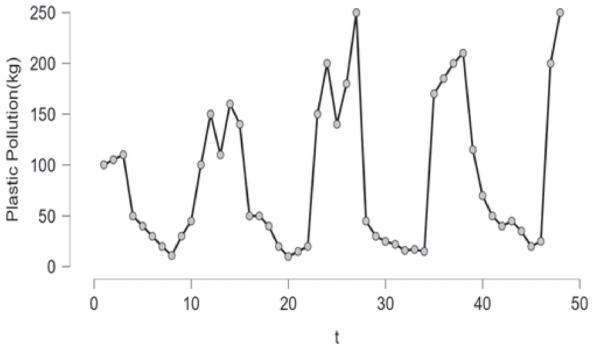

Fig. 2. Time Series plot of Macroplastic pollution

Linear Regression Results-Plastic Pollution (kg)

The Linear Regression Model produced using information from Table 3 is given by:

Macroplastic Pollution (kg) = 20.47 + 175.5 Water Level + 0.645 Rainfall + 31.81 Flood Event

The linear regression equation above models the relationship between macro plastic pollution (kg) and three predictor variables: water levels (m), rainfall (mm), and flood events (Yes/No). The model intercept is 20.47 kg, the baseline of macro plastic pollution when all predictors are zero, water level = 0, rainfall = 0 mm, and no flood event. It suggests a minimum pollution level of 20.47 kg, likely due to background plastic waste accumulation even in dry conditions. The water level coefficient is 175.5, suggesting that, for every 1-meter increase in water level, macroplastic pollution increases by 175.5 kg (assuming other variables remain constant). Higher water levels may mobilize plastics from riverbanks and drainage systems, significantly increasing pollution loads. The rainfall coefficient of 0.645 also indicates that for every 1 mm increase in rainfall, macroplastic pollution increases by 0.645 kg. While this effect is relatively small, consistent rainfall may gradually contribute to higher plastic transport. It aligns with the hypothesis that rainfall induces runoff, carrying plastic waste into rivers and streams. The flood Event coefficient of 31.81 suggests that if a flood event occurs (Yes= 1, No = 0), macroplastic pollution increases by 31.81 kg on average. Floods significantly increase plastic transport, likely by washing large amounts of waste into water bodies.

The linear regression model implies that water levels strongly influence macro plastic pollution, suggesting that river levels play a significant role in plastic transport. Floods and rainfall also contribute, but to a lesser extent, indicating that while storms increase pollution, persistent water flow is the key driver. The model suggests that even in the absence of rain or floods, plastic pollution still occurs (intercept = 20.47 kg), highlighting some background macro-plastic pollution in the system. 95% confirmed that the average baseline macroplastic pollution (when water level = 0, rainfall = 0, and no flood event) falls between 9.56 kg and 31.37 kg. The fact that the CI (9.56;31.37) does not include zero confirms that macro plastic pollution is consistently present, even in dry conditions and a narrow range (9.56 to 31.37) suggests that the estimate of baseline pollution is relatively precise. It further emphasizes the need for continuous waste management efforts, regardless of rainfall or flooding. Since the p-value is less than 0.001, all the predictors (water level, rainfall and

Table 3. Coefficients of the Regression Model

Model				95%CI		
		Unstandardised	P	Lower	Upper	R^2
M_1	Intercept	20.47	< 0.001	9.56	31.37	0.858
	Water Levels (m)	175.50		384.15	735.14	
	Rainfall (mm)	0.645		0.06	1.22	
	Flood Event (Yes/No)	31.81		11.19	74.8	

flood events) have a strong statistically significant relationship with macroplastic pollution at a 99.9% confidence level. The strong relationship suggests that increased water levels, rainfall, and flood events consistently lead to higher macro-plastic pollution levels. Hence, this model can predict pollution levels and inform waste management policies during extreme weather conditions.

In this study, an R^2 value of 0.858 indicates that approximately 85.8% of the variability in macro-plastic pollution explains the model's predictors-namely water level, rainfall, and flood events. It suggests that variations in these predictors are responsible for most of the variability in macroplastic pollution, with random variation and other factors not included in the model accounting for only 14.2% of the variability. Hence, the linear regression model is a good fit for explaining macro-plastic pollution variations in Masvingo Urban. This strong explanatory power reinforces the conclusion that these environmental variables are critical drivers of macro-plastic pollution and validates the model's usefulness in predicting future pollution trends and informing waste management and flood mitigation strategies.

Table 4. Stationarity Results

Test	Statistic	P	H_0
Augmented Dickey-Fuller t	-4.396	0.010	Non-Stationary

The Augmented Dickey-Fuller (ADF) test statistic from Table 4 above is -4.396. It suggests strong evidence against non-stationarity. The p-value (0.01) is less than 0.05, meaning we reject the null hypothesis (H : non-stationary) at a 95% confidence level. Therefore, the time series is stationary, meaning its mean, variance, and autocorrelation structure remain consistent over time. A stationary pollution time series suggests that long-term trends are stable, making it easier to model and predict pollution levels.

Table 5. Coefficients of an ARIMAX (1,1,1) Model

		95% CI	
	Estimate	Lower	Upper
Drift	0.642	0.037	1.247
AR (1)	0.189	-0.148	0.526
MA (1)	-1.00	-1.120	-0.880
Water Levels(m)	331.88	151.729	815.49
Rainfall(mm)	0.766	0.261	1.27

Using Table 5 results above, theARIMAXmodel for macroplastic pollution is:

$$Y_t = 0.642 + 0.189Y_{t-1} - 1\varepsilon_{t-1} + 331.88W_t + 0.766R_t + 95.427F_t + \varepsilon_t$$

This ARIMAX (1,1,1) model explains macroplastic pollution by combining its past behaviour with the effects of key environmental factors. Its intercept of 0.642 represents the baseline level of macroplastic pollution when all predictors are zero. The autoregressive term, with a coefficient of 0.189, indicates that previous pollution levels (Y) have a positive, though moderate, influence on current pollution levels, reflecting persistence over time. The moving average component, at -1, shows that past errors or shocks correct current values, smoothing out unexpected variations. Among the exogenous variables, water level exerts a substantial impact, with a coefficient of 331.88, suggesting that increases in water level are strongly associated with higher macro plastic pollution because higher water levels facilitate the transport of plastic waste. Rainfall also contributes positively, though to a lesser extent (coefficient 0.766), implying that more rainfall leads to increased runoff and plastic mobilization. Flood events have a pronounced effect, with a coefficient of 95.427, indicating that they increase pollution levels due to the extensive mobilization and accumulation of plastic waste during such events. This ARIMAX model effectively captures both the inherent temporal patterns of macro plastic pollution and the significant impact of environmental drivers on pollution dynamics in Masvingo Urban.

Macro-plastic pollution steadily increases over the next 5 months, from 251 kg to 264 kg. This gradual increase suggests that the driving factors (water level and rainfall) will lead to higher plastic transport into water bodies as the month's progress. The forecasted increase in pollution is consistent with the positive relationship between water levels and rainfall in the ARIMA model. The water level increases slightly from 0.176 m to 0.186 m. It indicates a steady but slight rise, possibly due to seasonal changes or gradual increases in precipitation or runoff. The relatively small increase in water level aligns with a moderate impact on pollution in the model, meaning it does not cause drastic changes in pollution over this period. Rainfall increases from 191 mm to 215 mm over the 5 months, a moderate rise. This forecast aligns with the positive relationship between rainfall and macro plastic pollution, where more rainfall contributes to

Table 6. Forecasts Results

Time (t) (Month/2024)	Macroplastic Pollution (kg)	Water Level (m)	Rainfall (mm)	Flood Event (Yes/No)
49	251.21	0.176	191.94	0.813
50	255.51	0.182	204.69	0.690
51	257.75	0.184	210.72	0.610
52	261.36	0.185	213.82	0.558
53	264.06	0.186	215.66	0.524

increased pollution due to runoff. The flood events show a decreasing trend in the probability of occurrence for the next five months (January to May) from 0.813 to 0.524. The high to moderate probability of flood events during the next three months (January to March) is consistent with the expected increased rainfall and flood risk during the rainy season. The low probability of flood events in April and May is also consistent with the expected decrease in rainfall since it is a dry season. The slightly increasing trend in macroplastic pollution reflects the combined effects of rising flood events, water levels and rainfall, which facilitate the movement and accumulation of plastics. Therefore, environmental factors and implementing measures need monitoring to mitigate pollution in anticipation of these increasing trends.

CONCLUSION

Time series analysis and regression modelling have revealed valuable insights into the changes in flood-induced macroplastic pollution in Masvingo Urban. Flood events, water levels, and rainfall are key drivers of macroplastic pollution in Masvingo Urban. Past pollution levels moderately influence current pollution, suggesting persistent pollution over time. The ARIMAX (1,1,1) model and regression analysis emphasize the importance of water level fluctuations and rainfall in driving plastic transport, especially during flood events. The steady forecasted increase in pollution suggests the need for proactive waste management and flood mitigation strategies to address the growing pollution levels.

Way forward

Given the findings from the time series and regression analysis of flood-induced macroplastic pollution in Masvingo Urban, several solutions and recommendations emerge to mitigate this growing issue. Firstly, improved waste management systems should prevent plastic waste from being carried into waterways during floods by implementing regular waste collection and sorting at the source, promoting public education campaigns on proper waste disposal and recycling and designing landfills and treatment facilities near flood-prone areas. Additionally, elevated waste bins and enclosed waste collection points, should be introduced to prevent waste from being washed away during heavy rains. Improving stormwater drainage systems, constructing retention basins and flood barriers and integrating plastic pollution monitoring with flood forecasting will help control water flow and reduce the displacement of plastic waste. Community-based flood cleanup programs should remove plastic waste from urban rivers before, during and after flood events. Educational campaigns should highlight the environmental impacts of macro-plastic pollution, promoting behavioural changes such as reducing the use of single-use plastics and adopting eco-friendly alternatives. Regular monitoring in flood-prone areas will help assess the impact of environmental factors such as water level, rainfall, and water levels on plastic pollution.

Providing incentives for plastic waste recycling programs, such as tax benefits for industries using recycled materials and subsidies for community-based recycling initiatives, can further encourage sustainable waste management practices. By implementing these recommendations, Masvingo Urban can significantly reduce macro-plastic pollution in flood-prone areas, contributing to environmental sustainability and public health

Future research should focus on a multidisciplinary approach to flood-induced macro-plastic pollution, integrating environmental science, urban planning, policy analysis and community engagement. Addressing the long-term impacts of climate change, flood management strategiesand waste infrastructure will be key to mitigating the growing threat of plastic pollution in urban environments.

ACKNOWLEDGEMENTS

All sources were acknowledged.

Conflict of Interest - None

Source of funding

The author has not received any funding from any organization to publish this manuscript.

Contribution of the author

Moyo Ever came up with the idea, did the literature search and data analysis and developed the final draft.

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