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Empirical Analysis of the EKC Hypothesis for Municipal Solid Waste Across Indian States

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Abstract

This study investigates the Environmental Kuznets Curve (EKC) hypothesis in the context of municipal solid waste (MSW) generation across 31 Indian states and Union Territories during 2013–2021. Using fixed effects panel regression, we explore whether economic growth initially increases MSW generation and subsequently reduces it beyond a certain income threshold. The results confirm an inverted U-shaped relationship between Gross State Domestic Product (GSDP) and MSW, supporting the EKC hypothesis. Sectoral drivers such as education, tourism, industrial activity, energy consumption, and agricultural land use are incorporated into the analysis. Higher education levels are associated with reduced waste generation, while industrial expansion and electricity consumption are positively correlated with MSW. In contrast, tourism activity is found to be statistically insignificant in influencing waste levels. The study also highlights considerable interstate heterogeneity, emphasizing that income growth alone does not ensure environmental improvements without supportive infrastructure and policy interventions. These findings call for state-specific waste management strategies to align economic development with environmental sustainability.
Keywords: *Municipal solid waste, hypothesis, EKC, industries, education, electricity, farming, tourism, night light*

1 INTRODUCTION

The rapid pace of urbanization has led to a dramatic surge in municipal solid waste (MSW) generation, one of the most significant by-products of modern urban life. According to the World Bank (2012), a decade ago, around 2.9 billion urban residents produced approximately 0.64 kilograms of MSW per person per day, totaling 0.68 billion tonnes annually. Today, this has risen to nearly 3 billion residents generating 1.2 kilograms per person daily, amounting to 1.3 billion tonnes of waste each year. Projections suggest that by 2025, urban populations will grow to 4.3 billion, with daily per capita waste generation reaching about 1.42 kilograms, resulting in 2.2 billion tonnes annually. These figures highlight the urgent need for efficient and sustainable waste management strategies as cities continue to expand Kaza et al. (2018).

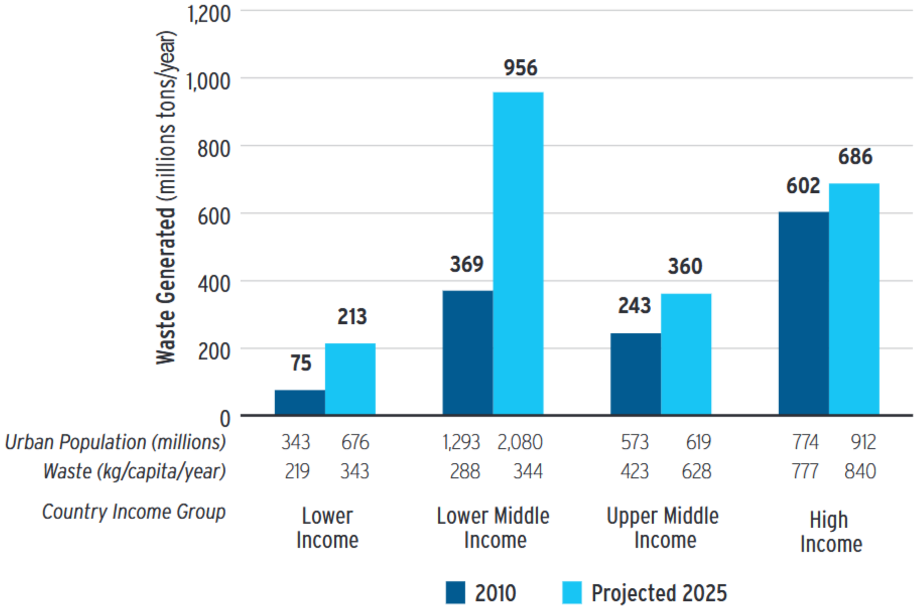

Figure 1: Urban Waste Generation by Income Level and Year

Solid waste management (MSW) is now a major environmental concern in the face of India's growth and urbanization. As household incomes have been increasing and cities expanded in the country, waste generation has increased phenomenally, subjecting the existing infrastructure for waste management to unprecedented pressures. Ineffective collection infrastructure, poorly regulated dumps, and lack of sustainable facilities for waste treatment have further contributed to the burden, causing spillover impacts on public health, environmental health, and the local ecosystem. It is thus crucial to disentangle the relationship between economic growth and waste generation so that appropriate policy packages can be formulated to decouple economic growth from environmental stress.

The Environmental Kuznets Curve (EKC) hypothesis provides an easy-to-conceptualize model to account for such a correlation. The EKC hypothesis was originally conceived by Grossman and Krueger (1991a) as an inverted U-shaped correlation between per capita income and environmental deterioration. Early in the phase of economic growth, pollution and environmental degradation increase with income owing to industrialization, urbanization, and growth based on natural resources. At some point in time, however, a level is attained—the so-called "turning point" of income—and richer nations allegedly invest in cleaner technologies, exert stricter controls over the environment, and practice more sustainable consumption patterns and hence reduce environmental destruction. While the EKC has been tested considerably for the cases of air and water pollution, relatively fewer empirical studies have applied the hypothesis for solid waste, particularly in developing countries such as India. This paper contributes to the expanding literature by empirically testing the EKC hypothesis for Indian states' production of MSW. Employing state-level panel data, the research tests whether the interaction between per capita income and MSW production conforms to the inverted U-shape functional form of the EKC model. Analysis accounts for the significant variables like population density and urbanization and employs the fixed effects and instrumental variable (IV) estimation to account for unobserved heterogeneity as well as the possible endogeneity in income. Following the approach of Lora et al. (2013) in their research on landfill waste in Colombia, the paper employs the standard quadratic specifications and more flexible specifications to test the robustness of the EKC relationship.

Initial results indicate the existence of an EKC-like curve, with the production of MSW increasing at lower income levels and decreasing with increasing income levels. The turning point, however, differs across states and seems to be a function of the efficacy of policy, infrastructure investment, and social awareness. The research also identifies a great deal of heterogeneity across states, which implies that a one-size-fits-all policy will not work. Rather, state-specific policies attuned to local socioeconomic and environmental conditions will be more effective.

By considering MSW as the hub of EKC, this article extends the scope of EKC research and offers new concepts to policymakers interested in addressing the environmental cost of economic growth. This article also proposes the necessity of incorporating waste management in overall discourses on sustainable development in India's federal context.

2 LITERATURE REVIEW

2.1 Literature Review 1 (Manish Bhadauriya)

2.1.1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis suggests economic growth initially worsens then improves environmental quality after reaching an income threshold. This study examines the EKC for municipal solid waste (MSW) in India, where rapid growth (6-7 percent annually) and urbanization (34 percent) create significant waste challenges. Analysing 31 states (2013-2021), we confirm the inverted U-shaped pattern: early development increases waste through industrialization (scale effect), while higher incomes enable reduction via better infrastructure (technique effect). Industrial activity and energy use drive waste generation, while education reduces it, with tourism showing minimal impact. Wealthier states like Maharashtra demonstrate waste stabilization, while others struggle with basic collection, revealing stark regional disparities. These findings highlight three key insights: first, the EKC framework applies to MSW in developing contexts; second, economic growth alone cannot ensure sustainable waste management without targeted policies; and third, India's diverse states require customized approaches. The results emphasize the need for decentralized strategies combining infrastructure investment, education programs, and strict policy enforcement to align economic development with environmental sustainability goals across India's varied regional contexts.

2.1.2 Early MSW Management Practices and EKC Foundations

Patel et al. (2023) critically analyzed India's management of MSW, presenting how the unsuitable disposal practices, specifically open dumping, have resulted in fresh environmental and health risks . Enforcement of the Solid Waste Management Rules (2016) remains patchy, and the technological infrastructure for treatment of waste is absent. These findings represent the "scale effect" of economic growth in the EKC model—early growth enhances waste creation. Sharholy et al. (2008a) established core context, stating that earlier, about 90 percent of india's MSW solid waste disposed off openly. This supports the upward slope of the EKC at initial stages of economic growth. Gour and Singh (2023) use a structural shift in the waste pattern . Previously, the waste was predominantly organic; however, with increasing incomes, higher percentages of plastics, metals, and electronic trash have been generated. This "composition effect" further makes MSW management more difficult, demanding more advanced technologies and systems. At the international theoretical level, Grossman and Krueger (1991b) empirically confirmed the inverted-U relationship between GDP and pollution measures such as sulfur dioxide and smoke . While their topic was air pollution, the magnitude, make-up, and technique effects they outlined can be transferred to MSW.

2.1.3 Evidence from Indian States and CPCB Data

Particularly in the Indian context, Khajuria et al. (2011) supported evidence from panel data that Maharashtra and Gujarat states are showing early trends of MSW stabilization. This implies that richer states and states with more developed waste management infrastructure are starting to cross the EKC turning point. The CPCB's 2014-15 report added that even though India produces approximately 62 million tonnes of MSW every year, only 70 percent is collected and only 20 percent is treated.Those like Delhi, Mumbai, and Bangalore far surpass the national per capita waste generation, affirming EKC pressures in highly urbanized areas.Sector-specific drivers also play a significant role. Urbanization at a rapid pace—with India's urban population already at over 34 percent—has caused waste levels to soar. However, cities such as Pune and Bengaluru, which have invested in segregation and recycling through the Swachh Bharat Mission (SBM), show successful transitions to the EKC's decreasing curve.

2.1.4 Sectoral Drivers of MSW Generation

Industrialization plays a two-edged role: it assists in augmented MSW generation (especially through hazardous and non-biodegradable wastes), industries also encourage innovation in waste treatment technology. Mishra and Singhal (2019) further mention the extra complexity introduced through industrial solid wastes getting combined with municipal waste, especially in cities such as Surat and Chennai.Tourism is another factor. Arbulú et al. (2015) demonstrated that increasing tourism is related to the generation of MSW. The relationship is, however, multifaceted; while some studies (Isik et al., 2020) indicate the EKC driven by tourism applies to some nations such as France, others Hacıimamoğlu (2023) observe a U-shaped rather than an inverted U-shaped relationship. Tourist spots such as Goa in India have experienced seasonal increases in MSW generation, indicating that tourism can extend the rising EKC slope unless sustainability policies are implemented.Education is a strong intermediary. Kinnaman and Fullerton (2002) showed that higher education levels are related to lower waste generation in the household. Abrate and Ferraris (2010) confirmed this by showing education's negative relationship with waste generation. In India, higher literacy states like Kerala and Himachal Pradesh have better segregation and recycling of waste. Energy consumption is another sector directly associated with waste management.

2.1.5 Energy Consumption and Structural Transformation

.Rahman et al. (2024) reaffirmed that rising energy consumption, in the absence of policy measures, exacerbates environmental degradation. Therefore, as the energy consumption of India increases, in the absence of cleaner substitutes, MSW processing and disposal loads will also increase.Villanthenkodath et al. (2021) highlighted that structural change towards services and from the manufacturing heavy industries can contribute to less environmental degradation. In India, the states with a strong services sector will generate somewhat lower MSW in terms of GDP again supporting the "technique effect.

2.1.6 Spatial Factors and Policy Initiatives

Spatial factors also complicate MSW dynamics. Lora et al. (2013) found that elevation and population density significantly influenced waste behavior. Similarly, densely populated cities in India face more acute MSW problems than low-density cities. Government initiatives such as Swachh Bharat Mission (SBM) and supporting waste-to-energy (WTE) plants in Delhi and Pune are positive steps. But skepticism regarding the economic viability, environmental integrity, and operational efficiency of WTE projects suggests that technology is not sufficient without better governance and citizen participation.

2.1.7 Conclusion

The empirical evidence from Indian states largely validates the EKC hypothesis for MSW generation, though with notable regional variations. While rapid economic growth initially increases waste through urbanization and industrialization (scale effect), wealthier states like Maharashtra and Gujarat show signs of stabilization through improved infrastructure and policies (technique effect). Key findings reveal industrialization and tourism drive waste generation, while education and service-sector transitions help mitigate it. Despite policy gaps in SWM Rule implementation, initiatives like Swachh Bharat Mission demonstrate the potential of governance-public partnerships. Moving forward, India must prioritize decentralized waste management, stricter regulation enforcement, and targeted awareness campaigns to accelerate the transition toward sustainable waste management across all states.

2.2 Literature Review 2 (Shivam Bist)

2.2.1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis, developed in the early 1990s as an extension of the original Kuznets curve on economic growth and income inequality, states that the relationship between economic development and environmental quality follows an inverted U-shaped trajectory. In the initial phases of economic growth, environmental degradation tends to increase; however, beyond a certain point (inflection point or the turning point), further economic growth is associated with improvements in environmental quality Shafik and Bandyopadhyay (1992). Theoretical models explain this dynamic through three main mechanisms: the scale effect, structural transformation, and rising demand for environmental quality as incomes rise. While the expansion of economic activity initially exacerbates pollution, shifts in industrial structure and increasing environmental awareness can lead to pollution reductions at higher income levels. Notably, Andreoni and Levinson (2001) developed a straight-forward static model of the microfoundations of this relationship showing that the EKC can result purely from the technological relationship between the consumption of desired goods and the generation (and abatement) of pollution, independent of externalities or political interventions.

2.2.2 Literature on EKC for Solid waste

The Environmental Kuznets Curve (EKC) hypothesis has been widely tested across various environmental degradation indicators, eg. air pollutants, (CO, CO_2, NO_x, $PM_{2.5}$, PM_{10}, greenhouse gases (GHGs)) water pollutants (Sinha and Bhattacharya (2017), Wang et al. (2016), Danesh Miah et al. (2010)) and deforestation rate Bhattarai and Hammig (2001). Although the EKC is a widely discussed hypothesis, empirical evidence for its validity in the context of municipal solid waste (MSW) generation remains largely unexplored compared to traditional pollutants.

Early studies such as Gnonlonfin et al. (2017) found evidence supporting an EKC relationship for MSW in high-income countries, where waste generation initially rises with income growth but later declines after reaching a certain threshold. Similarly,Wu et al. (2015) documented a comparable inverted U-shaped relationship for MSW generation across Chinese provinces.

Wang et al. (2021) provided global evidence on the EKC for municipal solid waste, confirming an inverted U-shaped relationship between income and MSW generation, particularly in high-income nations, and highlighting industrial structure and energy consumption as key drivers. Ercolano et al. (2018) analyzed municipal-level panel data from Lombardy, Italy, and also confirmed the inverted U-shape, consistent with the Waste Kuznets Curve (WKC) hypothesis. Trujillo Lora et al. (2013) analyzed the Environmental Kuznets Curve (EKC) hypothesis for municipal solid waste disposed of in landfills across Colombia. Using panel data from 707 municipalities between 2008 and 2011, their study confirmed the existence of an inverted U-shaped relationship between economic development and landfilled solid waste.

2.2.3 EKC of MSW in context of India and evidence for potential factors

The Environmental Kuznets Curve (EKC) hypothesis has been widely applied to study the relationship between economic development and various forms of environmental degradation, including municipal solid waste (MSW) generation. However, in the Indian context, empirical research focusing on EKC for MSW remains limited. Only one major study by Khajuria (2012) has empirically tested the Environmental Kuznets Curve (EKC) for municipal solid waste generation in India. Existing studies have mainly concentrated on air and water pollution, while solid waste management has received comparatively less attention. Available evidence suggests that India may still be positioned in the early, rising phase of the EKC, where economic growth is associated with increasing levels of waste generation Sharholy et al. (2008b)

One important factor, though a good proxy for economics development influencing MSW generation is industrialization. In India industries sectors such as textiles, chemicals, electronics, and automobile manufacturing produce considerable amounts of non-biodegradable and hazardous waste Mishra and Singhal (2019). A study by Li et al. (2020) on China's upper-middle-income regions finds that industrialization and population density raise energy use, while urbanization lowers it, with the EKC showing an inverted "N" shape after accounting for spatial effects. This highlights the critical role of including industrialization and urbanization in EKC analysis.

Tourism is another factor contributing to MSW generation, with Arbulú et al. (2015) confirming a non-linear and significant effect of tourism indicators on waste levels. Studies by Işik et al. (2020) and Hacıimamoğlu (2023) found limited support for the tourism-induced EKC, observing either validity only for France or a U-shaped relationship instead of the expected inverted U-shape. These findings suggest that tourism may continue to exert environmental pressure without necessarily leading to improvements.

Education is a key factor in municipal solid waste (MSW) generation. Kinnaman and Fullerton (2002) found a negative relationship between education and waste production, while Abrate and Ferraris (2010), using the share of adults with a high school degree as a proxy, also confirmed its significant influence on household waste patterns, stressing the need to include education in MSW studies.

Rahman et al. (2024) investigated the relationship between energy consumption and environmental degradation across five South Asian countries over the period 1972–2021. Their results validated the Environmental Kuznets Curve (EKC) hypothesis and revealed that energy consumption is positively correlated with CO_2 emissions.

2.3 Literature Review 3 (Udit Chauhan)

2.3.1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis argues that environmental pollution is initially linked to economic growth, but thereafter the trend is reversed after exceeding a certain level of income, and the curve takes an inverted U-shape relative to income and pollution intensity. In the context of generation of Municipal Solid Waste (MSW), specifically, the EKC hypothesis suggests that waste generation increases in line with increasing prosperity up to a point. Following this, higher technology, greater awareness, and application of effective policies should lead to a reduction in waste generation.

However, empirical data to verify the hypothesis has research results spread over a broad spectrum with the majority being subject to the methodology used, aggregating data levels, and the contextual explanatory variables included in the models. There have been numerous studies examining the relationship between economic growth and waste generation, with differing outcomes depending on regional and national variations, such as socio-economic variables of urbanization, industrialization, and energy consumption.

This research will add to an extension of this literature by examining the specific dynamics of MSW generation in Indian States, with an emphasis on the most important variables such as electricity use, industrial production, education, tourism, and urbanization, in an attempt to provide a more geographically situated assessment of the EKC. Through this lacuna, the research aims to provide thought-provoking contributions to the environmental-economic nexus, which has been relatively under-explored in the current literature, particularly in the Indian state context.

2.3.2 Studies Investigating the EKC for MSW

The first wave of research during the 1990s widely used cross-country panel data to empirically test the EKC relationship. Such research in general was not able to validate the EKC hypothesis for MSW, showing a monotonically increasing income-waste relationship. For example, research by Shafik and Bandyopadhyay (1992), Shafik (1994), and Matthew A. Cole and Bates (1997) mostly witnessed continuous increases in waste with increasing GDP, indicating that economic growth in itself does not necessarily lead to better waste management. More recent research has, however, moved towards within-country research—especially at the national, regional, and city levels—where the EKC has been empirically validated to a greater extent. Research by Lim (1997), Qian Song and Zeng (2008), Mazzanti et al. (2009), and Khajuria et al. (2012) validate the existence of the EKC in South Korea, China, Italy, Japan, and India.

A significant consequence of such studies is the determination of the point of inflection, where decoupling of economic growth from environmental degradation begins. Daisuke Ichinose and Yoshida (2011) place the point at Japan's average income levels and therefore absolute decoupling, but for Italy and China, it is near peak income levels and therefore relative decoupling. Such a variation generally is caused by variations in policy efficiency, awareness of environmental concerns, and waste handling facilities. The cross-national versus within-national difference estimate resulted in rejection of the hypothesis postulating the same waste-income relationship for every nation. Vincenzo Iafolla and

Nicolli (2010) applied a Seemingly Unrelated Regression model to test this and determined heterogeneous slopes of the EKC, dividing nations into absolute decoupling (e.g., Austria, Germany), relative decoupling (e.g., UK, Netherlands), and no decoupling (e.g., Belgium, Denmark, France).

2.3.3 Review of Variable Selection in EKC Studies

These findings have significant implications for the independent variables' contribution in EKC models, namely education, industrial production, electricity consumption, tourism, net sown area, and night-time light intensity. Education appears as a significant driver, with Halkos and Petrou (2020) pointing out that increased education levels lead to increased environmental concern and proactive measures like recycling and waste reduction. The study of Khajuria et al. (2011) also encompasses literacy rate as an important demographic factor, recognizing it as an environmental action determinant. Improved literacy rates are related to greater public awareness and acceptance of waste minimization practices. This means that education is a key variable which facilitates disconnection of municipal solid waste generation and economic development. Literacy is thus a key driver of implementation of sustainable development policies.

Systematic review by Mandal and Chakravarty (2017) utilized a Tobit model for 235 EKC studies and verified that the addition of energy-related variables, e.g., consumption of electricity, is likely to increase the turning point of the EKC as estimated. This implies that energy consumption plays an important role in influencing the economic-environmental relationship. The research puts in perspective the significance of specification and model selection. It suggests the use of electricity consumption in modeling the EKC for accurate estimation.

Gnonlonfin et al. (2017) applied the Environmental Kuznets Curve (EKC) to Municipal Solid Waste (MSW) in 19 Mediterranean countries from 1990 to 2010, finding that the EKC hypothesis only holds for developed nations with very high turning points. The study identified socio-economic factors like urbanization, working women, industrial growth, and international trade as key determinants of MSW. These factors, rather than economic growth alone, contribute to higher MSW levels, challenging the assumption that economic development reduces waste generation. The authors argue that, in the short to medium term, Mediterranean countries cannot rely on growth policies to reduce MSW.

Instead, ambitious public policies focused on waste reduction are necessary. Their findings highlight the role of socio-demographic factors and technological effects, suggesting that policy interventions must address these issues for effective waste management.

According to the EKC hypothesis theory, tourism has been identified as a source of economic growth and a major cause of environmental degradation.

Majumdar and Paris (2022) in the United Arab Emirates conducted a study on how tourism influences the link between economic development and carbon emissions. The findings showed a positive relationship between tourist inflow and higher CO2 emissions, thereby confirming the theory that tourism can lead to environmental degradation with economic development.

But the study also discovered that environmental impacts resulting from tourism were based on a complex relationship and were determined by energy consumption and urbanization, among others. Although tourism was a prime cause, the study discovered that the causal relationship between tourism and emissions was two-way, i.e., the impact of tourism on the environment is not linear but is determined by other structural and economic determinants.

3 DATA

In this study, the outcome variable represents the key dependent variable of interest *Municipal Solid Waste (MSW)* which we aim to explain or predict through our empirical analysis. This variable has been selected due to its relevance to environmental sustainability and urban development discussions.

3.1 Definition and Measurement

The main outcome variable is *Municipal Solid Waste (MSW)*. It is measured in Tonnes per day (TDP) and reflects the total amount of solid waste generated by households, businesses, and institutions within a municipality. The data is obtained from *Central Pollution Control Board*, and covers the period from *2013 - 2021* on an annual basis.

3.1.1 Role in the Analysis

MSW serves as the dependent variable in our regression models. Its generation is hypothesized to be influenced by several key socioeconomic and sectoral indicators, which serve as independent variables in the analysis. These include:

- **Education(EDU):** Number of enrollments in the under-graduate program per year, representing the level of education and awareness, which may influence waste behavior. Source: AISHE annual report, Ministry of Education.

- **Electricity Consumption(ELEC):** Number of units consumed, serving as a proxy for economic activity and living standards. Source: RBI

- **Industrial Activity(NOF):** Number of registered factories, capturing the intensity of local industrial operations. Source: RBI

- **Farming(NSA):** Net sown area, indicating the extent of agricultural activity, which may have an inverse relationship with urban waste. Source: RBI

- **Tourism(TOUR):** Number of Hotels with at least 1 star rating, representing temporary population pressure and consumption behavior. Source: Ministry of Tourism website.

- **Night-time Lights(nL):** NTL Radiance, Satellite-derived night light intensity, used as a proxy for economic development and urbanization. Source: National Remote Sensing Centre ISRO.

Understanding the relationship between these factors and municipal solid waste generation is crucial for evaluating the Environmental Kuznets Curve (EKC) hypothesis in the context of waste production, and for informing more targeted environmental and urban planning policies.

Table 1: Summary Statistics

Variable	**N**	**Mean**	**Std. Dev.**	**Min**	**Max**
MSW	239	4952.45	5891.96	13	26820
GSDP	279	4.04e+07	4.30e+07	903842	2.05e+08
NSA	270	4632.19	5492.12	15	18423
NOF	272	7768.02	9282.20	66	39512
ELEC	278	3719.17	4017.53	40	17282
TOUR	234	51.54	98.01	1	694
EDU	279	903391.3	1029652	14980	5548134
NL	279	126.22	363.99	0.63	1827.65

4 EMPIRICAL METHOD

4.1 Fixed Effects Panel Regression

This study employs a Fixed Effects (FE) panel regression model to analyze the relationship between municipal solid waste (MSW) generation and various socio-economic indicators across states over time. The fixed effects model controls for unobserved, time-invariant characteristics of each state that could bias the estimates if omitted. These may include regional governance practices, cultural attitudes, waste infrastructure, or environmental enforcement levels.

By using fixed effects, the model effectively isolates the impact of time-varying independent variables on the dependent variable within each entity (state), thereby accounting for individual-specific heterogeneity.

The fixed effects panel regression model is specified as:

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \tag{1}$$

Where:

- Y_{it} denotes the dependent variable (MSW generation) for state i at time t,
- X_{it} is a vector of time-varying independent variables (e.g., GSDP, education level, number of factories),
- α_i represents the unobserved state-specific fixed effect (intercept),
- β is the coefficient vector capturing the impact of the independent variables,
- ε_{it} is the idiosyncratic error term.

The fixed effects estimator uses only the within-entity (within-state) variation over time, thereby eliminating bias from unobserved factors that do not change over time.

4.3 Hypotheses Formulation

Guided by the Environmental Kuznets Curve (EKC) framework and supported by the broader literature on waste generation and socioeconomic dynamics, we derive the following testable hypotheses for the panel data regression analysis. Due to high pairwise correlation among predictors and the focus on variable-specific EKC patterns, we estimate separate panel fixed-effects models for each explanatory variable with squared GSDP term. These hypotheses aim to identify the direction and significance of various independent variables on municipal solid waste (MSW) generation across Indian states from 2013 to 2021.

Hypothesis 1 (H1): The EKC Hypothesis for MSW Generation

We hypothesize that MSW generation follows an inverted-U shaped relationship with economic development, proxied by Gross State Domestic Product (GSDP). This implies that:

$$H_1 : \beta_{GSDP} > 0 \quad \text{and} \quad \beta_{GSDP2} < 0$$

A positive coefficient on $GSDP$ and a negative coefficient on $(GSDP)^2$ would suggest that waste generation initially increases with economic growth, but declines after reaching a certain income threshold—consistent with the EKC hypothesis.

Hypothesis 2 (H2): Impact of Education

We hypothesize that higher levels of education, proxied by undergraduate enrollments, are associated with lower MSW generation due to greater awareness and behavioral shifts toward sustainability:

$$H_2 : \beta_{EDU} < 0$$

Hypothesis 3 (H3): Role of Agricultural Activity

Agriculture-intensive states are expected to produce less urban waste, as reflected by the extent of net sown area. Thus:

$$H_3 : \beta_{NSA} > 0$$

Hypothesis 4 (H4): Effect of Industrial Activity

Industrialization, captured through the number of registered factories, is expected to increase solid waste due to higher production and consumption:

$$H_4 : \beta_{NOF} > 0$$

Hypothesis 5 (H5): Influence of Tourism

Higher tourism intensity, measured by the number of hotels with alteast one star ratings, is hypothesized to increase MSW due to temporary population surges and increased consumption:

$$H_5 : \beta_{TOUR} > 0$$

Hypothesis 6 (H6): Electricity Consumption

Electricity consumption serves as a proxy for living standards and commercial activity. It is expected to positively correlate with MSW generation:

$$H_6 : \beta_{ELEC} > 0$$

Hypothesis 7 (H7): Night-time Light Intensity and Urbanization

Night-time light radiance, representing urbanization and infrastructure density, is expected to show a positive relationship with MSW generation:

$$H_7 : \beta_{nL} > 0$$

These hypotheses are empirically tested using a fixed-effects panel regression model.

Regression Models

The following regression models are estimated for each hypothesis, using panel data with fixed-effects:

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \epsilon_{it} \tag{2}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{EDU}} \cdot \mathbf{EDU}_{it} + \epsilon_{it} \tag{3}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{NSA}} \cdot \mathbf{NSA}_{it} + \epsilon_{it} \tag{4}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{NOF}} \cdot \mathbf{NOF}_{it} + \epsilon_{it} \tag{5}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{TOUR}} \cdot \mathbf{TOUR}_{it} + \epsilon_{it} \tag{6}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{ELEC}} \cdot \mathbf{ELEC}_{it} + \epsilon_{it} \tag{7}$$

$$\mathrm{MSW}_{it} = \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{nL}} \cdot \mathbf{nL}_{it} + \epsilon_{it} \tag{8}$$

$$\begin{aligned} \mathrm{MSW}_{it} = {} & \alpha + \beta_{\mathrm{GSDP}} \cdot \mathrm{GSDP}_{it} + \beta_{\mathrm{GSDP2}} \cdot (\mathrm{GSDP}^2)_{it} + \beta_{\mathrm{EDU}} \cdot \mathrm{EDU}_{it} \\ & + \beta_{\mathrm{NSA}} \cdot \mathrm{NSA}_{it} + \beta_{\mathrm{TOUR}} \cdot \mathrm{TOUR}_{it} + \epsilon_{it} \end{aligned} \tag{9}$$

5 RESULTS

5.1 Correlation Matrix

As shown in Table 2, a correlation matrix was calculated to understand the relationships of Municipal Solid Waste (MSW) with the different socio-economic and sector variables. The correlation matrix aids to understand to which extent the said variables are co-related with the generation of MSW. Following are the salient findings derived from the correlation analysis:

Table 2: Correlation Matrix

	MSW	**GSDP**	**GSDP2**	**NSA**	**NOF**	**ELEC**	**TOUR**	**EDU**	**nL**
MSW	1.0000	0.9279	0.8363	0.7004	0.7914	0.9052	0.1717	0.8360	0.1198
GSDP	0.9279	1.0000	0.9229	0.7227	0.8442	0.9406	0.2773	0.8384	0.0062
GSDP2	0.8363	0.9229	1.0000	0.6098	0.7334	0.8302	0.1992	0.7209	-0.0426
NSA	0.7004	0.7227	0.6098	1.0000	0.5042	0.8244	0.0836	0.7682	-0.1888
NOF	0.7914	0.8442	0.7334	0.5042	1.0000	0.8545	0.2307	0.6865	-0.1038
ELEC	0.9052	0.9406	0.8302	0.8244	0.8545	1.0000	0.1763	0.8686	-0.0662
TOUR	0.1717	0.2773	0.1992	0.0836	0.2307	0.1763	1.0000	0.1946	-0.0195
EDU	0.8360	0.8384	0.7209	0.7682	0.6865	0.8686	0.1946	1.0000	-0.0496
nL	0.1198	0.0062	-0.0426	-0.1888	-0.1038	-0.0662	-0.0195	-0.0496	1.0000

Key Findings:

Notably, **GSDP** and **ELEC** share a very high correlation (0.9406), suggesting a close association between economic output and electricity consumption. **GSDP** is also strongly correlated with **NOF** (0.8442), **EDU** (0.8384), and **GSDP2** (0.9229), the squared term of economic output, which is expected by construction.

NSA (Net Sown Area) shows moderate correlations with **EDU** (0.7682) and **ELEC** (0.8244), indicating that more agriculturally productive states may also be relatively developed in terms of infrastructure and services.

Meanwhile, **TOUR** and **nL** (Night-time Lights) have weak correlations with the rest of the variables, suggesting their effects are relatively independent in the model context.

While some strong pairwise bivariate correlations exist, especially involving GSDP, it does not immediately indicate perfect multicollinearity concerns.

The **regression findings**, as shown in table below, demonstrate the interconnections between important economic, industrial, and socio-environmental determinants and Municipal Solid Waste (MSW) production. The model applies a fixed-effects panel regression to control for unobserved heterogeneity and to capture both time-varying and time-invariant effects on MSW. The coefficients offer information on the importance and direction of each determinant's effect on waste production, providing useful implications for environmental policy and waste management practice.

	(1) MSW	(2) MSW	(3) MSW	(4) MSW	(5) MSW	(6) MSW	(7) MSW	(8) MSW
GSDP	0.0000971***	0.000113***	0.0000627**	0.000133***	0.0000974***	0.0000700**	0.0000969***	0.0000789**
	(4.44)	(5.05)	(2.74)	(4.78)	(4.30)	(3.01)	(4.41)	(3.28)
GSDP2	-3.61e-13***	-3.75e-13***	-2.29e-13*	-4.82e-13***	-3.63e-13***	-3.58e-13***	-3.60e-13***	-2.44e-13*
	(-3.68)	(-3.87)	(-2.27)	(-4.23)	(-3.61)	(-3.72)	(-3.66)	(-2.42)
EDU		-0.0007995**						-0.0006845*
		(-2.62)						(-2.22)
NSA			1.737***					1.856***
			(4.25)					(4.17)
NOF				-0.290*				
				(-2.10)				
TOUR					-0.276			0.85
					(-0.10)			(0.33)
ELEC						0.526**		
						(3.01)		
nL							-0.124	
							(-0.15)	
Constant	2345.6***	2563.3***	-4534.9**	3544.4***	2407.0***	1487.9*	2366.1***	-5459.7*
	(4.06)	(4.48)	(-2.61)	(4.39)	(3.94)	(2.35)	(3.97)	(-2.69)
Observations	239	239	230	234	204	239	239	196

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Estimate table

5.2 Results and Interpretation

The regression analysis provides robust evidence in support of the Environmental Kuznets Curve (EKC) hypothesis for municipal solid waste (MSW) generation. Across all eight model specifications, Gross State Domestic Product (GSDP) is positive and statistically significant, with coefficients ranging from 0.0000627 to 0.000133. For instance, in Model (4), a unit increase in GSDP corresponds to a 0.000133 tonne increase in MSW per day, significant at the 1% level ($t = 4.78$).

The squared term of GSDP (GSDP2) enters with a negative and significant coefficient across all models, confirming the inverted-U relationship characteristic of the EKC. The coefficient ranges from -2.29×10^{-13} to -4.82×10^{-13}, with Model (4) again showing the strongest effect ($t = -4.23$). This suggests that while MSW initially increases with economic growth, the trend eventually reverses as income levels rise further, likely due to improved efficiency, policy interventions, and environmental awareness.

Among the control variables, education (EDU) demonstrates a significant negative impact on MSW in Models (2) and (8), with coefficients of -0.0007995 ($t = -2.62$) and -0.0006845 ($t = -2.22$), respectively. This indicates that higher undergraduate enrollment—used as a proxy for public awareness and environmental literacy—contributes to reductions in waste generation.

Net Sown Area (NSA) is positively and significantly associated with MSW in Models (3) and (8), with coefficients of 1.737 ($t = 4.25$) and 1.856 ($t = 4.17$), respectively. This result suggests that regions with higher agricultural activity also generate more waste, possibly due to changing land use patterns and integration with urban markets.

The number of registered factories (NOF) exhibits a negative and marginally significant coefficient in Model (4), estimated at -0.290 ($t = -2.10$), which contrasts with theoretical expectations and prior literature that generally suggest a positive association between industrial activity and waste generation.

Electricity consumption (ELEC), included in Model (6), shows a positive and significant relationship with MSW, with a coefficient of 0.526 ($t = 3.01$). This finding supports the idea that higher energy use, a proxy for material consumption and affluence, is associated with greater waste output.

On the other hand, variables such as tourism (TOUR) and night-time light intensity (nL) are statistically insignificant in their respective models. TOUR shows coefficients of -0.276 ($t = -0.10$) and 0.85 ($t = 0.33$) across models, while nL has a coefficient of -0.124 ($t = -0.15$), suggesting that these indicators do not have a strong direct relationship with MSW in our research.

In summary, the results confirm the EKC pattern and highlight the importance of education, energy use, and structural transformation in shaping waste generation. These insights can inform targeted policy strategies aimed at sustainable urban and environmental planning.

6 DISCUSSION AND POLICY IMPLICATIONS

The findings of this research hold a number of important implications for Indian economic and environmental policy. Even if the EKC hypothesis holds that there is an ultimate fall in environmental degradation like MSW generation at increasing income levels, this connection is neither common nor automatic over Indian states. The inter-state diversity mentioned emphasizes the paramount role played by context-specific variables like trends in urbanisation, quality of institutions, awareness among citizens, and regimes of policy.

Targeted Waste Management Strategies: States with different levels of economic development generate different amounts of waste. Policymakers need to design targeted interventions that are sensitive to each state's particular income level, urban nature, and waste management capability. Low- and middle-income states need to prioritize setting up rudimentary collection and disposal facilities, while wealthier states need to invest in advanced waste processing technologies such as composting, recycling, and waste-to-energy.

Proactive Environmental Regulation: The inflection point in the EKC does not naturally happen without institutional and regulatory backing. Government action by way of strict environmental legislation, enforcement of segregation of waste at source, and encouragement of extended producer responsibility (EPR) is required so that increasing income levels get reflected in improved environmental performance.

Investment in Green Infrastructure: Growth in income by itself will not ensure sustainable waste management unless accompanied by investment in environmentally friendly infrastructure like decentralized composting, material recovery facilities, and improved landfill facilities. PPP roles can play a crucial role for better service provision and mass replication of new technology.

Awareness and Behavioral Change: Economic growth should be sustained by public awareness campaigns and outreach efforts at the community level, which lead to environmentally conscious behavior. Awareness of the requirement to segregate waste can accelerate the declining slope of the EKC.

Monitoring and Data-Driven Policy: There must be continuous monitoring and quality data collection of MSW generation and disposal at the state level. A good database will enable policymakers to observe trends, evaluate the effectiveness of policies, and take evidence-based decisions appropriate to local conditions.

7 CONCLUSION

This paper presents an application of the Environmental Kuznets Curve (EKC) hypothesis to municipal solid waste (MSW) generation across Indian states, highlighting the relationship between economic growth and environmental outcomes. Utilizing fixed effects panel regression and additional controls, the study empirically confirms the existence of an inverted-U shaped relationship between income levels and MSW generation.

By incorporating a range of sectoral and demographic factors, the analysis refines traditional EKC applications and demonstrates that industrial and educational drivers significantly shape MSW trajectories. Importantly, while initial economic growth tends to increase MSW generation, rising incomes accompanied by better policy frameworks and public awareness can lead to reductions. However, the relationship is complex and not uniform across all regions. Future research may extend these findings by integrating spatial spillover effects, waste composition dynamics, and broader urban infrastructure indicators. Additionally, the establishment of reliable, standardized waste management databases by Urban Local Bodies (ULBs) is crucial to enable more accurate assessments and to strengthen policy interventions in the MSW sector.

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Appendix A: Tables

Authors	Sample	Estimator	No. obs.	EKC
Within country level				
Khajuria et al. (2012)	India (1947–2004)	Time series	8	Valid
Ichinose et al. (2011)	Japanese municip.	Cross-section	1,796	Valid
Mazzanti et al. (2009a)	Italian regions (1996–2005)	Panel	180	Valid
Mazzanti et al. (2009b)	Italian cities (2000)	Panel	515	Valid
Lim (1997)	South Korea	Time series	11	Valid
Song et al. (2008)	29 Chinese prov. (1985–2005)	Panel	–	Valid
Cross-country level				
Iafolla et al. (2010)	EU (15) (1997–2005)	Panel	195	Not valid
Mazzanti and Zoboli (2009)	EU (25) (1995–2007)	Panel	275	Not valid
Cole and Bates (1997)	13 countries OECD (1971–1992)	Panel	52	Valid
Shafik (1994)	39 countries (1985)	Cross-section	39	Not valid
Shafik and Bandyopadhyay (1992)	39 countries (1985)	Cross-section	39	Not valid

Table A1: Summary of EKC literature with respect to waste generation

Appendix B: Figures

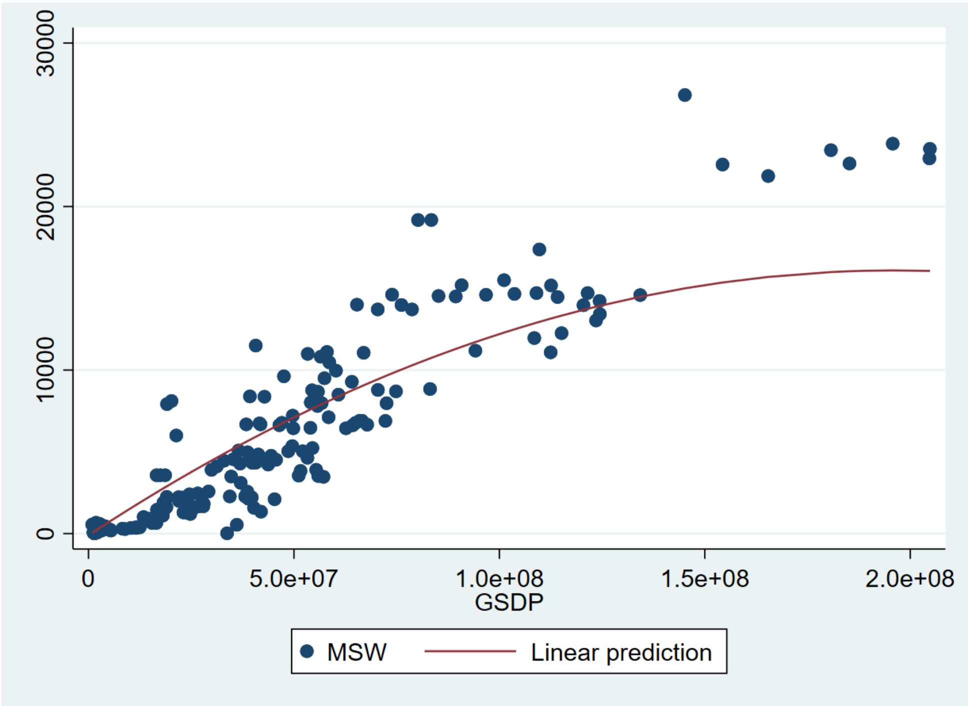

Figure B1: Urban Waste Generation by Income Level and Year.