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COMPARATIVE ASSESSMENT OF SOLID WASTE MANAGEMENT SYSTEMS AND OPERATIONAL EFFICIENCY IN COASTAL URBAN LOCAL BODIES: A STUDY OF RATNAGIRI, CHIPLUN, AND KHED MUNICIPAL COUNCILS

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Abstract

Municipal Solid Waste Management (MSWM) in ecologically sensitive coastal and riverine terrains poses complex operational, infrastructural, and environmental challenges. This study investigates and compares the solid waste management systems, operational processing capacities, and disposal efficiencies of three major Urban Local Bodies (ULBs) Ratnagiri, Chiplun, and Khed Nagar Parishads located in the Ratnagiri District of Maharashtra, India. Utilizing empirical primary data from field observations, municipal administrative records, and structured interviews covering the period 2021–22 to 2024–25, the study evaluates waste generation profiles, processing infrastructure intensity, capacity utilization, vehicle logistics, and landfill diversion rates. The empirical findings reveal that while all three ULBs have achieved 100% primary door-to-door collection coverage, their post-collection operational systems vary significantly. Khed exhibits the highest per capita waste generation (0.319 kg/person/day) and infrastructure density (2.394 TPD/km2). Ratnagiri achieves an exceptional waste diversion rate of 99% (1% landfill disposal) utilizing an integrated multi-technology infrastructure. Chiplun and Khed achieve 80% waste diversion (20% landfill disposal). Processing capacity utilization ranges from 75.0% in Chiplun to 88.9% in Khed. Non-parametric and descriptive evaluations substantiate significant inter-municipal disparities, highlighting the need for decentralized processing, GPS-enabled fleet rationalization, and source-specific handling rather than uniform district-wide policies. The findings provide a critical roadmap for municipal administrators to enhance resource recovery, mitigate seasonal flood-related disruptions, and achieve financial sustainability through improved waste processing efficiency. This comparative analysis serves as a foundational reference for similar Tier-II and Tier-III urban bodies seeking to optimize their sanitation systems in ecologically fragile regions.

Keywords: Municipal Solid Waste Management, Urban Local Bodies, Waste Diversion Rate, Capacity Utilization, Processing Infrastructure.

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1. Introduction:

Rapid urbanization, demographic growth, and changing consumption lifestyles have intensified the quantum and complexity of municipal solid waste in developing nations like India. Municipal Solid Waste Management (MSWM) comprises the systematic administration of waste generation, on-site storage, primary collection, transportation, processing, resource recovery, and final scientific disposal (Tchobanoglous et al., 1993). Under the Constitutional framework of India, public health and sanitation fall within the State List, delegating operational responsibilities to Urban Local Bodies (ULBs) such as Municipal Corporations and Municipal Councils (Nagar Parishads).

Located between the Sahyadri Mountains and the Arabian Sea, the Ratnagiri District has unique geography and water systems (Government of Maharashtra, 2024). The area experiences heavy yearly rainfall (2,500 to 3,500 mm), has rough rocky terrain, and contains delicate river mouths. Cities in this district face different challenges based on their economy, tourism, and local industries. Three main Municipal Councils (Nagar Parishads) represent the different types of urban areas found here:

- Ratnagiri Nagar Parishad: Founded in 1876, this historic district hub is known for its busy shops and coastal tourism.
- Chiplun Nagar Parishad: Established in 1964, it is a major center for trade and transport located along the flood-prone Vashishti River.
- Khed Nagar Parishad: Set up in 1940, this growing industrial and business center is situated near the Lote Parshuram industrial zone.

National laws like the Solid Waste Management Rules, 2016 (Ministry of Environment, Forest and Climate Change, 2016) and national guidelines focus on recycling and reducing landfill use (Central Pollution Control Board, 2023) and the Swachh Bharat Mission focus on recycling and reducing landfill use. However, coastal towns still face big hurdles, such as a lack of available land, difficulty managing vehicle fleets, seasonal floods, and limited waste processing facilities.

2. Literature Review:

The functional elements of solid waste management generation, collection, transfer, processing, and disposal must be integrated within an environmentally sound and economically viable framework (Tchobanoglous et al., 1993).

- **Waste Generation and Urbanization:** Studies show that municipal solid waste generation is non-linearly correlated with urban population size, driven extensively by per capita income, tourism influx, and commercial concentration (Kaza et al., 2018; UNEP, 2015). In small and medium towns, spatial density and economic profile heavily dictate waste composition and bulk density.
- **Collection and Transportation Logistics:** Primary collection constitutes up to 70% of total municipal solid waste operational budgets in small urban local bodies (Tchobanoglous et al., 1993; Scheinberg et al., 2010). Fleet management, vehicle turnaround times, and door-to-door coverage define baseline system adequacy. However, high collection efficiency does not automatically imply sustainable waste management if downstream processing infrastructure is deficient.
- **Resource Recovery and Processing Infrastructure:** Sustainable waste management hinges on moving up the waste hierarchy prioritizing source reduction, composting, material recovery facilities (MRFs), and biomethanation over landfilling (UNEP, 2015; Scheinberg et al., 2010). Decentralized treatment systems are widely recommended for hilly and coastal regions due to geographical barriers to centralized hauling.

- **Performance Metrics in MSWM:** Contemporary urban studies utilize quantifiable indicators, such as Landfill Diversion Rate, Capacity Utilization Ratio, and Infrastructure Density, to benchmark municipal efficiency rather than relying on gross waste volume estimates (Kaza et al., 2018; Scheinberg et al., 2010).

2.1 Research Gap:

While extensive literature exists on municipal solid waste management in metropolitan cities and Tier-I urban agglomerations in India, empirical and comparative investigations focusing on Class-B and Class-C Municipal Councils (Nagar Parishads) in coastal and ecologically fragile districts remain scarce. Most regional studies restrict their scope to macro-level descriptive summaries or qualitative compliance checklists without rigorously examining:

- Inter-municipal variations in physical waste characteristics (per capita generation and spatial waste density) across varying urban profiles.
- Quantitative operational processing infrastructure capacity, capacity utilization rates, and empirical landfill diversion performance across comparable local bodies.

This study addresses this empirical gap by evaluating comparative municipal operational performance in Ratnagiri, Chiplun, and Khed Nagar Parishads.

3. Objectives of the Study:

To present an empirical evaluation based on the field data, the research focuses on the following two specific objectives:

- To evaluate and compare the solid waste management systems, waste generation patterns, and physical processing infrastructure adopted by Ratnagiri, Chiplun, and Khed Urban Local Bodies.
- To examine and benchmark the operational efficiency of the solid waste management systems in Ratnagiri, Chiplun, and Khed ULBs through processing capacity utilization, collection fleet performance, and waste diversion rates.

4. Hypotheses of the Study:

To statistically and analytically validate the research objectives, the following null and alternative hypotheses are formulated:

- **Hypothesis 1:**

H_{10} **(Null Hypothesis):** There are no significant differences in solid waste generation patterns, waste composition, and processing infrastructure systems adopted among Ratnagiri, Chiplun, and Khed Urban Local Bodies.

H_{11} **(Alternative Hypothesis):** There are significant differences in solid waste generation patterns, waste composition, and processing infrastructure systems adopted among Ratnagiri, Chiplun, and Khed Urban Local Bodies.

- **Hypothesis 2:**

H_{20} **(Null Hypothesis):** There are no significant differences in the operational efficiency, processing capacity utilization, and waste diversion performance among the solid waste management systems of Ratnagiri, Chiplun, and Khed Urban Local Bodies.

H_{21} **(Alternative Hypothesis):** There are significant differences in the operational efficiency, processing capacity utilization, and waste diversion performance among the solid waste management systems of Ratnagiri, Chiplun, and Khed Urban Local Bodies.

5. Research Methodology:

- **Research Design:** The study employs an empirical, descriptive, analytical, and comparative research design.
- **Study Area and Sampling Framework:** The study area is purposely restricted to the three major Nagar Parishads (Urban Local Bodies) of Ratnagiri District, Maharashtra: Ratnagiri, Chiplun, and Khed. Complete census enumeration of the operational units within these three administrative jurisdictions was conducted.
- **Data Sources:** Both the primary and secondary data is employed in the study.
  - Primary Data: The primary data is collected between 2021–22 and 2024–25 through structured field schedules administered to municipal administrative heads, sanitation supervisors, health department officials, field inspections of processing yards/dumpsites, and vehicle fleet verification.
  - Secondary Data: The secondary data is collated from Municipal Annual Administrative Reports, municipal budgets, District Census Handbooks, City Sanitation Plans, and guidelines from the Maharashtra Pollution Control Board (MPCB) and Central Pollution Control Board (CPCB) (Central Pollution Control Board, 2023; Government of Maharashtra, 2024).
- **Analytical Tools and Performance Indicators:**
  - Per Capita Waste Generation (kg/person/day)=Total Municipal PopulationTotal Daily Waste Generated (kg)
  - Spatial Waste Density (TPD/km2)=Administrative Area (km2)Total Waste Generated (TPD)
  - Processing Capacity Utilization (%)=(Installed Processing Capacity (TPD)Daily Waste Generated (TPD))×100
  - Waste Diversion Rate (%)=(Total Waste Generated (TPD)Total Waste Diverted from Landfill (TPD))×100=100%−Landfill Disposal Rate (%)
  - Quantitative comparative tables, cross-tabulation, percentage analysis, and ranking techniques.

6. Data Analysis and Interpretation:

The analysis and interpretation of the data remains as follows.

6.1 Demographic, Administrative, and Waste Generation Profile:

The spatial and demographic dimensions of the three Nagar Parishads display substantial divergence in scale, urban structure, and operational requirements.

Table 1: Demographic, Spatial, and Waste Generation Characteristics

Metric / Parameter	**Ratnagiri Nagar Parishad**	**Chiplun Nagar Parishad**	**Khed Nagar Parishad**
Year of Establishment	1876	1964	1940
Population (2011)	1,17,100	55,139	25,100
Admin. Area (km²)	13.60	14.60	3.76
Number of Wards	16	14	10
Assessed Tax Properties	17,206	14,721	9,555
Total Waste Generated (TPD)	22.00	15.00	8.00
Per Capita Gen. (kg/day)	0.188	0.272	0.319
Waste Density (TPD/km²)	1.62	1.03	2.13

Source: Primary data and Municipal records compilation

As shown in Table 1, Ratnagiri is the largest ULB by population (1,17,100) and generates the highest absolute waste volume (22 TPD). However, Khed exhibits the highest per capita waste generation (0.319 kg/person/day), followed by Chiplun (0.272 kg/person/day) and Ratnagiri (0.188 kg/person/day). In terms of spatial waste concentration, Khed records the highest waste density (2.13 TPD/km2) owing to its compact administrative area (3.76 km2), placing intensive operational pressure on primary collection logistics compared to Ratnagiri (1.62 TPD/km2) and Chiplun (1.03 TPD/km2).

6.2 Physical Composition and Dominant Sources of Municipal Waste:

Understanding the waste stream breakdown is vital for designing treatment units.

Table 2: Municipal Solid Waste Composition Breakdown (%)

Waste Category	**Ratnagiri (%)**	**Chiplun (%)**	**Khed (%)**
Household Waste	58.00%	50.00%	55.00%
Industrial / Commercial Waste	20.00%	30.00%	18.00%
Medical Waste	7.00%	5.00%	7.00%
Construction & Demolition (C&D) Waste	10.00%	8.00%	15.00%
Other (Market / Sweeping / Institutional)	5.00%	7.00%	5.00%
Total	100.00%	100.00%	100.00%
Dominant Waste Profile	Household + Industrial	Household + Industrial	Household + Ind. + C&D

Source: Primary data compilation

Household organic waste forms the primary constituent across all three ULBs (50% to 58%). Chiplun records the highest proportion of industrial/commercial waste (30%), influenced by its central commercial trade market and proximity to industrial zones. Khed displays the highest share of Construction and Demolition (C&D) debris (15%), reflecting rapid peri-urban construction activities linked to surrounding industrial expansion.

6.3 Processing Infrastructure and Operational Technology Profile:

The three ULBs demonstrate diverse physical infrastructure assets and resource recovery initiatives.

Table 3: Waste Processing Infrastructure and Resource Recovery Initiatives

Infrastructure / Technology Component	**Ratnagiri Nagar Parishad**	**Chiplun Nagar Parishad**	**Khed Nagar Parishad**
Installed Processing Capacity (TPD)	29.00	20.00	9.00
Composting Facilities	Operational (Mechanical/Pit)	Operational (Windrow/Pits)	Operational
Material Recovery Facility (MRF)	Operational	Operational	Non-dedicated / Manual
Recycling Integration	Formal Tie-ups	Formal Tie-ups	Partial / Informal

Incineration / RDF Processing	Operational	Non-operational	Non-operational
Biogas / Biomethanation Plant	Operational	Operational	Operational
NGO / Community Partnership	Nil (Municipal managed)	Active (SNM partnership)	Nil
Annual Income from Resource Recovery	₹8,75,000	₹6,90,000	₹5,60,000
Infrastructure Classification Level	Advanced	Advanced	Moderate

Source: Primary data compilation and Researcher developed measurements

Ratnagiri and Chiplun maintain diversified physical infrastructure classified at the Advanced Level, possessing dedicated MRFs, composting systems, and biomethanation units. Ratnagiri additionally possesses specialized RDF/incineration processing. Khed maintains a Moderate Level infrastructure, integrating composting and localized biogas production, but lacks a mechanized MRF. Resource recovery revenues reflect infrastructure maturity: Ratnagiri generates ₹8.75 Lakhs annually, Chiplun earns ₹6.90 Lakhs, and Khed generates ₹5.60 Lakhs.

6.4 Operational Efficiency: Fleet, Capacity Utilization, and Waste Diversion:
System efficiency is evaluated by assessing primary collection intensity, installed plant utilization, and final landfill diversion rates.

Table 4: Comparative Operational Efficiency and Performance Metrics

Operational Metric	**Ratnagiri**	**Chiplun**	**Khed**
Door-to-Door Collection Coverage (%)	100.00%	100.00%	100.00%
Total Collection Fleet (Vehicles)	22	14	10
Population Served per Vehicle (Persons)	5,323	3,063	1,476
Waste Handled per Vehicle (kg/day)	1,000	833	471
Average Daily Collection Time (Hours/Day)	8.0 hrs	8.0 hrs	1.5 hrs
GPS Tracking Deployment on Fleet	No	Yes (7% fleet)	No
Daily Waste Generated (TPD)	22.00	15.00	8.00
Installed Processing Capacity (TPD)	29.00	20.00	9.00
Processing Capacity Utilization (%)	75.90%	75.00%	88.90%
Surplus Processing Capacity (TPD)	+7.00 TPD	+5.00 TPD	+1.00 TPD
Infrastructure Status	Adequate	Adequate	Near Full
Landfill Disposal Rate (%)	1.00%	20.00%	20.00%
Waste Diversion Rate (%)	99.00%	80.00%	80.00%
Overall Operational Efficiency Rating	Very High	High	High

Source: Primary data compilation and Researcher developed measurements.

- **Collection Logistics:** All three ULBs maintain universal (100%) primary collection coverage. However, vehicle operational workload varies substantially. In Khed, dense vehicle availability results in a low population load of 1,476 persons per vehicle and an average collection turnaround of 1.5 hours. Ratnagiri maintains 5,323 persons per vehicle with an 8-hour daily shift. Chiplun is the only ULB to have initiated GPS-enabled fleet tracking.

- **Capacity Utilization:** Ratnagiri utilizes 75.9% of its installed processing capacity (22 TPD generated vs. 29 TPD capacity), leaving a safe operational buffer of 7 TPD. Chiplun utilizes 75.0% (15 TPD generated vs. 20 TPD capacity). Khed operates at 88.9% capacity utilization (8 TPD generated vs. 9 TPD capacity), placing it in the Near Full category with only 1 TPD of reserve capacity.
- **Waste Diversion Performance:** Ratnagiri achieves an exceptional waste diversion rate of 99%, disposing of only 1% of residual inert waste in landfills through its multi-tiered processing chain. Chiplun and Khed achieve an 80% diversion rate, routing 20% of unsegregated or non-recyclable fractions to dumping sites.

7. Hypothesis Testing Results:

The results are as follows.

- **Evaluation of Hypothesis 1:** Empirical data demonstrates significant variations in per capita waste generation (0.188 to 0.319 kg/person/day), spatial density (1.03 to 2.13 TPD/km2), C&D waste proportions (8% to 15%), and processing infrastructure tiers (Advanced vs. Moderate) among the three ULBs. Thus, the null hypothesis H_{10} is rejected, and the alternative hypothesis H_{11} is accepted.
- **Evaluation of Hypothesis 2:** Substantial variations exist in operational capacity utilization (75.0% in Chiplun vs. 88.9% in Khed), fleet workload, and landfill diversion rates (99% in Ratnagiri vs. 80% in Chiplun and Khed). Consequently, the null hypothesis H_{20} is rejected, and the alternative hypothesis H_{21} is accepted.

8. Findings and Conclusions:

The major findings and conclusions are as follows.

- **Divergence Between Waste Volume and Per Capita Generation:** The findings demonstrate that gross waste generation is primarily driven by population scale (Ratnagiri generating 22 TPD), but generation intensity is governed by commercial and industrial concentration (Khed generating 0.319 kg/person/day). High per capita generation in Khed and Chiplun underscores the significant contribution of non-residential commercial activities.
- **Infrastructure Concentration vs. Spatial Strain:** Khed records the highest waste density (2.13 TPD/km2), requiring rapid and dense vehicle turnaround. Conversely, Chiplun's larger geographical spread (14.6 km2) requires extensive transit routes, making GPS-enabled monitoring essential.
- **Capacity Utilization Pressures:** While Ratnagiri and Chiplun retain comfortable operational buffers of 7 TPD and 5 TPD respectively, Khed operates under near-capacity constraints (88.9% utilization with only 1 TPD buffer). Any seasonal spike in industrial or commercial waste threatens to overload Khed's processing facilities.
- **Determinants of Diversion Efficiency:** Universal (100%) collection does not ensure zero landfilling. Ratnagiri's superior diversion performance (99%) is directly attributable to its integrated adoption of composting, MRF, RDF, and biomethanation, aligning with sustainable global waste frameworks (UNEP, 2015; Scheinberg et al., 2010). Chiplun and Khed's 20% landfill disposal rate highlights gaps in dry recyclable segregation and commercial waste recovery.
- **Fiscal Sustainability Disparities:** The analysis indicates a direct correlation between municipal financial autonomy and the quality of waste processing infrastructure, where ULBs with established user fees demonstrate higher resilience in sustaining long-term operational expenditures.

- **Role of Informal Sector Integration:** Current data highlights that formalization of waste picker contributions into decentralized material recovery facilities is essential for bridging the gap between existing diversion rates and zero-landfill targets, particularly in smaller ULBs.
- **Need for Integrated Regional Governance:** The findings suggest that transitioning from isolated municipal management to a cluster-based regional framework for waste processing is critical to overcoming the land-use limitations and logistical hurdles faced by individual Nagar Parishads and Nagar Panchayats.
- **Seasonal and Hydrological Vulnerabilities:** Field observations reveal that Chiplun faces acute seasonal operational disruption during the southwest monsoon due to recurring flooding of the Vashishti River, causing drain blockages and waterlogged collection routes. Ratnagiri faces tourism-driven seasonal volume fluctuations.

9. Recommendations and Suggestions:

Based on the empirical findings, the following policy measures are proposed:

- **Immediate Capacity Expansion in Khed:** Given Khed's high capacity utilization (88.9%), the municipal council must expand its processing infrastructure by at least 3 to 5 TPD within the next 12–18 months to prevent unscientific dumping.
- **Adopt Fleet-wide GPS Tracking Practise:** Replicating and scaling Chiplun's pilot GPS initiative across the entire vehicle fleet of Ratnagiri and Khed will optimize fuel consumption, rationalize collection routes, and provide real-time verification of primary collection. **Upgrading Material Recovery Facilities (MRFs):** Chiplun and Khed must establish mechanized dry waste sorting and baling facilities under public-private partnerships (PPP) to elevate their waste diversion rates from 80% to above 95%.
- **Monsoon Flood Safety Plan:** Chiplun Nagar Parishad should formulate a specialized monsoon contingency plan, including elevated waste transfer platforms and reinforced drain grating along the Vashishti riverfront, to prevent solid waste wash-off during flood events.
- **Source-Specific C&D Waste Management in Khed:** To address Khed's high C&D waste share (15%), a separate collection and processing framework for inert debris should be institutionalized to avoid mixing with biodegradable waste streams.
- **Implement Mandatory Solid Waste Management Cess:** Introduce a dedicated municipal sanitation cess (e.g., ₹30–₹50 per property/month) across all ULBs to build dedicated operational funds and reduce reliance on general revenue subsidies.
- **Develop Regional Waste Processing Clusters:** Establish shared, inter-municipal processing facilities to help smaller Nagar Panchayats and municipalities achieve economies of scale for advanced composting and plastic recycling.
- **Strengthen Agricultural Linkages:** Institutionalize formal linkages between municipal composting facilities and local Agricultural Produce Market Committees (APMCs) or agricultural universities to create steady markets for compost and generate sustainable municipal revenue.
- **Capacity Building of workforce:** Implement structured, quarterly technical training programs for sanitation supervisors and operational staff across all ULBs to improve workforce competency and align operational standards with current SBM and SWM guidelines (Ministry of Environment, Forest and Climate Change, 2016; Central Pollution Control Board, 2023).

10. Limitations and Future Scope:

The limitations of the study and scope for research in future are as follows.

10.1 Limitations:

This study is geographically restricted to three municipal councils in Ratnagiri District, utilizing census-based records and periodic field measurements. It excludes industrial hazardous waste from MIDC complexes and specialized biomedical waste managed by Common Bio-medical Waste Treatment Facilities (CBWTF). Additionally, the study acknowledges the following constraints:

- **Self-Reporting Bias:** The study relies partially on data from municipal administrative records; despite cross-verification during field visits, the possibility of minor inaccuracies or under-reporting in municipal records cannot be entirely discounted.
- **Waste segregation Complexity:** The categorization of waste (e.g., separating mixed construction and demolition debris from municipal solid waste) involves estimation in areas where precise weigh-bridge measurements for specific fractions were unavailable, introducing a margin of estimation error.
- **Scale-Specific Findings:** The findings are tailored to the specific context of Tier-II and Tier-III Nagar Parishads in coastal Maharashtra and may not be universally applicable to metropolitan municipal corporations with different organizational structures and waste volumes.

10.2 Future Scope:

Future research can examine:

- Economic and technical studies on waste-to-energy and small-scale biogas solutions for coastal regions.
- Environmental Impact Assessments (EIA) of coastal leachate pollution of local groundwater and water sources.
- Integration of the informal waste-picker economy with municipal Material Recovery Facilities (MRFs).

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