WASTE MANAGEMENT: A FRAMEWORK FOR INTERVENTION

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by

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In the loving memory of our beloved cats Motula and Munni...

Certificate

This is to certify that the thesis entitled **"Waste Management: A Framework for Intervention"**, submitted by **Miss Kaveri Kala** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of the original, bonafide research work carried out by her under my supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree.

The results contained in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma to the best of our knowledge.

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(Kaveri Kala)

Abstract

Municipal Solid Waste Management (MSWM) is a complex system wherein a typical waste management process, and intervention includes segregation, collection, processing, and disposal. Moreover, waste management apparatus varies from region to region; therefore, site-specific data and analysis are often required to determine appropriate and region-relevant waste management strategies. The complexities of a waste management system in India are even further complicated due to the involvement of various participants in the decision-making process, such as the government, local municipalities, the informal sector, institutional experts, and on occasions, the general public. Citizens are one of the primary stakeholders and play an important role in the value chain before the waste is collected. At the same time, municipalities and the informal sector are equally important stakeholders, majorly responsible for the collection and processing of the waste.

Evidently, the waste management system in India encompasses multiple socio-economic and environmental facets. In a country as diverse as India, there is a need for heterogeneous, context-based, and evidence-driven policies that lead to efficient outcomes. It is important the policies thus designed should also focus on identifying the strengths of a country and leveraging them.

The currently practiced homogenous policy framework for waste management is indeed not working in favor of India. This can be illustrated by the World Bank data, according to which India generates the highest amount of waste worldwide, more than even China. As much as 77 percent of this waste is simply dumped in the open, with all its noxious fumes and toxins. And Delhi is one of the tops in the list of Indian cities with maximum waste generation. Therefore, Delhi has been chosen to demonstrate the need for contextual policies.

There is a clear need to limit the disturbing trend of waste generation and mitigate the consequences. This can only happen if we break the old systems of waste management and build new ones through context-based policy-making, such that we: 1) capture the perception of citizens belonging to different socio-economic categories while simultaneously designing waste management policies contingent on the type of residence, 2) devise ways to make both formal and informal system of waste management work in conjunction and 3) make currently existing waste collection system

more efficient. The work in the thesis caters to the three aspects (above mentioned) around which waste management policies should be designed.

Accordingly, the framework and models are developed for Delhi to yield interesting insights. This work suggests possible recommendations that can make waste management more efficient and thus, may enable shifting of policy framework from exclusivity to inclusivity.

Keywords: Municipal Solid Waste Management, Contextual Policy, Stakeholders in Waste Management, Data-driven Approaches, Citizen Engagement

सार

नगरपालिका ठोस कचरा प्रबंधन (एमएसडब्ल्यूएम) एक जटिल प्रणाली है जिसमें प्ररूपी कचरा प्रबंधन प्रक्रिया और हस्तक्षेप में पृथक्करण, संग्रह, प्रसंस्करण, और निपटान शामिल है। इसके अलावा, कचरा प्रबंधन उपकरण एक क्षेत्र से दूसरे क्षेत्र में भिन्न होता है; इसलिए, उचित और क्षेत्र-प्रासंगिक कचरा प्रबंधन रणनीतियों को निर्धारित करने के लिए अक्सर साइट-विशिष्ट डेटा और विश्लेषण की आवश्यकता होती है। भारत में कचरा प्रबंधन प्रणाली, निर्णय लेने की प्रक्रिया में विभिन्न प्रतिभागियों, जैसे सरकार, स्थानीय नगर पालिकाएं, अनौपचारिक क्षेत्र, संस्थागत विशेषज्ञों और कभी-कभी आम जनता, की भागीदारी के कारण और भी जटिल हो गई हैं। नागरिक प्राथमिक हितधारकों में से एक हैं और कचरा एकत्र करने से पहले मूल्य श्रृंखला में महत्वपूर्ण भूमिका निभाते हैं। साथ ही, नगर पालिकाएं और अनौपचारिक क्षेत्र समान रूप से महत्वपूर्ण हितधारक हैं, जो कचरे के संग्रह और प्रसंस्करण के लिए प्रमुख रूप से जिम्मेदार हैं।

जाहिर है, भारत में कचरा प्रबंधन प्रणाली में कई सामाजिक-आर्थिक और पर्यावरणीय पहलू शामिल हैं। भारत जैसे विविधतापूर्ण देश में, विविध, संदर्भ-आधारित और साक्ष्य-संचालित नीतियों की आवश्यकता है जो कुशल परिणाम प्रदान करें। यह महत्वपूर्ण है कि इस प्रकार तैयार की गई नीतियों का ध्यान इस देश की शक्तियों की पहचान करने और उनका लाभ उठाने पर भी होना चाहिए।

कचरा प्रबंधन के लिए वर्तमान में प्रचलित समरूप नीति ढांचा वास्तव में भारत के पक्ष में काम नहीं कर रहा है। इसे विश्व बैंक के आंकड़ों से स्पष्ट किया जा सकता है, जिसके अनुसार भारत दुनिया भर में सबसे अधिक मात्रा में कचरा उत्पन्न करता है, यहां तक कि चीन से भी अधिक। इस कचरे का 77 प्रतिशत हिस्सा अपने सभी हानिकारक धुएं और विषाक्त पदार्थों के साथ खुले में फेंक दिया जाता है। और दिल्ली सबसे अधिक कचरा उत्पन्न करने वाले भारतीय शहरों की सूची में शीर्ष पर है। इसलिए, प्रासंगिक नीतियों की आवश्यकता को प्रदर्शित करने के लिए दिल्ली को चुना गया है।

कचरा उत्पादन की चिंताजनक प्रवृत्ति को सीमित करने और परिणामों को कम करने की स्पष्ट आवश्यकता है। यह केवल तभी हो सकता है जब हम संदर्भ-आधारित नीति-निर्माण के माध्यम से कचरा प्रबंधन की पुरानी प्रणालियों को तोड़ें और नई प्रणालियों का निर्माण करें, जैसे कि हम: 1) कचरा प्रबंधन नीतियों को डिजाइन करते समय विभिन्न सामाजिक-आर्थिक श्रेणियों से संबंधित नागरिकों की धारणा को पकड़ें, 2) कचरा प्रबंधन की औपचारिक और अनौपचारिक दोनों प्रणालियों को एक साथ काम करने के तरीके ईजाद करें और 3) वर्तमान में मौजूद कचरा संग्रहण प्रणाली को और अधिक कुशल बनायें। थीसिस में काम तीन पहलुओं (ऊपर उल्लिखित) को पूरा करता है जिसके आसपास कचरा प्रबंधन नीतियों को डिजाइन किया जाना चाहिए।

तदनुसार, दिलचस्प अंतर्दृष्टि प्राप्त करने के लिए दिल्ली के लिए रूपरेखा और मॉडल विकसित किए गए हैं। यह कार्य संभावित सिफ़ारिशों का सुझाव देता है जो कचरा प्रबंधन को अधिक कुशल बना सकते हैं और इस प्रकार, नीति ढांचे को विशिष्टता से समावेशिता की ओर स्थानांतरित करने में सक्षम बना सकते हैं।

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Abbreviations

WM	**W**aste **M**anagement
MSW	**M**unicipal **S**olid **W**aste
SDMC	**S**outh **D**elhi **M**unicipal **C**orporation
WMCP	**W**aste **M**anagement **C**ommunication **P**olicy
SDG	**S**ustainable **D**evelopment**G**oal
UN	**U**nited **N**ations
CE	**C**ircular **E**conomy
IWMS	**I**nformal **W**aste **M**anagement **S**ystem
NCT	**N**ational **C**apital**T**erritory
SWMR	**S**olid **W**aste**M**anagement**R**ules
WCS	**W**aste **M**anagement**S**ystem
ORS	**O**pen **R**esidential **S**paces
LR	**L**ogistic **R**egression
BLR	**B**inomial **L**ogistic **R**egression
MLR	**M**ultinomial **L**ogistic **R**egression
TOPSIS	**T**echnique for **O**rder **P**erformance by **S**imilarilty to **I**deal **S**olution
GST	**G**oods and **S**ervices **T**ax
WTE	**W**aste**T**o **E**nergy
BHM	**B**oard of **H**ostel **M**anagement
EPA	**E**nvironment **P**rotection **A**ct
BAU	**B**usiness **A**s **U**sual
ULB	**U**rban **L**ocal **B**ody
MRF	**M**aterial **R**ecovery **F**acility
PPE	**P**ersonal **P**rotective **E**quipment
SC	**S**egregation **C**oefficient
ERC	**E**ase of **R**ecycling **C**oefficient

IRC	**I**nformal **R**ecycling **C**oefficient
MC	**M**otivation **C**oefficient
NEP	**N**ational **E**nvironment **P**olicy
NFP	**N**ational **F**orest **P**olicy
EPR	**E**xtended **P**roducer **R**esponsibility
SBA	**S**wachh **B**harat **A**bhiyan
NAPCC	**N**ational **A**ction **P**lan for **C**limate **C**hange
DS	**D**entralised **S**ystem
HW	**H**ousehold **W**aste
SES	**S**ocio **E**conomic **S**tatus
HEI	**H**igher **E**ducation **I**nstutute
HIG	**H**igh **I**ncome **G**roup
MIG	**M**iddle **I**ncome **G**roup
LIG	**L**ow **I**ncome **G**roup

Symbols

P	probability of the event
H_0	null Hypothesis
H_1	alternate Hypothsis
x_i	independent variables
Y	the specific variable/ intervention being analyzed
α	significance level
p	likelihood of an event under null hypothesis
I	set of the trucks at the garage (1,2,..., I)
G	set of depots (1,2,...,G)
N	set of collection points (1,2,. . . ,N)
L	set of landfill sites (G+N+1,. . . G+N+L)
i	vehicle index (i)
j, k	indices of nodes (j,k$\in G \cup N \cup L$)
m	index for the trip (m $\in M$)
g	index of the depots (g $\in G$)
l	index of the landfills (l $\in L$)
B	total number of trucks currently being used
M	maximum number of trips a truck can take (heuristics)
q_g	quantity of waste at depots
q_l	quantity of waste at landfills
q_k	quantity of waste at k^{th} collection point
$d_{j,k}$	distance between j^{th} and k^{th} collection point
$t_{j,k}$	travel time between j^{th} and k^{th} collection point
$F_{i,g}$	capacity of i^{th} truck from g^{th} depot
C_f	fixed cost of running a truck
C_v	variable cost of running per km

$T_{i,g}$ maximum shift time for i^{th} truck from g^{th} depot