Review Article

WM&R

Waste Management & Research
1–14

DOI: 10.1177/0734242X15607428
wmr.sagepub.com
SAGE

Development of performance indicators for municipal solid waste management (PIMS): A review

V Sanjeevi and P Shahabudeen

Abstract

The aim of this paper is to review papers on municipal solid waste management (SWM) systems, especially on performance indicators (PIs), and suggest practical methods to manage the same by administrators. Worldwide, about 4 billion metric tons of solid waste (SW) is generated annually; the management of SW across cities is increasingly getting more complex and the funds available for providing service to citizens are shrinking. Analysis of the non-technical research papers shows that focus areas on SW can be grouped into 18 types, one being PIs. Historically, PIs for municipal SWM (PIMS) commenced with the publication of guidelines by various government agencies, starting in 1969. This was followed by a few benchmarking studies, commencing in 1998, by various international institutions. Many published comparative studies also disseminated good practices across the cities. From the 1990s onwards, research work started defining PIMS. These initiatives by various researchers took multiple dimensions and are reviewed in this paper. In almost all studies, the PIMS is measured in terms of investment decisions, public acceptance levels, social participation and environmental needs. The multiple indicators are complex, however, and managers of cities need simple tools to use. To make it simple, five-factor PIs are arrived at, considering simplicity and covering all the factors. A research agenda is outlined for future directions in the areas of cost reduction, citizens' services, citizen involvement and environmental impact.

Keywords

Review, performance indicators, municipal solid waste, effective and efficient resources use, measurement practices

Introduction

The management issues relating to solid waste (SW) all over the world are going up day by day due to unplanned urbanization. According to Katkar (2012), the urban population in India will go up from 300 million in 2001 to 395 million in 2011. The trend is almost the same in all developing countries. According to a World Bank report (2009), more than 70% of the global gross domestic product (GDP) comes from cities. Worldwide, about 4 billion metric tons of municipal SW (MSW) is generated (UNEP, 2013) and US$410 billion is spent on the collection of SW to recycling. However, the estimates by Kawai and Tasaki (2015) show that 1.3 billion metric tons of MSW are generated worldwide every year. The SW a year in India is likely to reach 260 billion kilograms by 2047, which is more than five times the current level (Swaminathan et al., 2007). With shrinking budgets for various city managements across the world, the mission is to increase the collection of waste with the lowest cost (Rogoff et al., 2010). Currently, most SW management (SWM) is carried out using open-cycle waste management systems, instead of closed-cycle systems (Zia and Devadas, 2008).

SW contaminates the ground as well as surface water and increases air pollutants, leading to miserable living conditions for people. The Society of Solid Waste Management Experts in Asia and Pacific Islands (SWAPI) started in 2005 compiling a series of articles covering the SWM aspects of 14 countries and published a book titled *Municipal Solid Waste Management (MSWM) in Asia and Pacific Islands – Challenges and Strategic Solutions* (Pariatamby and Tanaka, 2013). The case studies focus on reduction, reuse and recycling (3Rs). There is an urgent need to look into the issues of SWM and improve the ability of city leaders to manage with shrinking budgetary support. One of the prerequisites for better management is the ability to identify and measure performance of various operating elements. Performance indicators (PIs) are measurement tools used by organizations to evaluate the success or failure of a given activity. It is vital to choose the right PIs before applying the same. Periodic assessments of PIs lead to identification of the improvements needed in the system. PIs guide the operating and managerial personnel on what needs to be done. According to Parmenter (2007), one of the

Department of Industrial Engineering, College of Engineering, Anna University, Sardar Patel Road, Guindy, Chennai 600025, India

Corresponding author:
V Sanjeevi, Research Scholar, Department of Industrial Engineering, College of Engineering, Anna University, Sardar Patel Road, Guindy, Chennai-600025, India.
Email: sanju0207@gmail.com

largest airways in Europe was turned around in the 1980s with just one PI – timely arrival and departure of airplanes.

While research is being carried out extensively to improve SWM, not much work is being done to identify the PIs to help improve the capability of city managers in monitoring. Here, the case studies carried out across the world are compiled by the authors, and specifically reviewed for any developments in the area of PIs for municipal SWM (PIMS). This helps the authors suggest simple PIs, covering all the essential areas of municipal SWM (MSWM).

Taxonomy of research papers on solid waste management

The SWM models were classified by the European Environmental Authority (EEA) in the Environmental and Developmental Conference organized by the United Nations, in Rio (UNCED, 1992). The UN conference classified the SWM models into two groups: (1) the models relating to minimization of waste generation and (2) the resources needed to manage waste. The SWM models were also classified by MacDonald (1996) and were divided into nine types, such as forecasting, facility site location, capacity expansion, operation-based models, vehicle routing, manpower assignment, system scheduling etc.

Bojrkluand and Bjuggren (1998) did pioneering work in introducing factors such as environmental performance, in addition to mathematical models such as static models, dynamic models, simulation models, optimization models and multi-criteria optimization models, together with geographical information systems (GIS), scenario comparisons and input–output analysis. The initial SWM models were optimization models and most dealt with minimizing costs (Berger et al., 1999). There were developments of new models by researchers such as Gottingger (1991) and Huang et al. (1994). As per Abou Najm et al (2002) and Abou Najm and El-Fadel (2004), with increasing complexity in SWM in the cities of the developing world, selection or setting up of an optimum SWM system becomes difficult for technical and operation research professionals. This led to the use of various mathematical models and systems analysis techniques to develop integrated solid wastes management systems. Bhat (1996) focused on allocation of trucks in the handling of MSW using simulation models. Most of the research work in the area of SWM may also be classified under two major divisions, one dealing with Environmental Sciences related subjects such as recycling, repeocessing, handling of hazardous wates, composting, land fill technologies, energy recovery etc., and the other dealing with the application of general management techniques such as operations research, supply chain systems, transport systems, regulations by government agencies, productivity tools etc. By focussing on the second division, the research papers are grouped under various types, as shown in the flowchart in Figure 1. The flowchart makes it easier to understand the nature of SWM systems, conceived by several researchers using various tools and technologies for decision making in modern city contexts.

For this work, 387 research papers, published in the area of SWM covering most journals, were first compiled in chronological order. The increasing awareness among citizens, scientists and world leaders across the world is one of the factors leading to more and more research papers being published year after year. This probably indicates an increase in seriousness and concern for research in the area of SWM. Of course, the digital revolution is another major factor for the growth in research work. After analysing all the available research papers, the authors grouped the papers for each decade under the 18 different types as shown in Table 1.

All 18 types can be grouped as detailed below:

- Cost reduction studies using operations research methods and mathematical algorithms;
- Optimization/simulation studies to improve operational efficiency;
- Reports and legislations by various government agencies, decision support systems and characteristics of SW in various cities;
- PIMS; and
- Productivity improvement studies through adoption of modern technological tools such as GIS and radio frequency identification tags (RFID) (Karadimas et al., 2007).

The other inferences are:

- Cost reduction models, mainly using operations research techniques, accounting for almost 50% of the studies from the 1990s.
- Government guidelines and legislations – over the years, these played a major role in outlining the need for standards in MSW. Interest shifted to general management/decision support analysis/decision support systems and information relating to characteristics of SW in various municipalities across the world.
- Research focusing on the introduction of GIS, RFID, barcodes and their implications in improving SWM, which started to appear only since 2000, in synchronization with the commercial arrival of these technologies.
- Stand-alone Performance Monitoring Models, which started appearing in the 1990s. Their share in the total number of research papers almost doubled in the 2000s.

Of the 387 papers, 59 involved case studies, covering various cities across the world. The continent-wise, country-wise details of the case studies are given in Table 2. A glimpse of the contents of the case studies showed that they covered 46 cities across 30 countries. More and more studies were done in emerging cities, mainly in Asia. The authors conclude, from Table 2, that more research works are being carried out, mainly in Asia where new cities emerge. Most studies focused on determining the characteristics of SW, a few on applications of optimization techniques, some on cost reduction exercises and a few on PIMS. The list of the case study-based research papers considered for this study is given in Appendix A.

Building blocks of performance indicators

Analysis of the research papers shows that application of PIs in the area of MSWM has evolved over the last five decades. Added to this, the current research on MSWM in the Chennai

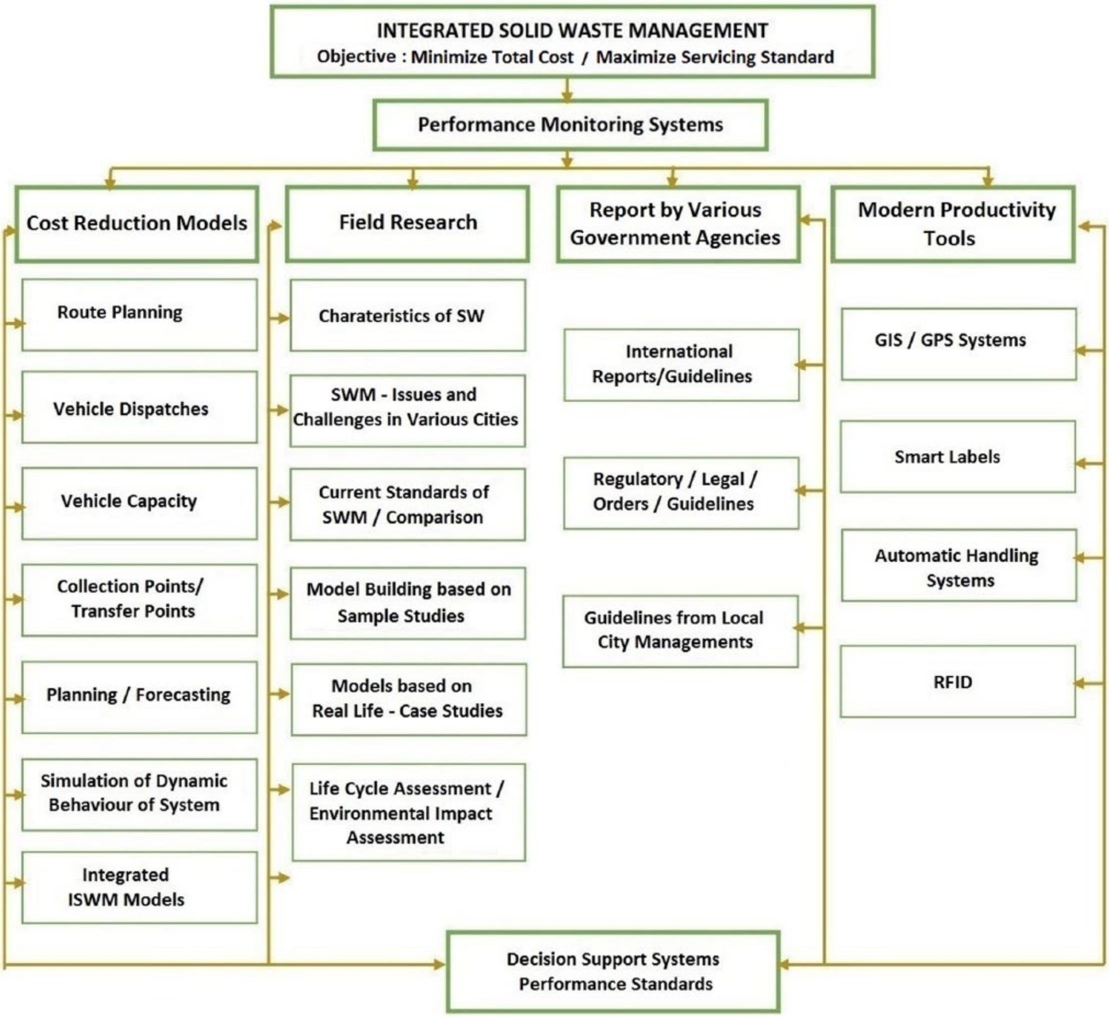

Figure 1. Research work integrated solid waste management (ISWM). GIS, geographical information system; GPS, global positioning system; RFID, radio frequency identification tag.

Metropolitan Area (CMA) by the authors has brought out the need to analyse and develop the PIs. The main building blocks for the development of PIMS may be summarized as follows:

(1) Efforts by various Government agencies in issuing guidelines and bringing out legislations;
(2) Benchmarking SWM practices across cities by researchers, government bodies and funding agencies; and
(3) Development of PI by researchers.

City leaders across the world realized the need of maintaining the environment in the 1960s and sensitized society by enacting legislations (Washington DC State Legislature, 1969). Many cities in the USA and Europe followed the Washington legislation and enacted guidelines or laws to manage city SW in the late 1970s. In the case of India, a report sponsored by the Supreme Court of India (1999) suggested steps to be initiated for the management of SW by central, state governments and local city managements. The World Bank has also initiated consultancy studies across the world since 1984, to provide the impetus to look at the MSWM scientifically in various countries. This resulted in the publication of *Refuse Collection Vehicles for Developing Countries* in 1989 (UNCHS, 1989). Since then, various government-supported studies have been initiated and guidelines were issued regularly. Various international agencies, such as the United Nations Human Settlement Program (UN-HABITAT), United Nations Conference on Environment and Development [UNCED], United Nations Center for Human Settlements (UNCHS), United Nations Environment Program (UNEP), World Bank, European Union, European Environmental Authority, 3R forum for Asia and Pacific Islands Under United Nations Centre for Regional Development etc. are involved in an organized way to propagate the need for cooperative practices and benchmarking of good practices in MSWM. A committee appointed by the UN-HABITAT published a number of reports including a detailed report on MSWM in 2010. This 2010 report brings out the importance of SW services in cities. Managing SW is one of the most costly urban services, typically absorbing 20–40% of municipal revenues in developing countries. With the growth of urban areas, almost all countries across the world have taken legislative measures. Various government agencies and legislatures played a major role in bringing in some basic discipline in MSWM.

The list, consisting of select publications and legislations brought out by various government and multilateral agencies, is given in Table 3.

Table 1. Decade-wise and category-wise publication of research papers.

Taxonomy of articles in solid waste management (SWM)								
Focus area		Period (years)						
		60–69	70–79	80–89	90–99	2000–09	2010–13	Total
1.0	Cost reduction							
1.1	Route improvement/optimization	4	4	6	16	45	3	78
1.2	Forecasting/planning			2	1	1	1	5
1.3	Collection crew estimation				2			2
1.4	Location/collection: bins/area solid waste			2		2	3	7
1.5	Location of transfer stations		1	2		1	1	5
1.6	Models in SW management		5	1	19	5		30
1.7	Truck allocation/dispatches/scheduling				5	1		6
2.0	Simulation/optimization							
2.1	Simulation				8	5	3	16
2.2	Optimization			1	5	8	5	19
3.0	Government regulations, decision support systems, characteristics							
3.1	Decision analysis/support systems		5		2	3		10
3.2	Status/characteristics/issues/challenges			3	12	15	9	39
3.3	General management of SWM				17	66	25	108
3.4	Report by government agencies/legislations			3	5	10		18
4.0	Performance indicators							
4.1	Performance indicators for municipal solid waste management (MSWM)				3	5	6	14
5.0	New technology							
5.1	Geographical information system (GIS)					12	6	18
5.2	Smart labels bar-code					1		1
5.3	Radio frequency identification tag (RFID)					6	3	9
5.4	Others					2		2
Total		4	15	20	95	188	65	387

Table 2. Details of case study research papers by continents and countries.

Continents (countries covered, total papers, cities covered)	Countries (number of research papers, number of cities covered)
Asia (13, 31, 21)	Bangladesh (1, 1), Bahrain (1, 1), China (3, 3), Honk Kong (1, 1), India (16, 7), Iran (1, 1), Philippines (1, 1), Palestine (1, 1), Singapore (1, 1), Taiwan (2, 1), Vietnam (1, 1), Russia (1, 1), Indonesia(1, 1)
Africa (4, 4, 4)	Tanzania (1, 1), Nigeria (1, 1), Morocco (1, 1), Liberia (1, 1)
Americas (4, 10, 9)	United States (6, 6), Mexico (1, 1), Canada (2, 1), Argentina (1, 1)
Europe (8, 13, 11)	Turkey (4, 3), United Kingdom (1, 1), Germany (1, 1), Belgium (1, 1), Greece (2, 2), Croatia (2, 1), Serbia (1, 1), Italy (1, 1)
Australia (1, 1, 1)	New Zealand (1, 1)
Total	(30, 59, 46)

As can be seen from the content column of Table 3, various government agencies guided city managers to arrive at policy changes, set up norms based on benchmarking studies and improved awareness levels in SWM. The data collated from benchmarking exercises has probably become the guiding information for building the PIs for MSWM.

The second building block in the introduction of PIs is that of the studies undertaken by researchers to determine the characteristics of SW and benchmarking the practices across cities. According to Berthier (2003), human societies may be evaluated by studying the characteristics of SW generated by them and how they manage the same. Bruvoll (2001) studied the relationship between income groups and population density with waste handling and generation practices. Bandara et al. (2007) established the relationship between socio-economic factors and waste generation. The good practices in a few cities became disseminated through various benchmarking details carried out across of the world. A few of the basic and important benchmarking studies are given in Table 4.

Table 3. Select publications by government agencies.

Authors/organization	Year	Title	Content
Washington DC State Legislature	1969	Solid Waste Management Act	Made the local government responsible for SWM
United States Environmental Protection Agency (USEPA)	1976	Resource Conservation and Recovery Act	Each state need to prepare plan for SWM
Hoy and Robinson	1979	Recovering the past: a hand book of community recycling programs	Traces the history of garbage management from 1840 to 1945 in USA
World Bank – Water Sanitation Program and Ministry of Urban Development (MOUD), New Delhi	1993	Community based solid waste management – Project preparation, Panaji case study	Template for detailed project report for a city based on Panaji experience
National Environmental Engineering Research Institute (NEERI), Nagpur, India	1995	Strategy paper on SWM in India	Outlines steps for SWM in India
Coffey	1996	Guidelines for solid waste management for developing countries	Outlines the policies, procedures, systems needed for improvement in the management of SW
United States Environmental Protection Agency (USEPA)	1997	WRAP: a model for solid waste management planning user's guide :a handbook	Provides detailed costing for SWM
World Bank	1997	Per capita solid waste management in developed countries	Per capita solid waste generation in developed nations
Supreme Court of India	1999	Report of the Supreme Court Appointed Committee on solid waste management in class I cities in India	Brought out the steps to be initiated by central, state governments and local city managements
World Bank	1999	What a waste: solid waste management in Asia	Solid waste management in various Asian countries
Central Pollution Control Board, Ministry of Environment and Forests, New Delhi, India	2000	Status of municipal solid waste generation, collection treatment, and disposal in class I cities	Details of SWIM in 27 cities of India – Basic requirements for selection of landfills
MOUD, New Delhi	2005	Management of solid waste in Indian cities	Criteria for solution of appropriate technology for SWIM – suggests composting schemes
Weaver	2005	Innovation in municipal solid waste management in England: policy, practice and sustainability	Compare SW management practices in England and brings out the difficulties in policy guided sustainability
National Environmental Engineering Research Institute (NEERI), Nagpur, India	2005	Study on the composition and per capita generation of waste in India	Survey carried out in 54 cities in India during 2004 and 2005
Asnani	2006	Solid waste management report. India infrastructure report	Facilities available in various cities of India for SWM
International Bank for Reconstruction and Development (IBRD), World Bank	2008	Improving municipal solid waste management in India	Suggestions on policy changes for improved SWIM, source book for policy makers and practitioners
United Nations Human Settlements Program (UN-HABITAT), compiled by Wilson et al.	2010	Collection of municipal solid waste in developing countries	Bench marking and disseminating information across the world
UN-HABITAT	2010	Comparing solid waste management in the world's cities	Bench marking study across 20 cities of various countries

SWM, solid waste management.

Most of the studies listed in Table 4 compared the basic parameters of SWM across cities, mainly in Asia and Europe. These studies focused only on disseminating the parameters of SWM across cities but did not focus on development of PIs for measuring the effectiveness of SWM. However, these studies helped increase the awareness level of city managements, thereby fulfilling the main objective of benchmarking.

Performance indicators for municipal solid waste management

Of the 387 research papers on SWM taken for this study, only 14 discussed the performance measurements and monitoring systems. Historically, researchers in MSWM focused on cost-reduction systems using operations research techniques,

Table 4. Select publications on municipal solid waste management: comparisons across cities.

Author	Year	Title	Content
NEERI	1995	Solid waste management	Incorporates the waste generated per day in 27 cities, India
Chung and Poon	1998	A comparison of waste management in Guangzhou and Hong Kong	Comparison between two cities of China
Zurbrügg	2002	Urban solid waste management in low-income countries of Asia, How to cope with the garbage crisis?	Analyses the elements of Asian SWM systems
Visvanathan and Glawe	2006	Domestic solid waste management in South Asian countries – a comparative analysis	Covers the perceptive SW composition, collection, transport systems
Rodic and Wilson	2010	Comparing solid waste management in the world's cities	Comparison of waste policy in 20 cities across the world
Contreras et al.	2010	Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston	Issue driven analytical framework for managing SW in both the cities
Pires et al.	2011	Solid waste management in European countries – a review of system analysis	SWIM is being carried out in many countries, 31 European countries
Wilson	2012	Comparative analysis of solid waste management in cities around the world	Progress achieved, governance features etc.
Ong and Sovacool	2012	A comparative study of littering and waste in Singapore and Japan	Comparison between two cities Singapore and Yokohama, Japan
Kaushal et al.	2012	Municipal solid waste management in India – current state and future challenges: a review	Comparison of major Indian cities on SWIM
Hotta and Aoki-Suzuki	2014	Waste reduction and recycling initiatives in Japanese cities: lessons from Yokohama and Kamakura	Factors for the success of waste reduction and recycling are identified

SWM, solid waste management.

decision support systems etc. However, many international organizations and government departments have taken the initiative to propagate the importance of monitoring systems, as they became answerable to their citizens. Based on these studies, many municipalities across various countries issued guidelines for SWM performance requirements. The member countries of the EEA (1998), at the conference held at Copenhagen, brought out the statistics on waste generated in 14 European countries. The EEA (2003) and Arendse and Godfrey (2010) of the UNEP published the waste management indicators in select cities. The reports mainly compared the composition and characteristics of SW, methodologies used for collection, transportation and disposal/recycling, and public–private partnerships in the programmes.

The authors feel that while research fanned out in a number of directions in benchmarking SWM practices (World Bank, 1999), very little work was actually done in the area of PIs. In fact, as more and more funds were allocated for managing the SW in a city, it became vital to measure the efficiency and effectiveness of the efforts put in for improving SWM productivity and reducing costs while concurrently improving customer-servicing standards.

Keeping these facts in view, Ristic (2005) analysed the need for SWM indicators for bringing improvement in city SWM. According to Ristic, if there was one field that needed PI in environmental management, it was that of the SWM. He said that PIs were needed to achieve improved results in SWM. The indicators covered the basic ones with comparison between policy issues and assessment in areas such as waste generation and landfilling. The Japan International Cooperation Agency (JICA) (2005) is one of the first to introduce software components in addition to equipment while funding for SWM works in developing countries.

PIMS were specifically highlighted in the model developed for monitoring and improving waste management practices in Ireland by Desmond (2006). According to the analysis of Desmond, the intended objective of sustainability of SWM may not be fully achieved without indicators. To assess the level of achievements, various global trends suggest the setting of objectives and measuring them periodically. Keeping this in view, she made use of the EEA data for 30 countries and listed 13 indicators for waste management that needed to be monitored. All the indicators enumerated by Desmond are given in Table 5.

They were used as indicators of the current status rather than of the performance improvement and were carried out once in a while when the Strategic Environmental Assessment Directives required them of the member European Union countries. Their focus was mainly on sustainability. There were additions and

Table 5. Performance indicators for municipal solid waste management (Desmond, 2006).

Theme	Indicator
Environment	Municipal wastes generated – kilograms per household per year
	Total tonnage of municipal waste recycled, composed and land-filled in percentages
	Avoided emissions to air and water due to waste management facilities
	Un-authorized waste activities
Economic	Cost of municipal wastes disposal per metric ton
	Net cost of operating and maintaining recycling facilities
Social	Public acceptance of waste management plans and actions
	Public participation in planning and implementation
Administration	Availability of separate collection of dry recyclables/bio-wastes/residuals
	Percentage of population served by kerbside collection of recyclables

Source: Desmond (2006).

deletions by various researchers, depending on the target groups and the purpose of the indicators. Based on six case studies, an exhaustive one prepared by Chariotte, Plano, and Waco for the Solid Waste Association of North America (SWANA, 1995) listed about 100 data items leading to more than 20 performance and efficiency indicators. SWANA analysed various trends and technologies based on the six case studies in the USA, and listed the PIMS and suggested ways and means to reduce resources requirements. The indices were exhaustive covering the entire gamut of collection, transportation, disposal and cost elements.

Viatcheslav et al. (2010) developed a general model to help the decision makers with information support tools, incorporating the economic and ecological benefits through a waste management efficient decision model (WAMED). The system involved capital investment analysis and only analysed various waste management models. The models mainly suggested alternatives based on the entire life cycle, ecological and economic viability. What was needed of the PIs was to guide the management on a day-to-day basis and the need for improved performance through indicators and provide a direction for supervision.

Boston Public Works (2010) prepared a one-page quarterly report on the SW collected from each household in Boston and the percentage of waste that was recycled. Armijo et al. (2011) attempted to develop a tool to measure the performance of SWM systems and used data from a case study in Mexico. All 18 indicators listed by them in their work are given in Table 6.

Armijo et al. (2011) incorporated key requirements such as social participation, social perception and communication levels like those of the PIMS for the first time. They designed a driving-force-pressure-state-impact-response (DPSIR) model, involving 18 indicators such as coverage, generation, composition and efficiency. They also suggested that a user-friendly tool, which captured the complexity of the SWM, be developed. Although the performance criteria were detailed, indicators such as the percentage of citizens in favour of recycling and those complying with the government regulations might not be required from the PI's point of view.

On similar lines to the Mexico study, Tseng (2011) reemphasized the need for performance evaluation systems and developed a performance analysis system using case study data from Taipei, Taiwan. He used 33 criteria and identified dependence relations between four aspects, namely human development, social, economic and sustainable development, using an analytical network process (ANP). Simoes et al. (2012) used non-parametric techniques to evaluate the performance of 196 refuse collection services in Portugal, using many macro-level indicators such as gross domestic product and population density. This analysis, however, did not focus on the micro- and macro-level periodic management. There are a few studies on SW material recycling to achieve reduction in greenhouse gases (GHG). The notable ones are by Menikpura et al.(2013a), outlining that material recycling offered the maximum reduction in GHG emissions from a life cycle point of view and also recording that landfilling is the most cost-effective system applied throughout the world (Menikpura et al., 2013b). Menikpura suggested low cost options for integrated SWM and used life cycle assessment for estimating the net GHG. These chemical technology-based indicators are important for the society, but do not strictly fall into the scope of PIs. All these parameters or indicators would be meaningful for measuring the environmental impact of MSWM. Zaman and Lehmann (2013) developed a zero waste index, which focused on using processes to avoid and eliminate waste, and to recover all resources from the waste stream. The recovery percentage merely calculated the recycling performance. The zero waste index was not merely the weight recovered but incorporated, and the energy that was consumed for producing the recovered items, say paper, glass and metal by including the energy substitution efficiency and reduction in emissions and water savings. The zero waste indexes of Adelaide, San Francisco and Stockholm were found to be 0.23, 0.51 and 0.17, respectively (i.e. around 23%, 51% and 17%) of resources that were recovered and potentially substituted for virgin materials. In addition, the zero waste index estimated the potential energy and the GHG due to resource recovery from municipal SW. The zero waste index was also an innovative tool to assess the waste management performance and material substitution by waste management systems in different cities. However, the index did not cover the social cost aspects of SWM, although it extensively covered the environmental aspects in the best possible way.

Table 6. Performance indicators for municipal solid waste management.

Criteria	Indicator
Operation cost	Average cost per metric ton ($/metric ton)
Social perception	% of persons not satisfied with the waste management system
Handling	% of recoverable material collected
	% of waste collected to the waste generated
Quality	Average qualification to the WM system and collection service
Final disposal	Comply with government regulation
Resources	Coverage of the collection service
Social Participation	% of homes that separate waste (of the total number of homes)
	% of the population eager to participate in the separation of waste
	% of comments in favour of recycling
Financial	Financial autonomy
Recovery and Treatment	% of recyclable waste recovered
	Total metric tons recovered compared with the total generated (%)
Communication	Percentage of persons having knowledge about SWM program
Composition	Composition of waste collected (% each category)

Source: Armijo et al. (2011). SWM, solid waste management.

SWAPI focused on the 3Rs to ensure a resource efficient society and a green economy in the Asia-Pacific regions part of the Ha Noi 3R Declaration: Sustainable 3R Goals for Asia and the Pacific for 2013–2023 (2013). The Ha Noi declaration suggested an exhaustive list of 105 indicators for monitoring SWM in the 14 member countries. The Fifth 3R Forum that met at Surbaya in 2014 suggested a key set of nine indicators (Pariatamby and Hotta, 2014) such as total MSW generated and disposed, per capita generation of MSW, overall recycling rate etc.

Teixeira et al. (2014) developed a scientific way for the measurement of PI for each SW collection route using statistical analysis, with data collated for the city of Oporto in Portugal. The three parameters of PIs were: the effective collection distance, the effective collection time and the effective fuel consumption. Their recommendations were more scientific. While scientific studies were more accurate and good, the same needed to be simplified for practical management use. The practitioners looked for simple and easy-to-use indicators, which were self-explanatory to the wide range of people involved in the work. This particular paper took into account the topography of the site and the vehicles in use. As the topography changed from city to city, it would be more complex to use the PIs as benchmarking for different cities for the measure of SWM performance.

The territorial conditions of respective sites played a major role in assessing the PIMS. Passarini et al. (2011) brought out this point in a focused way. The efficiency of waste collection not only depended on managerial capabilities but also on the varying economic, cultural and social conditions of the particular territory. Passarini et al. (2011), based on a case study in Italy, concluded that municipalities having a population density of 150–500 inhabitants per km^2 can easily achieve high efficiency and performance.

The development of PIs over the years is tabulated in chronological order and the same is given in Table 7.

The authors of this paper believe that more and more studies will emerge on performance monitoring systems, relating to SWM in the years to come, on account of increasing social accountability in the management of cities.

Discussion of results

PIs involve measuring the accomplishment of a given task against preset known standards of accuracy, cost and completeness. Fundamentally, the PIs need to involve the needs of all the key players of the MSWM. The key players need to be clear about the ultimate objective of MSWM. The key players in MSWM are the citizens of the city, the city administrators and the environmental needs. The ultimate needs or objectives for each of the key players are different and the same are listed in Table 8. The needs are then divided into activities of measurable form leading to PIs. The current standards prevalent in CMA are worked out by authors to provide the status.

The five PIs as given in Table 8 consist of two financial, two social and one environmental indicator. The financial PIs may be used for optimization of costs, the social indicators for improved communication with citizens and the environmental PI for improving the eco system of the municipality. For the essential needs of cost reduction, improved customer service requirements, pressure on the leaders and city managers to creating a good impression, and to make citizens responsible for waste management and environmental issues, the PI above are sufficient.

Based on the research papers reviewed above, the building blocks of PIs for MSWM and the authors' empirical experiences, it is suggested that the following *key performance indicators* capture all essential parameters that need to be monitored in a simplified way.

- *Collection cost (CC)* – cost incurred for collection from generating points, that is, mainly households, parks as cost per metric ton.
- *Transportation cost (TC)* – cost incurred for transporting SW from generating nodes to sink nodes, cost per metric ton (to dumping yards, recycling point).

Table 7. The development trail of performance indicators for municipal solid waste management.

Author	Year	Study area	No. of indicators	Theme
European Environmental Authority (EEA)	1998	14 countries in Europe	Comparison of basic statistics	Benchmarking of data across countries; general guideline for cost reduction
European Environmental Authority (EEA)	2003	9 European countries	Comparison of discharges	Recycling percentage, waste generation etc.
Ristic	2005	Compared 14 European countries	4	Environmental Indicator
Desmond	2006	Ireland-compared with 30 countries	12	Environment, Economic, Social and Administrative
Viatcheslav	2010	Sweden	28	Model for life cycle, ecological economics
Boston Public Works	2010	Boston, USA	3	Used by Mayor of Boston as MIS
Armijo	2011	Mexico	18	Cost, communication to citizens, Disposal, composition of waste collected etc.
Tseng	2011	Taipei	33	Social, economic and Sustainable development aspects
Passarini et al	2011	Italy	Territorial enablers for performance improvement	Classification of territorial characteristics
Simoes	2012	Portugal	14	Evaluate the performances of 196 collection services.
Zaman	2013	San Francisco, Adelaide, Stockholm	1	Zero waste index
Teixeira et al.	2014	Opporto, Portugal	3	Method for measurement of performance indicators for each solid waste collection route.

Table 8. The building blocks of performance indicators for municipal solid waste management (SWM).

Key players	Ultimate need/objective	Performance indicators (PIs)	Current standards
Citizens of the city	Need to be satisfied with the SW handling by city management	1. Social Perception	As of now, no measurement except for the daily complaints.
	Separate wastes into recyclables, compostable and others	2. Social Participation	Only 8400 homes do segregation out of 2.1 million homes (0.4%)
City administrators	Reduce cost of managing SW	3. Collection/transportation cost of SW	These costs come to Indian Rupees (INR) 1513 per metric ton (73.2% of total SWM costs).
	Minimize number of complaints from citizens	4. Social Perception	About 154 complaints are received daily.
Environmental needs/ ecosystem needs	Move towards closed-loop system, or zero waste system	5. Environmental Impact	The SWs are dumped at Dumping Yards.

Source: Corporation of Chennai, analysis by the authors. SW, solid waste.

- *Social perception (SPC)* – percentage of citizens not satisfied with SW collection service (need to ascertain through a quarterly survey with simple questionnaire, designed according to local needs and may be a statistically significant sample to be obtained).
- *Social participation (SPP)* – calculate the percentage of homes that separate waste into recyclable, compostable and others. (This may be collected even on a daily basis by the garbage collectors and reported quarterly for policy changes in terms of incentives and penalties. Many cities such as London follow this, where the household/personnel who do not separate waste are compelled to dump the waste at their own cost in a faraway place.)
- *Environmental impact (EI)* – percentage of waste that is recycled.

As explained in Table 8, the current standards indicate that it is feasible to collect and analyse the required PIs on a periodic basis. Many studies presented in this paper such as the zero waste index etc. also support the feasibility of collecting the required PIs. However, clarity is needed in terms of the unit of measurement, the activities that are measured, the context in which the activities may be measured and the frequency for measurement. All these details are presented in Table 9.

The frequency of reporting and monitoring may be done every month/every quarter. This period of a quarter provides 90 management cycles for any change to stabilize and gives the right time limit for changes in the activities and supervisory management systems.

The proposed PIs are simple to arrive at, understand and initiate steps for corrective actions on a periodical basis by the city

Table 9. Key Performance Indicators with unit of measurement, activity, context and frequency.

Key performance indicators	Unit of measurement	Activity being measured	Context	Frequency of reporting
Collection cost	INR/metric ton of waste (total cost incurred/ total tonnage collected)	Cost incurred (man power, fuel, maintenance and apportionment of one-time cost etc.) for collecting solid waste from households, parks etc.	Define the population density, per capita solid waste generation	Monthly
Transportation cost	INR/metric ton of waste (total cost incurred/total tonnage transported)	Cost incurred (man power, fuel, maintenance and apportionment of one-time cost etc.) to transport solid waste from street bins to dumping yard (sink nodes)	The weighted average lead distance from bins to sink nodes (geography of the city), capacity of existing transport vehicles	Monthly
Social perception	Percentage (citizens satisfied with waste collection service/total citizens)	Satisfied citizens to be measured based on survey with statistically significant sample size	Finalize the current levels and study the trend	Quarterly
Social participation	Percentage (citizens doing waste separation/ Total citizens)	Number of homes that adopt waste separation at household level	Start with glass, paper, stationary, compostable and move on to other wastes	Quarterly
Environmental impact	Percentage (waste recycled/total waste)	Quantity of waste that is recycled	Start with glass, paper, stationary, compostable and move on to other wastes	Quarterly

INR, Indian currency in Rupees.

administrators. This will probably lead to more and more city managements implementing PIs similar to commercial organizations, which is the need of the hour.

The city leaders and managers need to agree on a target for each of the above factors and the improvements they are seeking. The trends are to be monitored on a periodical basis, to initiate corrective actions. Depending on the importance of each of the above five factors for the city, the city leaders can give weight to each factor and calculate the PI as one single index as well.

There is lack of research on the resident time of SW from generation point to sink or recycle point. This resident time is vital in emerging economies such as China and India, where the moisture content is more than 40% (Chang and Wang, 1996). At high moisture levels, the waste becomes spoilt, leading to various health issues. There is a need to incorporate the resident time of waste as one of the indicators of good SWM. The lower the indicator, the better the SWM. The potential risks to human health from MSW and from the airborne pollutants were studied and reported by Bridges et al. (2000).

A research agenda for the future

From the authors' current research on MSWM in the Chennai metropolitan area and from the reviews to build a backdrop for their case study, five indicators from social, economic, environmental, political and administrative/governance points of view would be ideal for any city and simple enough for execution and performance evaluation and monitoring of an integrated SWM system. The agenda for the future can be derived from the suggested PIs, such as, cost management, service to citizens, citizen involvement and environmental impact assessment. For each of the PIs, there are concerns due to increasing price for services, increasing citizens' needs, the cultural aspects of the community for segregation of waste etc. and the sustainability of the Earth. The authors suggest select approaches addressing each of the concerns and predict the likely outcomes. Table 10 summarizes the research agenda suggested for future studies on MSWM of any city in the world. The ultimate outcome of the agenda for research will be *environmental citizenship of the people of the cities* across the world, where their active participation is sought for MSWM in sustainable environmental behaviour. Environmental citizenship is concerned with the embodiment of a sense of responsibility and active participation in sustainable environmental behaviour. While much research has been done on the topic, this has focused on organizations (e.g. Hawthorne and Alabaster, 1999) rather than people. Hawthorne and Alabaster developed a model for environmental citizenship and tested it through a survey based on a public questionnaire.

Conclusions

Increasing SW has brought in pressure on researchers, academics and administrative systems of city management for improvements. Worldwide, 4 million metric tons of SW are generated

Table 10. A suggested research agenda for the future for municipal solid waste management in cities of the world.

Performance indicators	Research focus	Areas of concern	Methods/approaches	Outcomes
Cost Reduction	Reducing costs for solid waste transport and disposals	Increasing haul costs, transfer and disposal costs	Shortest-path algorithms, LP/ simulation models, scheduling techniques, GIS based optimization	A GIS solution for cost reduction, optimum network structure design, continuous improvements in cost reduction
Citizens' Services	Environmental citizenship as the dependent variable and demographic variables as the independent variables	Ever increasing citizens' needs and requirements	Questionnaire surveys, Environmental citizenship behaviour analysis	Improved satisfaction level of citizens
Citizen Involvement	Beliefs, attitudes and behaviour vis-à-vis SWM, community engagement, people's participation	Culture and tradition of community	Focus group, participatory planning and appraisals, participatory action research (PAR)	Strategies for improved community/citizens' engagement with environmental citizenship among the participants
Environmental Impact Assessment	Minimize consumption and reduce waste	Sustainability of Earth	Zero waste concept	Reduction in disposable waste

Source: Authors' researches and reviews. LP, linear programming; GIS, geographical information systems; SWM, solid waste management.

annually and this volume is increasing year after year. Analysis of research reported here shows that the research papers published went up by 12 times from the 1970s to the 2000s. The research work in the initial decades, say in the 1960s, focused on cost reduction models and slowly moved to decision support systems including guidelines and legislation by governments. Papers on PIs started to appear in the 1990s, but less than 4% of the total papers covered PIs and were cited by the authors. The studies on PIs started with the benchmarking studies carried out by international agencies such as the EEA, various wings of the United Nations, the World Bank, SWAPI, JICA etc. The success or failure of a given activity depends on how the PI is defined and monitored periodically for corrective action. The specific SWM PIs were highlighted in the model developed for monitoring and improving waste management practices in Ireland by Desmond (2006). She made use of the EEA data for 30 countries and listed 13 indicators for waste management that needed to be monitored. Others in recent years have developed tools to measure the performance of SWM systems and they used data from a case study in Mexico. The present authors reviewed research papers on performance monitoring systems and listed the trail of the PIs for MSW, moving from guidelines issued by government agencies to simple benchmarking to the development of PIs.

Any performance measurement system needs to fulfil the needs of key players. The key players in MSWM are the citizens of the city, city administrators and the environmental needs of society. The needs of each of the key player will vary but all need to be clear about the ultimate objective of MSWM. As seen in Table 8, the PIs were derived from the objective of each key player. These steps lead to five PIs, incorporating two financial, two social and one environmental indicator. This study reviewing the papers on the performance measurements and monitoring of MSW arrived at were: *collection cost*, *transportation cost*, *customer service*, *customer involvement* and *environmental impact*, as the vital ones. The city managements need to set objectives periodically for all five indicators and need to monitor the same for corrective action.

Further research needs to be done on the resident time of SW in cities and on the steps needed to reduce that time. A research agenda is outlined for future directions in the areas of cost reduction, citizens' services, citizen involvement and environmental impact.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The study was made possible by the active support of the Management and Engineers of the Corporation of Chennai and the facilities offered by the College of Engineering, Anna University Chennai, India.

References

Abeliotis K, Karaiskou K, Togia A and Lasardi K (2009) Decision support systems in solid waste management: a case study at the national and local level in Greece. *Global Nest* 11(2): 117–126.

Abou Najm M and El-Fadel M (2004) Computer-based interface for an integrated solid waste management optimization model. *Environmental Modeling and Software* 19: 1151–1164.

Abou Najm M, El-Fadel M, Ayoub G, El-Taha M and Al-Awar F (2002) An optimization model for regional integrated solid waste management. 1: Model formulation. *Waste Management and Research* 20: 37–45.

Agarwal A, Singhmar A, Kulshrestha M and Mittal AK (2005) Municipal solid waste recycling and associated markets in Delhi, India. *Resources, Conservation and Recycling* 44: 73–90.

Agha SR (2006) Optimizing routing of municipal solid waste collection vehicles in Deir El-Balah-Gaza Strip. *The Islamic University Journal (Series of Natural Studies and Engineering)* 14(2): 75–89.

Al Ansari M (2012) Municipal solid waste management systems in the Kingdom of Bahrain. *International Journal of Water Resources and Environmental Engineering* 4(5): 150–161.

Al-Khatib I, Monou M, Abu Zahra ASF, Shaheen HQ and Kassinos D (2010) Solid waste characterization, qualification and management practices in developing countries. A case study: Nablus district Palestine. *Journal of Environmental Management* 91(5): 1131–1138.

Apaydin O and Gonullu MT (2007) Route optimization for solid waste collection: Trabzon (Turkey) case study. *Global Nest* 9(1): 6–11.

Apaydin O and Gonullu MT (2008) Emission control with route optimization in solid waste collection process: a case study. *Sadhana* 33(2): 71–82.

Arendse I and Godfrey L (2010) *Waste management indicators for national state of environmental reporting*. United Nations Environment Programme (UNEP), Publications.

Armijo C, Puma A and Oieda S (2011) A set of indicators for waste management programs. In: *2nd International Conference on Environmental Engineering and Applications, IPCBEE*. Singapore: IACSIT Press, Volume 17, pp. 144–148.

Asnani PU (2004) *United States Asia Environmental Partnership Report*. Ahmedabad: United States Agency for International Development, Centre for Environmental Planning and Technology.

Asnani PU (2006) *Solid waste management*. India Infrastructure Report. New Delhi: Government of India Publications, pp. 160–189.

Bandara NJ, Hettiaratchi JP, Wirasinghe SC and Pilapiya S (2007) Relation of waste generation and composition of socio-economic factors: a case study. *Environmental Monitoring Assessment* 135(1–3): 31–39.

Baud ISA and Schenk H (1994) *Solid Waste Management: Modes, Assignments, Appraisals and Linkages in Bangalore*. New Delhi: Manohar Publishers.

Bautista J and Pereira J (2006) Modeling the problem of locating collection areas for urban waste management: an application to the metropolitan area of Barcelona. *Management Science* 34(6): 617–629.

Becker C, Hegemann M, Morstadt S and Striegel KH (2007) Automatic reporting based on a central database in north Rhine-Westphalia/Germany – first step: the digital waste disposal atlas 2007. *Proceedings of the Eleventh International Waste Management and Land Fill Symposium*, 1–5 October, Sardiana, Marghorita-di-Pula, Italy.

Berger C, Savard G and Wizere A (1999) EUGENE: an optimization model for integrated regional solid waste management planning. *International Journal of Environment and Pollution* 12(2/3): 280–307.

Berthier HC (2003) Garbage, work and society. *Resource Conservation and Recycling* 39(3): 193–210.

Bhat VN (1996) A model for optimal allocation of trucks for solid waste management. *Waste Management and Research* 14: 87–96.

Bojrkluand A and Bjuggren C (1998) Waste modelling using substance flow analysis and life cycle assessment. Paper 98-A431. In: *Proceedings of the Air and Waste Management Association's Annual Meeting*, 14–18 June, San Diego, CA.

Bonomo F, Duran G, Larumbe F and Marenco J (2012) A method of optimizing waste collection using mathematical programming: a Buenos Aires case study. *Waste Management and Research* 30(3): 311–324.

Boston Public Works (2010) *Performances report to mayor of Boston*. Boston, MA: Boston Municipal Office.

Bridges O, Bridges UJ and Potter JF (2000) A generic comparison of the airborne risks to human health from landfill and incinerator disposal of municipal solid waste. *The Environmentalist* 20: 325–334.

Bruvoll A (2001) Factors influence solid waste generation and management. *The Journal of Solid Waste Technology and Management* 27(3–4): 156–162.

Buenrostro O and Bocco G (2003) Solid waste management in municipalities in Mexico: goals and perspectives. *Resources Conservation and Recycling* 39(3): 251–263.

Carlic T (2006) *Improving of transport organization using heuristics methods* (Croatian). PhD thesis, University of Zagreb.

Central Pollution Control Board, Ministry of Environment and Forests (2000) *Status of Municipal Solid Waste Generation, Collection Treatment, and Disposal in Class I Cities*. New Delhi: Ministry of Environment and Forests.

Chaerul M, Tanaka M and Shekdar AV (2007) Municipal solid waste management in Indonesia: status and strategic actions. *Journal of the Faculty of Environmental Science and Technology* l2(I): 41–49.

Chi GF and Huang GH (1998) *Long-term planning of integrated solid waste management system under uncertainty*. Report submitted to the City of Regina, University of Regina, Saskatchewan, Canada.

Chung S and Poon C (1998) A comparison of waste management in Guangzhou and Hong Kong. *Resources, Conservation and Recycling* 22: 203–216.

Clark RM and Gillean JI (1975) Analysis of solid waste management operations in Cleveland, Ohio: a case study. *Interfaces* 6(1): 32–42.

Coffey M (1996) *Guidelines for Solid Waste Management for Developing Countries*. Nairobi: United Nations Center for Human Settlement (UNCHS).

Contreras F, Ishii S, Aramaki T, Hanaki K and Connors S (2010) Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston. *Waste Management & Research* 28: 76–93.

Desmond M (2006) Municipal solid waste management in Ireland: assessing for sustainability. *Irish Geography* 39(1): 22–23.

Dorigo M, Manniezzo V and Coloni A (1996) The ant system: optimization by a colony of corporation agents. *IEEE Transaction on Systems, Man and Cybernetics – Part B* 26: 29–41.

Erdelez A, Margeta J and Knezic S (2007) An integrated approach to municipal waste collection system management. *Gradevinar* 59(6): 505–516.

Esakku S (2006) *Assessment of reclamation and hazard potential of municipal solid waste dumpsites*. Doctoral thesis, Anna University, Chennai.

European Environment Agency (EEA) (1998) National strategies and local practices: MSW policy implementation by local government in the UK. In: *Proceedings of the advances in European Environmental Policy Conference*, September.

European Environment Agency (EEA) (2003) *Report net: Development of common tools and a shared information infrastructure for the European Environmental Information System*. Copenhagen: European Environment Agency.

Ghiani G, Guerriero F, Improta G and Musmannod R (2005) Waste collection in southern Italy: solution of a real-life arc routing problem. *International Transactions in Operations Research* 12(2): 135–144.

Gotoh S (1989) Issues and factors to be considered for improvement of solid waste management in Asian metropolises. *Regional Development Dialogue* 10(3): 1–12.

Gottinger HW (1991) *Economic Models and application of Solid Waste Management*. New York: Gordon and Breach Science Publishers.

Green Alliance edited by Ben Shah (2003) Waste Not, Want Not - A collection of responses to Collection of responses to Prime Minister's Strategy Unit, UK. Published April 2003, Green Alliance , 40 Buckingham Palace Road London.

Gupta S, Choudhary N and Alappat BJ (2007) Bioreactor landfill for MSW disposal in Delhi. In: *Proceedings of the International Conference on Sustainable Solid Waste Management*, Chennai, pp. 474–481.

Ha Noi 3R Declaration – Sustainable 3R Goals for Asia and the Pacific for 2013–2023 (2013) Fourth Regional Forum in Asia and the Pacific, 18–20 March, Ha Noi, Vietnam.

Hawthorne M and Alabaster T (1999) Citizen 2000: development of a model of environmental citizenship. *Global Environmental Change* 9: 25–43.

Hotta Y and Aoki-Suzuki C (2014) Waste reduction and recycling initiatives in Japanese cities: lessons from Yokohama and Kamakura. *Waste Management & Research* 32(9): 857–866.

Hoy SM and Robinson MC (1979). *Recovering the Past: A Handbook of Community Recycling Programs, 1890–1945*. Chicago, IL: Public Works Historical Society, pp. 1–24.

Huang GH, Baetz BW and Patry GG (1994) Grey dynamic programming for solid waste management programming under uncertainty. *Journal of Urban Planning and Development* 120: 132–156.

Huang GH, Yeomans JS and Yoogalingam R (2003) Combining simulation with evolutionary algorithms for optimal planning under uncertainty, an application to municipal solid waste management planning in the regional municipality of Hamilton-Wentworth. *Journal of Environmental Informatics* 2(1): 11–30.

International Bank for Reconstruction and Development (IBRD), World Bank (2008) *Improving Municipal Solid Waste Management in India*. Washington, DC: World Bank.

Jamshidi A, Taghizadeh F and Ata D (2011) Sustainable municipal solid waste management (case study: Sarab County, Iran). *Annals of Environmental Science* 5: 55–59.

Japan International Cooperation Agency: JICA (2005) *Supporting Capacity Development in Solid Waste Management in Developing Countries -Towards Improving Solid Waste Management Capacity of Entire Societies*. Tokyo: JICA publications (July 2005).

Kansal A (2002) Solid waste management strategies for India. *Indian Journal of Environmental Protection* 22(4): 444–448.

Karadimas NV, Papatzelou K and Loumos VG (2007) Optimal solid waste collection routes identified by the ant colony system algorithm. *Waste Management and Research* 25: 139–147.

Katkar A (2012) Improvement of solid waste collection by using optimization technique. *International Journal of Multidisciplinary Research* 2(4): 298–307.

Katpatal YB and Rama Rao BVS (2011) Urban spatial decision support system for municipal solid waste management of Nagpur urban area using high-resolution satellite data and geographic information system. *Journal of Urban Planning and Development* 137 (1): 65–76.

Kaushal RK, Varghese GK and Chabukdhara M (2012) Municipal solid waste management in India – current state and future challenges: a review. *International Journal of Engineering Science and Technology* 4(4): 1473–1489.

Kawai K and Tasaki T (2015) Revisiting estimates of municipal solid waste generation per capita and their reliability. *Journal of Material Cycles and Waste Management*, online first, February.

Kulcar T (1996) Optimizing solid waste collection in Brussels. *European Journal of Operations Research* 90: 71–76.

Kyessi AG (2009) *Tanzania GIS Application in Coordinating Solid Waste Collection: The Case of Sinza Neighbourhood in Kinondoni Municipality, Surveyors Key Role in Accelerated Development*. Dar es Salaam City, Tanzania, pp. 1–19.

Li YP and Huang GH (2006) An inexact two-stage mixed integer linear programming method for solid waste management in the City of Regina. *Journal of Environmental Management* 81: 188–209.

Lin MD, Wang C and Lin C (2006) Evaluation of solid waste management strategies in the Taipei metropolitan area of Taiwan. *Air and Waste Management* 56: 650–656.

MacDonald D (1996) Solid waste management models: a state of the art review. *Journal of Solid Waste Technology Management* 23(2): 73–83.

Makan A, Manamis D, Assobhei O, Loizidou M and Mountadar M (2011) Solid waste management: case of collection and vehicle routing problem in the city of Azemmour, Morocco. *International Journal of Management Science and Engineering Management* 6(4): 247–255.

Malviya R, Chaudhary R and Buddhi D (2002) Study on solid waste assessment and management – Indore city. *Indian Journal of Environmental Protection* 22(8): 841–846.

Markovic D, Janosevic D, Jovanovic M and Nikolic V (2010) Application method for optimization in solid waste management system in the city of Nis. *Mechanical Engineering* 8(1): 63–76.

Menikpura SNM, Sang-Arun J and Bengtsson M (2013a) Integrated solid waste management: an approach for enhancing climate co-benefits through resource recovery. *Journal of Cleaner Production* 58(1): 34–42.

Menikpura SNM, Sang-Arun J and Bengtsson M (2013b) Climate co-benefits of energy recovery from landfill gas in developing Asian cities: a case study in Bangkok. *Waste Management and Research* 31(10): 1002–1011.

Ministry of Urban development – MOUD Report (2005) *Management of Solid Waste in Indian Cities*. New Delhi: Ministry of Urban Development, Government of India.

Ministry of Urban Development (supported by World Bank) MOUD Report (1993) *Community Based Solid Waste Management – Project Preparation Panaji Case Study*. New Delhi: Ministry of Urban Development, Government of India.

Naresh Kumar K and Goel S (2009) Characterization of municipal solid waste and a proposed management plan for Kharagpur, West Bengal. *Resources, Conservation and Recycling* 53: 166–174.

National Environmental Engineering Research Institute (NEERI), Nagpur (1995) *Strategy Paper on Solid Waste in India*. New Delhi: Government of India Publications.

National Environmental Engineering Research Institute (NEERI), Nagpur (2005) *Study on Composition and Per Capita Generation of Waste*. New Delhi: Government of India Publications.

Nie Y, Li T, Yan G, Wang Y and Ma X (2004) An optimal model and its application for the management of municipal solid waste from regional small cities in Chin. *Air and Waste Management* 54: 191–199.

Ogwueleka TC (2009) Route optimization for solid waste collection: Onitsha (Nigeria) case study. *Journal of Applied Science and Management* 13(2): 37–42.

Ong BL and Sovacool BK (2012) A comparative study of littering and waste in Singapore and Japan. *Resources, Conservation and Recycling* 61: 35–40.

Or Ilhan and Curi Kriton (1993) Improving the efficiency of the solid waste collection system in İzmir, Turkey, through mathematical programming. *Waste Management and Research* 11(4): 297–311.

Ozeler D, Yetis U and Demirer GN (2006) Life cycle assessment of municipal solid waste management methods: Ankara case study. *Environmental International* 32(3): 405–411.

Pariatamby A and Hotta Y (2014) Suggested core set of 3R policy indicators. In: *Fifth Regional Forum in Asia and the Pacific*, 12–14 February, Surbaya, Indonesia.

Pariatamby A and Tanaka M (2013) *Municipal Solid Waste Management in Asia and Pacific Islands – Challenges and Strategic Solutions*. Singapore: Springer.

Parmenter D (2007) *Key Performance Indicators*. New York: John Wiley & Sons, pp. 3–4.

Passarini F, Vassura I, Monti F, Morselli L and Villani B (2011) Indicators of waste management efficiency related to different territorial conditions. *Waste Management* 31(4): 785–792.

Pires A, Martinho G and Chang NB (2011) Social waste management in European countries: a review of systems analysis techniques. *Journal of Environment Management* 92: 1033–1050.

Prime Minister's Strategy Unit

Rahman SH and Rahman S (2009) Urban solid waste management using GIS technique: a case study on Mohammadpur Thana at Dhaka of Bangladesh. In: *Proceedings of the International Conference on Solid Waste Management, Technical, Environmental and Socio-economical Contexts WasteSafe*, 9–10 November, Khulna, Bangladesh, pp. 239–248.

Read RO (1998) National strategies and local practices: MSW policy implementation by local government in the UK. In: *Proceedings of the advances in European Environmental Policy Conference*, September.

Ristic G (2005) Basic indicators of integrated solid waste management. *Working and Living Environmental Protection* 2(5): 383–392.

Rodic L and Wilson DC (2010) Comparing solid waste management in the world's cities. Based on *UN-HABITAT's Third Global report on water and sanitation in the World entries – 5th World Urban Forum*, 23 March, Rio, Brazil.

Rodionov M and Nakata T (2011) Design of an optimal waste utilization system: a case study in St. Petersburg, Russia. *Sustainability* 3: 1486–1509.

Rogoff MJ, Liluquist RE, Ross D and Wood JL (2010) Automated waste collection – how to make sure it makes sense for your community. In: *Proceedings of SWANA Waste Conference*, August.

Sharholy M, Ahmad K, Mahmood G and Trivedi RC (2005) Analysis of municipal solid waste management systems in Delhi, a review. In: *Proceedings for the Second International Congress of Chemistry and Environment*. Indore, India, pp. 773–777.

Sharholy M, Ahmad K, Mahmood G and Trivedi RC (2006) Development of predication model for municipal solid waste generation for Delhi city. In: *Proceedings of National Conference of Advanced of Mechanical Engineering (AIME-2006)*, Jamia Milla Islamia, New Delhi, pp. 1176–1186.

Shaw B (2003) *Waste not, want not - a collection of responses to Prime Minister's strategy unit*. London: Green Alliance.

Simoes P, Carvalho P and cunha Marques R (2012) Performance assessments of refuse collection services using robust efficiency measures. *Resources, Conservation and Recycling* 67: 56–66.

Singh SK and Singh RS (1998) A study on municipal solid waste and its management practices in Dhanbad-Jharia coal field. *Journal of Environment Protection* 18(2): 850–852.

Skordilis A (2004) Modelling of integrated solid waste management systems in an island. *Resources, Conservation and Recycling* 41: 243–254.
Solid Waste Association of North America (SWANA) prepared by Chariotte, Plano, and Waco (1995) *Getting More for Less: Improving Collection Efficiency by U.S. Environmental Protection Agency*.
Su JP, Chiueh PT, Hung ML and Ma HW (2007) Analyzing policy impact potential for municipal solid waste management decision-making: a case study of Taiwan. *Resources, Conservation and Recycling* 51: 418–434.
Sudhir V, Muraleedharan VR and Srinivasan G (1996) Integrated solid waste management in urban India: a critical operational research framework. *Socio-Economic Planning Science* 30: 163–181.
Sundberg J, Gipperth P and Wene CO (1994) A system approaches to municipal solid waste management: a pilot study of Goteborg. *Waste Management and Research* 12: 73–91.
Supreme Court of India (1999) *Report of the Supreme Court Appointed Committee on Solid Waste Management in Class 1 Cities in 'India'*. New Delhi: Supreme Court of India.
Swaminathan A, Essaku S, Parthiba Karthikeyan O, Kurian J and Palanivelu K (2007) Municipal solid waste management in Chennai City, India. In: *Eleventh International Waste Management and Landfill Symposium*, 1–5 October, Cagliari, Italy.
Teixeria CA, Avelino C, Ferraira F and Bentes I (2014) Statistical analysis in MSW collection performance assessment. *Waste Management* 34: 1584–159.
Thanh NP, Matsui Y, Ngan NVC, Trung NH, Vinh TQ and Yen NTH (2009) GIS application for estimating the current status and improvement on municipal solid waste collection and transport system: case study at Can Tho city, Vietnam. *Asian Journal of Energy and Environment* 10(2): 108–121.
Tseng ML (2009) Application of AHP and DEMATEL to evaluate the decision-making of municipal solid waste management in Metro Manila. *Environment Monitoring and Assessment* 156(1–4): 181–197.
United Nations Center for Human Settlements (UNCHS) (1989) *Refuse Collection Vehicles for Developing Countries*. Nairobi: UN Publications.
United Nations Conference on Environment and Development [UNCED] (1992), 2–14 June, Rio de Janeiro.
United Nations Environment Program (UNEP) (2013) Taking the pulse of the planet: connecting science with policy. UNEP *Global Environment Alert service (GEAS):* http://www.unep.org/geas.
United Nations Environment Program (UNEP) (2007) Assessment of solid waste management in Liberia. Working paper prepared by UNEP, Nairobi, Kenya, July 2007.
United Nations Human Settlement Program (UN-HABITAT) (2010). In Wilson DC, Rodic L, Scheinberg A and Alabaster G (compilers) *Collection of Municipal solid Waste in Developing Countries*: United Nations Publications. UN-HABITAT ISBN 978–92–1–132218–7.
United States Environmental Protection agency (USEPA) (1976) *Resource, Conservation and Recovery Act – 1976*. Washington DC.
United States Environmental Protection agency (USEPA) (1997) *WRAP: A Model for Solid Waste Management Planning User's Guide* (EPA/530/SW-574). US Environmental Protection Agency Ohio.
Viatcheslav M, Stenis J, Hogland W and Shepeleva A (2010) Solid waste management by application of the WAMED model. *Journal of Material Cycles and Waste Management* 12: 169–183.
Visvanathan C and Glawe U (2006) Domestic solid waste management in South Asian countries – a comparative analysis. Presented at *3R South Asia Expert Workshop*, 30 August–1 September, Kathmandu.
Ward JE and Wendell RE (1978) A million dollar annual savings from a transfer station analysis in Pittsburgh. In: *Proceedings of the Ninth Annual Pittsburgh Conference on Modeling and Simulation*, 9 April, Pittsburgh, PA, pp. 1305–1308.
Washington DC State Legislation (1969) Solid Waste Management Act – 1969.
Washington State Department (1979) *Solid waste management in Washington*. Twelfth Annual Status Report, Washington, USA.
Weaver PN (2005) Innovation in municipal solid waste management – England: policy, practice and sustainability development. *International Journal of Innovation and Sustainability Development* 3(1–2): 21–45.
Wilson DC (2012) Comparative analysis of solid waste management in 20 cities. *Waste Management and Research* 30(3): 237–254.
World Bank (1997) *Per Capita Solid Waste Generation in Developed Countries*. Washington, DC: World Bank.
World Bank (1999) *What a Waste: Solid Waste Management in Asia* Washington, DC: World Bank.
World Bank (2009) *World Development Report 2009: Reshaping Economic Geography*, Volume 1. Washington, DC: World Bank.
Xi BD, Su J, Huang GH, Qin XS, Jiang YH, Huo SL, Ji DF and Yao B (2010) An integrated optimization approach and multi-criteria decision analysis for supporting the waste management system of the city of Beijing, China. *Engineering Applications of Artificial Intelligence* 23: 620–631.
Zaman AU and Lehmann S (2013) The zero waste index: a performance measurement tool for waste management system in a zero waste city. *Journal of Cleaner Production* 50: 123–132.
Zia H and Devadas V (2008) Urban solid waste management in Kanpur: opportunities and perspectives. *Habitat International* 32: 58–73.
Zurbrügg C (2002) *Urban solid waste management in low-income countries of asia how to cope with the garbage crisis*. Presented for: Scientific Committee on Problems of the Environment (SCOPE) Urban Solid Waste Management Review Session, November, Durban, South Africa.