IIOAB JOURNAL
ISSN: 0976-3104

ARTICLE

EVALUATING PLASTIC WASTE DISPOSAL OPTIONS IN DELHI USING MULTI CRITERIA DECISION ANALYSIS

Saurav Bhagat*, Avdesh Bhardawaj, Piyush Mittal, Prateek Chandak, Mohammad Akhtar, Paaras Sharma

Department of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, INDIA

ABSTRACT

Continuous rise in the population of India has led to a steep increase in the amount of solid waste generated, particularly from urban areas which ultimately deteriorates soil and water due to unscientific disposal methods. Plastic forms an important constituent in the composition of the urban MSW because of its increasing use in our everyday lives and therefore requires the selection of a sustainable management option which is currently absent in the existing policy framework of India. This study uses the Multi Criteria decision analysis approach (MCDA) in order to evaluate different options for waste disposal for arriving at the most sustainable option for management and disposal of plastic waste in Delhi. A panel of nine members, who were faculty, researchers and students from the Indian Institute of Technology (IIT), Delhi was made and they evaluated seven disposal options against a set of environmental, health, financial and legislative criteria. The seven options included Landfill, Recycling, Incineration, Pyrolysis and a combination of two processes each from the first three mentioned in the study. The panel weighed the criteria and scored the options on them to arrive at an overall aggregate score for the best option. The study reveals that MCDA is a very effective and transparent measure of involving and encouraging public participation in decision making with highly successful results in the context of waste management. The panel suggested that a blend of recycling along with incineration was the best option which was followed by recycling and incineration. The worst method in the panel's consideration was the open landfilling currently practiced in Delhi which is a big source of soil contamination. The paper suggests that MCDA approach for evaluation of waste disposal options can arrest soil contamination to a great extent by providing the best waste management choice.

KEY WORDS
Delhi, Landfill, Multi Criteria Decision Analysis (MCDA), Plastic, Waste Management

Published: 10 Oct 2016

***Corresponding Author**
Email:
saurav.bhagat01@gmail.com
Tel.: +91-07838836939
Fax: +91-11-26581117

INTRODUCTION

India ranks second as the most populated country with the population anticipated to increase at an average annual rate of 1.2% from 1029 million to 1.65 billion from 2001 to 2026 [1]. With an overwhelming rise in population, it is anticipated that the amount of municipal solid waste (MSW) in the coming future will increase as India strives towards achieving the status of an industrialized nation [2-4]. With the present unscientific methods of waste disposal, this humongous waste will ultimately contaminate the soil.

The amount of waste generated is related to factors like life standards of people, extent of industrialization and urbanization as well as the economic activities being carried out in and around an area. With a change in the lifestyle of people and increasing urbanization, the extent of MSW generation in Indian cities is now ~ 8 folds than what was at the time of independence [5]. Economic prosperity and a greater urban population proportion in India is linked with higher waste generation evident from the figures of about 114,576 tonnes/day of MSW in 1996, predicted to increase fourfold to about 440,460 tonnes/day by 2026 [6]. Table-1 summarizes the quantity and per capita solid waste generated in different states/ UT in India [10].

The National Capital Region (NCR) of India, which is a conglomeration of Delhi and the neighbouring urban areas of Haryana, Rajasthan and Uttar Pradesh, forms one of the largest commercial and residential hubs in the country thus contributing to increased MSW generation from this area. The residents of Delhi generated MSW of about 7000 tons/day in 2007 which is expected to increase rise to around 17,000 – 25,000 tons/day by 2021 [7]. If it were even possible to use composting and incineration and for maximum waste reduction, there would still be a minimum of 4000 – 5000 tons of waste per day that would have to be landfilled in 2021 [8]. Management of such a huge quantity of waste plan requires the presence of a strong policy framework in pertaining to waste management and disposal operations along with significant cooperation from the public to lead to efficient enforcement. With this perspective in mind, the Municipal Corporation of Delhi (MCD) did a study to know the viability and came up with a Master Plan (MP) for first treatment and then subsequent disposal of MSW during 2005–2021 in order to get sustainable MSW management options for Delhi. Composting and biomethanation are the technologies proposed in the MP (2005– 2021) for dealing with the MSW [9]. However, the success of developing sustainable and effective waste management options depends upon the extent of cooperation and involvement of the people.

The physical composition of MSW generated in Delhi from 1982-2002 has been given in [Table 2]. There is a wide variety in the composition of MSW which subsequently opens up multiple options and processes of waste disposal or waste to energy conversions. The most commonly used of these are landfilling, recycling, thermal conversion - incineration, pyrolysis and gasification – and bio-chemical processes such as composting, vermicomposting, and anaerobic digestion [11]. Plastic waste, however, forms an important component of MSW because of its everyday use in essential items. Post the industrial production of plastic

Guest editors: Dr. SK Gupta and Prof. Mukesh Khare

IIOAB JOURNAL ISSN: 0976-3104

THE IIOAB JOURNAL

in the 1940s, the usage, and hence the waste generation rate of plastic solid waste (PSW) has augmented at a rapid rate of up to 3 % in Europe [12].

Furthermore, it can be seen that the fraction of plastic and non-biodegradables has been escalating in the Indian MSW mix [Table 2] which could be attributed to increased plastic packaging due to rise in living standards of the people [7]. It is highly imperative that we design use sustainable methods to dispose off plastic in an economically and environmentally feasible way.

Table 1: MSW generation in different states/ Union Territory (UT) in India [10]

S. No	Name of State/UT	Municipal population	Municipal solid waste (ton/day)	Per capita generated (kg/day)
1	Andaman & Nicobar	380,581	50	0.131378077
2	Andhra Pradesh	84,580,777	11500	0.1359647
3	Arunachal Pradesh	1,383,727	93.802	0.067789383
4	Assam	31,205,576	1146.28	0.036733179
5	Bihar	104,099,452	1670	0.016042352
6	Chandigarh	1,055,450	380	0.360036004
7	Chhattisgarh	25,545,198	1167	0.045683733
8	Daman Diu & Dadra	586,956	41	0.069851914
9	Delhi	16,787,941	7384	0.439839525
10	Goa	1,458,545	193	0.132323651
11	Gujarat	60,439,692	7378.775	0.122084921
12	Haryana	25,351,462	536.85	0.021176294
13	Himachal Pradesh	6,864,602	304.3	0.044328863
14	Jammu & Kashmir	12,541,302	1792	0.142887876
15	Jharkhand	32,988,134	1710	0.051836821
16	Karnataka	61,095,297	6500	0.106391168
17	Kerala	33,406,061	8338	0.249595425
18	Lakshadweep	64,473	21	0.325717742
19	Maharashtra	112,374,333	19.204	0.000170893
20	Manipur	2,855,794	112.9	0.039533664
21	Meghalaya	2,966,889	284.6	0.095925395
22	Mizoram	1,097,206	4742	4.321886683
23	Madhya Pradesh	72,626,809	4500	0.061960591
24	Nagaland	1,978,502	187.6	0.094819212
25	Orissa	41,974,218	2239.2	0.053347033
26	Puducherry	1,247,953	380	0.304498647
27	Punjab	27,743,338	2793.5	0.10069084
28	Rajasthan	68,548,437	5037.3	0.073485264
29	Sikkim	610,577	40	0.065511803
30	Tamil Nadu	72,147,030	12504	0.173312748
31	Tripura	3,673,917	360	0.09798806
32	Uttar Pradesh	199,812,341	11.585	5.79794E-05
33	Uttarakhand	10,086,292	752	0.074556636
34	West Bengal	91,276,115	12557	0.137571587
	Total	**1,210,854,977**	**127485.107**	**8.194978662**

Previous studies have shown that there are a number of sustainable and green methods of PSW handling viable from environmental and monetary point of view [13] and could be used to ensure proper PSW management. However, in a large number of cities in India, plastic disposal is carried out in open and unlined dumping areas in the vicinity of cities without any concern to environment. Alternative options for the disposal and treatment of plastic are required due to the increasing cost and decreasing space of landfills [14].

OBJECTIVES OF THE STUDY

The objective of the present this study is to utilize a simple multi criteria decision analysis (MCDA; elaborated further in this paper for examining and evaluating plastic waste disposal options in Delhi which is generally indiscriminately disposed off and contaminates the soil, depriving of its natural quality in addition to posing high risk to human health and environment. A panel of experts and residents of Delhi was formed and an assessment of plastic waste management options in Delhi was made by examining health, environmental effects of the different disposal processes considered. The disposal processes considered in the study are as follows: i) Landfilling, ii) Recycling, iii) Incineration and iv) Pyrolysis. Apart from these processes, a combination of landfilling and recycling, landfilling and incineration, recycling and pyrolysis have also been considered to arrive at a better outcome by using a combination of multiple methods and techniques. The criteria and the sub criteria considered for the analysis have been given in [Table 5].

Table 2: Physical constitution of MSW (as wt. %) in Delhi. Sources: [15-17]

S. No.	Parameters	2002	1995	1982
1	Biodegradable	38.6	38.0	57.7
2	Paper	5.6	5.6	5.9
3	Plastic	6.0	6.0	1.5
4	Metal	0.2	0.3	0.6
5	Glass and Crockery	1.0	1.0	0.3
6	Non-biodegradable (leather, rubber, bones, and synthetic material)	13.9	14.0	5.1
7	Inert (stones, bricks, ashes, etc.)	34.7	34.8	28.9

This paper is divided into the different sections. Section 3 gives us a review of MCDA and its need as policy framing and analysis tool along, use of MCDA in waste management options and an insight of plastic waste and its disposal options. Section 4 highlights the methodology adopted in this study. Section 5 gives an analysis and explanation of the results and discussions.

LITERATURE REVIEW

Multi- Criteria Decision Analysis

Multiple- Criteria Decision Analysis (MCDA) is a mechanism for assessing and understanding complex problems by breaking them down into simpler individual pieces and then using data to give an assessment on those individual pieces which when finally reassembled and combined present a coherent overall picture to decision makers [18]. In other words, it allows a complex problem to be appraised based on certain criteria (selected by the panel members) that have relative weightage (again assigned by the panel members) and uses a final sum of the weighted score of each option to offer the best elucidation. The panel is made up of a combination of experts and local residents who discuss and subjectively assign weightage to the criteria considered in the problem. The MCDA process has the following major stages [18]:

1. Setting up the aims of MCDA analysis; identifying decision makers, experts and other stake holders.
2. Establishing the context of MCDA and designing the socio-technical system for conducting it.
3. Identifying the various options that have to be evaluated and selecting the criteria for evaluating the options under consideration.
4. Prioritizing the criteria and assigning weights to determine their relative importance in decision making
5. Score the options on the criteria considered and then calculate overall weighted scores.
6. Examine the results and check their consistency; Discuss on the outcome achieved and make recommendations by carrying out sensitivity analysis.

MCDA has been used in the regulatory framework by many countries [19, 20], in a review of the decision analysis mechanism of United States Environmental Protection Agency (USEPA), a Multi-criteria Integrated Resource Assessment (MIRA) has been recognized as an substitute framework in place of current existing decision analysis methodologies. MCDA was utilized while carrying out Environmental Impact Assessment (EIA) in the Netherlands [21]. Furthermore, applications of MCDA can also be seen in the United Kingdom from evaluations of overseas trade being conducted by the National Audit Office to local authorities using MCDA modelling in order to decide the three-year strategic plan for management of their social care budget [18]. The key advantages of an MCDA include the following [22]:

- It invokes active participation of the stakeholders during the decision evaluating process and their interactive learning to appreciate viewpoints of others.

- It allows exploration of multiple dimensions of a problem taking into account the complexities associated with each proposed solution.
- It allows both quantitative as well as qualitative criteria to be taken into account. Thus it offers transparency in terms of analysis of a problem by including the importance of the qualitative social impact of the choices of a problem.

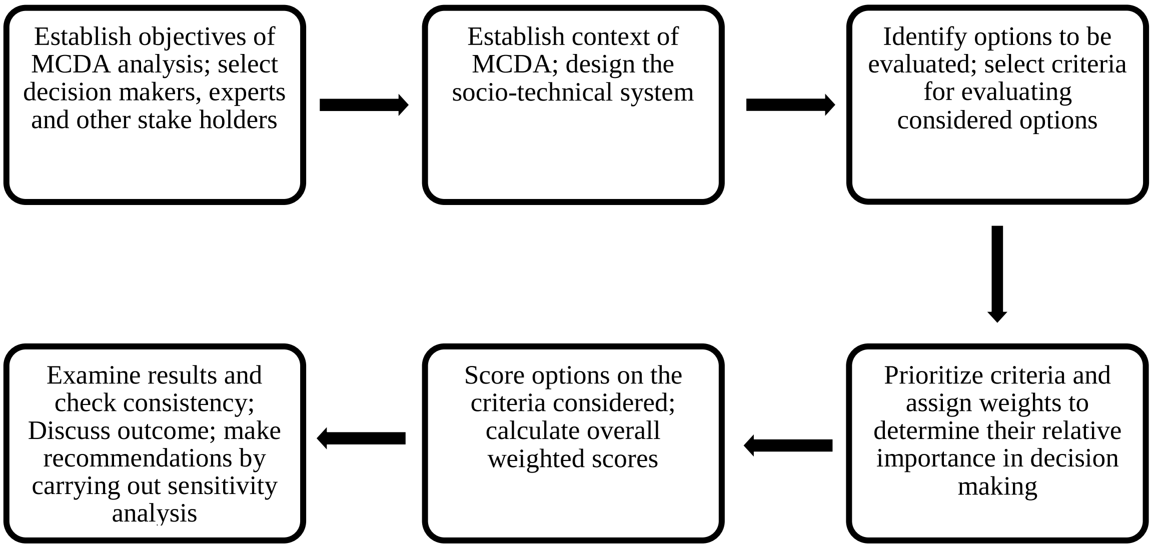

Fig. 1: The stages involved in an MCDA process

……………………………………………………………………………………………………..

However, in spite of all its benefits the MCDA has been criticized because of the subjectivity that it imparts to the decision making process. At times, there is no fixed rationale for determining the weights assigned to criteria and this allows decision making to border on uncertainty in some cases. Also, several problems such as domination of the MCDA panel by certain individualistic stake holders, presence of a certain bias in the minds of the panel deter in reaching a coherent and socially optimal decision. Furthermore, MCDA is incapable to quantify whether one decision crafts greater human prosperity than alternative decision [23].

Applications of MCDA in management of waste

Multiple- Criteria Various studies have been carried out by researchers in different countries that have used MCDA in order to determine waste disposal options. Janssen, 2001 [21] studied the application of MCDA while conducting EIA in Netherlands, and established the necessity of transparency in the decision process which can be done by imparting information to the stakeholders in a manageable and simple way. MCDA was utilized to analyze the waste disposal options for the management of paper waste on the Isle of Wight in the United Kingdom [23]. In that study seven waste management and disposal ways were evaluated by the panel on the basis of several criteria like: environment, finance, legislation and society. They concluded that gasification of waste on the island was the option that was most preferred by the panel members and MCDA was efficient technique to engage public in the decision making process for waste management. Similarly Powell et al. 1996, [24] examined six waste disposal options namely landfilling, incinerating and refuse-derived fuel (RDF), each with and without recycling) for management of waste in the UK. The analysis resulted in RDF with recycling coming out to be the best option and the results changing to landfilling when the weightage of cost of disposal technique was increased.

López, 2010 [25] carried out an MCDA for evaluating ways of energy recovery from waste in Reading, UK. The criteria that his study incorporated were financial (capital and running costs) and environmental (odour, noise, pollution) and inferred that gasification with a combination of heat and power to be the best method of waste management. The stake holders are influenced greater by economical factors than environmental. In another case at Saharawi refugee camps in Algeria, Garfi et al. 2009 [27] compared different waste management solutions in for arriving at a decision making method. Their study employed a mathematical technique, the analytical hierarchy process (AHP), for multi-criteria strategy making.

In a study conducted at an Indian city Dakar, MCDA was applied for studying solid waste management options in households [26]. The criteria considered in the study included generation, accumulation and treatment of waste along nine city zones and suggested different methods of waste disposal in these areas. Although difficulties were reported in generating consistent and significant data but conclusions were drawn such as adoption of measures such as increased recycling and reducing the source of waste [23].

Apart from these studies several other studies have been carried which give us a detailed idea of the importance of public participation in waste management [28], trade-offs made sometimes because of the diverging aims of policy makers with regards to little environmental impacts and expenditures [29]. With regards, to the Indian context there hasn't been a lot of work regarding the application of MCDA in waste management and the study aims to showcase effective application of MCDA to plastic waste management options thereby encouraging active public participation in policy enactment.

Methods of Plastic Waste Management

Landfilling

Multiple- Criteria Various studies Landfilling is the process in which wastes are deposited over an area of land thus degrading its soil quality from small to a large extent. The purpose of landfills is to avert contamination of the environment by the disposed waste, specifically the groundwater. Landfills are of following types: Open dumps, Semi-operated landfills & Sanitary landfills. Open, unlined, unengineered and unsanitary landfills are prevalent in India, resulting in contamination of soil, groundwater, foul smell and air pollution apart from dangerous levels of health risks. Other challenges of landfilling are limited availability of land for waste disposal and low awareness in public. Usually a high percentage of the solid waste along with plastics has been landfilled all over the world. However, landfill disposal has become unviable due to legislative reasons in some countries (which have targets of landfilling reduction by 35% in the time range of year 1995 to 2020), escalating maintenance expenditures, generation of GHGs like CH_4 and low degrading capacity of major disposed wastes [30]. Landfill gases contain around 0.01 - 0.6% cancer causing VOCs [31, 32].

Recycling

Recycling of plastic waste is reprocessing of the expended plastics for creating new products carried out in a way to cut down environmental pollution, thus enhancing efficiency during the process. There are multiple types of recycling processes, for example to cycle plastics- primary, secondary, tertiary and quaternary techniques may be employed [33].

Mechanical Recycling is a combination of primary and secondary recycling resulting in conversion of plastic waste into products with characteristics either similar to those of original product or different from that. Although the process seems to be an eco-friendly mechanism, the reprocessing process is uneconomical and inefficient as it requires lofty energy for intermediate processes leading to making of a new usable product [34]. Chemical recycling or tertiary recycling involves manufacture of fuels and chemicals from plastic waste. Its primary function is to transform waste polymers into their simpler forms and then into chemicals which is useful for catering to a diversity of industrial applications/fuels. Quaternary recycling recovers energy from waste plastics utilizing aerobic combustion at high temperatures called incineration thus reduce the CO_2 burden on the environment indirectly[35]. This method is presently not popular in India.

Incineration

Incineration is the process of combustion of waste substances which converts to ash residue and gases. The principle of generating energy from plastics waste incineration is useful for waste polymers that are recuperated and replace fossil fuels and thereby reducing CO_2 emissions virtually. The energy content and calorific value of polyethylene is almost same as traditional fuel oil and hence such substitution is feasible. Local authorities prefer incineration over other methods as energy recovery option since there is monetary profit in sales of plastic waste as fuel [36]. In India incineration is a poor option for MSW as the wastes are mostly unsegregated and consists of mainly high organic (40– 60%), inert (30–50%) and moisture content (40–60%) alongwith low calorific value (800–1100 kcal/kg). Additionally, the construction and operational costs of incineration plants are high [37]. However, using incineration as a means of disposing plastic is now being suggested in various places due to the reduction in volume this process achieves. Currently India doesn't have legislation or dedicated government departments to control this new sector of waste to energy incineration. But still this option is considered as a viable procedure for seeing off and managing disposal of waste under controlled conditions because of the primary reduction in the quantity of waste.

Pyrolysis

Pyrolysis is defined as anaerobic combustion at high temperatures. In plastic pyrolysis, the macromolecular polymers break down to simpler species and syngas (mixture of CO, H_2, CH_4 and higher hydrocarbons). It depends upon factors like temperature, retention residence time, catalysts etc. [35]. Plasma Pyrolysis is a novel technnique which integrates thermochemical properties of plasma with the pyrolysis process. The extreme heat generation potential of PPT enables it to set out various kinds of plastic wastes by a dependable and secure manner. Thus segregation of waste is not a prerequisite in Plasma Pyrolysis Technology [33]. By this mechanism, there is a more than 99% chance of conversion of waste into non-toxic gases. Plasma Pyrolysis Technology is not extensively used in India.

MATERIAL AND METHODS

Formation of the MCDA panel

The MCDA panel consisted of faculty, researchers and students of the different departments at IIT Delhi, one of the premier technical institutions in the country with feedback and suggestions from experts in the field of waste. Also, there was no political representation (such as counselors or members of the Municipal Corporation of Delhi) of any involvement of laymen from outside. The contact with the panel members was established verbally by approach and a panel of nine members upon their subsequent agreement with assurance of confidentiality of their identity. Details regarding the members of the panel have been given in [Table 3].

Table 3: Details of the panel members involved in the MCDA analysis

Panel Member No	Qualification	Discipline
1	PhD	Environment Engineering
2	PhD	
3	M.Phil, M.Sc	Environmental Sciences
4	M.Phil, M.Sc	
5	M.Phil, M.Sc	
6	M.Tech	Environment Engineering
7	M.Tech	
8	M.Tech	
9	M.Tech	

Panel Meeting & Discussion

The discussion among the panel members took place on a working day. The members of the panel were briefed on the problems created by improper management and disposal techniques of plastic waste. The procedure of an MCDA was thoroughly explained to all the members of the panel. After an initial briefing of the MCDA technique, the panel members were introduced to the following options considered for plastic management of waste disposal:

- Landfilling of the total plastic waste in the nearby landfills of Okhla, Bhalaswa and Gazipur
- Mechanical recycling of plastic waste
- Thermal recycling in the incineration units of Narela and Ghazipur
- Pyrolysis

Three more options which included i) Combination of incineration and landfilling. ii) Combination of mechanical recycling and landfilling and iii) Combination of incineration and landfilling were also provided to the panel in case a mixed solution was considered to be more appropriate than individual techniques.

An approach similar to the one used by Hanan et. al (2012) [23] was followed. The criteria used for MCDA were modifications of the ones used by Hannan et al. (2012) [23] whose criteria were in turn based on work done by Hirschberg et al. 2007 [38] in developing Bollinger and Pictet's (2008) criteria [39].

The members of the panel were asked to consider the following criteria (and add any one of their own if they deemed necessary) and allocate a total of 100 marks between these criteria (given in Table 4) in accordance to their relative significance during decision making procedure:

- Environmental criteria such as air, water and land pollution caused by the management techniques
- Health and Social Parameters which included the toxicity, aesthetic factors and cleanliness of the area
- Financial parameters which included the overall implementation cost of the technique used (inclusive of cost of collection and transport) and benefits from the by-products obtained from the process
- Confirmation to the prescribed legislative standards including local and national policies
- Practical implementation and feasibility of the proposed solution in terms of the number and capacity of the treatment plants in Delhi.

Table 4: Criteria considered for MCDA of plastic waste management

Serial No.	Criteria Considered	Sub – Criteria
1	Environmental	Pollution of air
		Degradation of water and land
2	Health and Social Parameters	risk/ chronic diseases capability - (individual)
		Aesthetic effects - (Cleanliness)
3	Financial	Cost of Collection, Transport and Implementation
		Economic Benefits from by products (if any)
4	Conforming to prescribed Legislative Standards	Local Policies
		National Standards
5	Practical Application & implementation	Feasibility of proposed solution
		Number of plants in the nearby area

For aiding the decision making process, the members of the panel were given the following information:

- An introduction about the common methods of waste disposal management [35].
- Environmental impacts of waste disposal of plastic through the considered options. This was provided in the form of an eco profiles for six divergent techniques in of disposing the plastic which included environmental impact in terms of global warming, solid waste generation, ozone depletion and nutrient enrichment (phosphorus and nitrogen) which have been given in [Table 5] [40]. Social parameters such as cleanliness were also obtained by correlating Area degradation with solid waste quantity.
- Relative cost of implementation of the techniques and their benefits (if any) were provided by waste management experts from IIT Delhi. Though exact quantitative data with regards to this wasn't available, an economic demarcation between the techniques could be made.
- To find the feasibility of the applied solution, data pertaining to the number, locations and capacity of landfills and incineration units in Delhi was provided to the panel.

Table 5: Environmental effects (as person equivalents) of the six disposal options [40]

	Process					
Environmental Effect	Recycling vision/ chemical separation	Recycling Dissolvent Separation	Recycling non-separation	Landfilling	Incineration with heat recovery	Pyrolysis
Global Warming	-39.56	-67.26	52.65	0.00	-12.21	145.39
Stratospheric Ozone Depletion	0.00	0.00	0.00	0.00	0.00	0.00
Acidification	-120.46	-128.64	23.02	0.00	-94.24	22.14
Nutrient Enrichment (nitrogen)	-62.50	-61.26	-0.19	0.00	-39.73	-2.28
Nutrient Enrichment (phosphor)	-2.06	-2.06	0.00	0.00	0.00	0.00
Photochemical ozone formation	-270.04	-302.22	75.88	0.00	-130.85	161.37
Solid Waste	386.87	375.92	269.30	2173.91	-193.83	887.28

Values are expressed in μPE/kg

The panel was asked to consider the options presented to them and rank each of them with respect to the criteria mentioned previously. The panel members rated the options on a scale ranging from 1 to 10 with 1 being the least preferred and 10 being the highest or most preferred. Once the panel members had scored the options, an aggregate of the scores for all the options was done and the options were compared. The outcome of the MCDA was discussed by the panel members who concluded that the option was correct in their combined opinion. A sensitivity analysis was carried out to see the impacts of changing relative weights of the criteria on the outcome.

RESULTS

The MCDA provides a clear and transparent mechanism to evaluate and arrive at the best possible option for disposal and management of plastic waste in Delhi. The weights that were assigned by the panel to the various criteria have been given in [Table 6]. A pie chart given in [Fig. 2] has also been plotted which allows us to assess the relative importance of the criteria considered by the panel. The scores given by the members of the panel have been given in [Table 7]. The aggregate total of the disposal option has been given in[Table 8] and another bar graph [Fig. 3] allowing us to compare the relative performance of each of the options.

From the results, we can show that the panel shows a clear preference for the combined option of recycling + incineration to be the preferred mechanism of handling solid plastic waste. Recycling of plastic as an option came in a close second which was followed by incineration. The reason could be that the panel thought that the combination would allow them to come up with a solution that would have the benefits of both the technologies and as a result would be better suited to handle the waste. Landfilling with recycling came in to be next perhaps because the panel considered that the option would have a high feasibility. The use of pyrolysis as a technique was not preferred by the panel and one of the major reasons for this were high chronic disease and air pollution associated with the technique. Open Landfilling, the way it is carried out in India, was considered to be the least preferred option.

Table 6: Weightage allotted to the criteria in the MCDA analysis

Serial No	Criteria Considered in MCDA analysis	Weightage considered
1	Pollution of air	15
2	Degradation of water and land	20
3	Risk/ chronic diseases capability - (individual)	15
4	Aesthetic effects - (Cleanliness)	8
5	Cost of Collection, Transport and Implementation	15
6	Economic Benefits from by products (if any)	8
7	Local Policies	4
8	National Standards	4
9	Feasibility of proposed solution	6
10	Number of plants in the nearby area	5
	Total	100

DISCUSSION

This study has been used to evaluate waste disposal options from a series of given alternatives to arrive at the best solution to disposing plastic waste options in the city of Delhi. The major advantage that an MCDA offers is that allows us to include qualitative criteria in addition to the quantitative criteria and also encourages a greater participation of the public as stakeholders in the decision making process. The involvement of the people ensures a greater chance of success in the implementation of the actions made by the policy makers.

The panel did not have the presence of decision making people such as counselors or people from the Municipal Corporation of Delhi (MCDA) who are actively involved in the decision making process. Thus, the panel lacked that key area of decision maker expertise. In spite of the above limitation, the panel was still able to arrive at a coherent decision of choosing a combination of recycling and incineration as the best options for plastic waste disposal and management. The relative importance or weights assigned to the criteria have an important role in deciding the outcome of the analysis. In the present study, the panel members awarded the highest importance to environmental and health based criteria in contrast to the financial criteria. This shows that the main focus of the panel was in evaluating and considering the impact of qualitative parameters like health and environment over the cost which indicates a more robust and holistic thinking. Legislative criteria were awarded lower importance perhaps due to a lack of data on that front. However, the panel also did not very highly weigh the practicality of the proposed solution to be an important parameter because they felt that the methods mentioned in the study were practical enough to be executed in the regions of Delhi. Also, the members of the panel were also guided by their personal feelings and intuitive knowledge in certain cases.

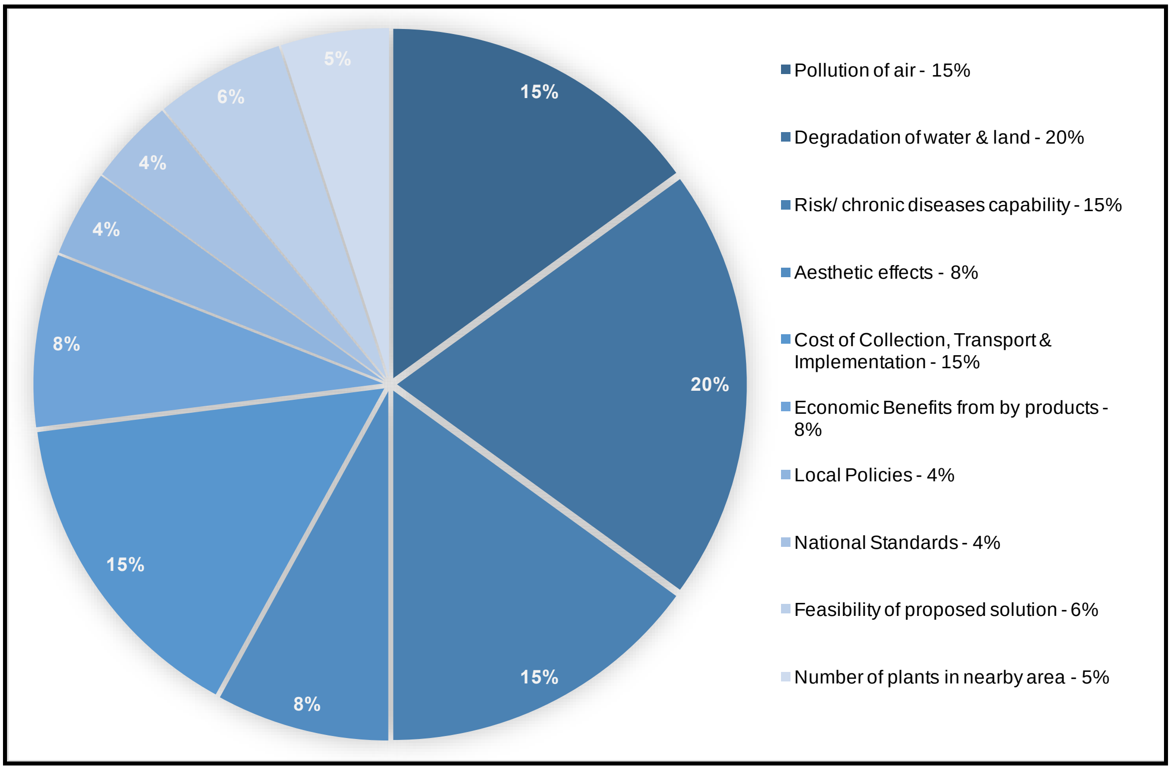

Fig. 2: Relative importance of the criteria in the MCDA analysis

Table 7: Scores given by the panel to various options considered in the MCDA

S No	Criteria considered for MCDA analysis	Landfill	Recycling	Incineration	Pyrolysis	Landfill + Incineration	Recycling + Incineration	Landfill + Incineration
1	Pollution of air	6.5	7	4.5	4	6.5	6.5	6.5
2	Degradation of water and land	2	5.5	8	6	5	7.5	4
3	Risk/chronic diseases capability (individual)	6.5	6.5	6	5.5	6.5	6.5	6
4	Aesthetic effects (cleanliness)	2	7	7	6	5.5	7	5.5
5	Cost of collection, Transport and Implementation	8	5	4.5	5.5	7	5	6.5
6	Economic Benefits from by products (if any)	2	7.5	7	6.5	4.5	7	4.5
7	Local Policies	7	6	6	5.5	6.5	6	6.5
8	National Standards	7	6	6	5.5	6.5	6	6.5
9	Feasibility of proposed solution	7.5	6	5.5	5	6	6	6
10	Number of plants in nearby area	7.5	6.5	5.5	5.5	6.5	6	6.5

Table 8: Aggregate scores for various plastic management and disposal options

S No		Total Score
1	Landfilling	525.5
2	Recycling	620
3	Incineration	605.5
4	Pyrolysis	546.5
5	Landfilling + Recycling	600.5
6	Recycling + Incineration	646
7	Landfilling + Incineration	550.5

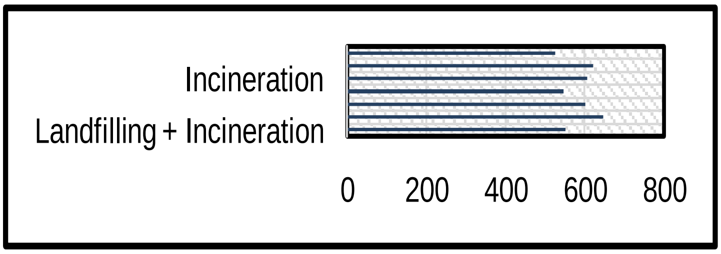

Fig. 3: Overall Score of the disposal options

A combination of recycling and incineration came out to be the best option and the panel discussed this towards the end of the meeting. The panel felt that a combination of the two processes provided a solution with the benefits of one counterbalancing the shortcomings of the other. The recycling option was seen to be better in reduced air pollution, economic benefits due to use of reprocessed plastic and feasibility because of a large number of recycling units present in the Delhi NCR. On the other hand, the reduction in waste volume carried out by incinerating it was seen to cause reduced land and water pollution and the technique scored fairly high in maintaining aesthetic quality of the land. Thus a combination of the two was preferred as the best option. Only recycling emerged as a superior option in comparison to only incineration since the benefits of recycling mentioned above seemed to outnumber those of incineration.

Landfilling was ranked as the lowest or the least preferred option. The reason for this was that the method of dumping is followed in the name of landfilling in the areas around Delhi. This criterion was least preferred as it contributed the most to land and water pollution and also had very few benefits from by products in comparison to the other methods. On the other hand, the simplicity and ease of dumping meant that the criteria scored very high in the financial category because of its low cost, ease of application and practicality. On the other hand, the panel members also scored pyrolysis as not a good method. This was because of the bias that existed in the minds of the people with regards to anaerobic combustion of plastic which was institutively thought to be a hazardous condition. Though, the panel conceded that techniques like Plasma Pyrolysis Technology (PPT) which were very clean and efficient were also prevalent but these were ruled out because they were not very practical and therefore could not be implemented in India.

In the study here, we haven't considered a sensitivity analysis by varying the relative weightage of the criteria. This can be considered as a scope for future research to test the robustness of the MCDA procedure.

CONCLUSION

The MCDA in spite of adding a lot of subjectivity to decision making allows us to come to a consensus and achieve a robust option for the management of plastic waste and hence soil quality conservation. It can be concluded that such methodological approaches must be encouraged in decisions especially pertaining to environmental management and conservation.

CONFLICT OF INTEREST
All the authors declare no conflict of interest whatsoever.

ACKNOWLEDGEMENTS
The authors sincerely acknowledge the panel members for sparing their valuable time for discussions on the topic for MCDA.

FINANCIAL DISCLOSURE
All the authors declare no conflict of financial interest.

REFERENCES

[1] Bongaarts J. [2009] Human population growth and the demographic transition. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 364(1532), 2985-2990.
[2] Sharma S, Shah KW.[2005]. Generation and disposal of solid waste in Hoshangabad. In: Book of Proceedings of the Second International Congress of Chemistry and Environment, Indore, India, 749–751.
[3] Central Pollution Control Board (CPCB), [2004] Management of Municipal Solid Waste. Ministry of Environment and Forests, New Delhi, India
[4] Shekdar AV, Krshnawamy KN, Tikekar VG, Bhide AD. [1992] Indian urban solid waste management systems – jaded systems in need of resource augmentation. Journal of Waste Management 12 (4):379–387.
[5] Sharholy M, Ahmad K, Mahmood G, Trivedi RC. [2008] Municipal solid waste management in Indian cities – A review, Waste Management 28:459–467.
[6] Hoornweg D, Laura T. [1999] What a waste: solid management in Asia. Working Paper Series No. 1. Urban Development Sector Unit, East Asia and Pacific Region, The World Bank, Washington, DC.
[7] Talyan V, Dahiya RP, Sreekrishnan TR. [2007] State of municipal solid waste management in Delhi, the capital of India, Waste Management 28:1276–1287.
[8] DUEIIP, 2001. Delhi urban environment and infrastructure improvement project. Government of National Capital Territory of Delhi and Government of India Ministry of Environment and Forests (MoEF), India.
[9] MCD, 2004. Feasibility study and master plan report for optimal solid waste treatment and disposal for the entire state of Delhi based on public and private partnership solution. Municipal Corporation of Delhi, Delhi, India.
[10] CPCB, 2012. Status report on municipal solid waste management.
[11] Singh RP, Tyagi VV, Allen T, Hakimi M I, Kothari R, [2011] An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario, Renewable and Sustainable Energy Reviews 15: 4797–4808
[12] Al-Salem S M, Lettieri P, Baeyens P.[2009] Recycling and recovery routes of plastic solid waste (PSW): A review, Waste Management 29:2625–2643.
[13] Howard GT,[2002] Biodegradation of polyurethane: a review. International Bio-deterioration and Biodegradation 49 (1):245–252.
[14] Zia KM, Bhatti HN, Bhatti IA. [2007] Methods for polyurethane and polyurethane composites, recycling and recovery: a review. Reactive & Functional Polymers 67 (8):675–692
[15] TERI, [2002] Performance Measurements of Pilot Cities. Tata Energy Research Institute, New Delhi, India.
[16] NEERI, 1996. Solid Waste Management in MCD Area. National Environmental Engineering Research Institute, Nagpur, India.
[17] IHPH, [1982] Studies of Institute of Hygiene and Public Health. Calcutta Metropolitan Development Authority, Calcutta, India.
[18] Department for Communities and Local Government, 2009. Multi-Criteria Analysis: A Manual. Department for Communities and Local Government, London, UK
[19] Stahl CH, Cimorelli AJ, Chow AH. [2002] A new approach to environmental decision analysis: Multi-criteria integrated resource assessment (MIRA). Bulletin of Science, Technology and Society 22:443–459
[20] Stahl CH. [2003] Multi-criteria integrated resource assessment (MIRA): A new decision analytic approach to inform environmental policy analysis [thesis].Wilmington (DE), USA: University of Delaware.
[21] Janssen R. [2001] On the use of multi-criteria analysis in environmental impact assessment in The Netherlands. Journal of Multi-Criteria Decision Analysis 10:101–109.
[22] Diakoulaki D, Grafakos S. [2004] Multi-criteria analysis. Work Package 4 Report, Externalities of Energy. <http://www.externe.info/expolwp4.pdf> (accessed 30.03.12).
[23] Hanan D, Burnley S, Cooke D. [2012] A multi-criteria decision analysis assessment of waste paper management options, Waste Management 33: 566–573.
[24] Craighill A, Powell J.[1996] Life cycle assessment and economic evaluation of recycling: a case study. Resources, Conservation and Recycling 17:75–96
[25] Lopez, P.I,[2010] Decision-support tool for energy-from-waste plants in development projects. In: 23rd International Expert Group for Life Cycle Assessment for Integrated Waste Management. Environment Agency, Bristol, UK.
[26] Kapepula KM, Colson G, Sabri K, Thonart P. [2007] A multiple criteria analysis for household solid waste management in the urban community of Dakar. Waste Management 27: 1690–1705.
[27] Garfì M, Tondelli S, Bonoli A, [2009] Multi-criteria decision analysis for waste management in Saharawi refugee camps. Waste Management 29:2729–2739
[28] Hung M-L, Ma H.-W, Yang W.-F. [2007] A novel sustainable decision making model for municipal solid waste management. Waste Management 27 (2):209– 219.
[29] Chang YH, Chang N. [1997] A fuzzy goal programming approach for the optimal planning of metropolitan solid waste management systems. European Journal of Operational Research 99:303–321
[30] Garforth AA, Ali S, Martı´nez JH, Akah A.[2004] Feedstock recycling of polymer wastes. Current Opinion in Solid State and Materials Science 8(6):419–25
[31] Residua, Landfill Information Sheet, Warmer Bulletin, May 2000.
[32] Montague P. [1998] Landfills are dangerous. Rachel's Environment and Health Weekly, 617
[33] Central Pollution Control Board (CPCB), India, Report on Plastic Waste Management – Chapter 11.
[34] Mantia PL, Handbook of Plastic Recycling, Fransecso, [2002] ISBN: 1859573258, 9781859573259
[35] Achyut K. Panda, RK Singh, DK Mishra, [2009] Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value added products—A world prospective. Renewable and Sustainable Energy Reviews 14 (2010) 233–248.
[36] Scott G. Polymers and the environment. Royal Society of Chemistry; 1999978-1-84755-172-6 [online]
[37] Agnihotri AK. [2014] Current scenario of Indian Landfill and its solution through Biotechnological approaches 2nd International Congress on Green Urban Futures 2014 The session on Biotechnological Approaches for Enhancing Functional Quality of Urban Landscapes. The Energy and Resources Institute (TERI) New Delhi.
[38] Hirschberg S, Bauer S, Burgherr P, Dones A, Simons A, Schenler W, Bachmann TM, Gallego Carrera D, [2007] Environmental, economic and social criteria and indicators for sustainability assessment of energy technologies. In: Project Co- funded by the European Commission Within the Sixth Framework Programme (2002–2006). Paul Scherrer Institute, Villigen PSI, Switzerland
[39] Bollinger D, Pictet J. [2008]. Multi criteria decision analysis of treatment and land- filling technologies for waste incineration residues. Omega 36:418–428.
[40] Molgaard C, [1996] Environmental impacts by disposal of plastic from municipal solid waste. Resources, Conservation and Recycling 15:5l-63.