Chapter 20
A Multi-criteria Based Analysis for Prioritization of Solid Waste Treatment Methods for Rural Areas

Pawle Md. Umar Ravish and Ajaykumar R. Kambekar

1 Introduction

The entire world is living in an unprecedented era of human, technological, and economic development. With trade and commerce reaching unparalleled heights due to globalization, not only it has made countries more prosperous but also it has drastically improved the living standards of people in the developed as well as the developing countries. All these activities have resulted in the generation of tremendous amount of municipal solid waste. Municipal solid waste generally refers to the waste collected by municipalities or other local authorities which typically comprises household waste, commercial waste, institutional waste, and waste generated from public places. It has been estimated that about 2.01 billion tons of municipal solid waste were generated in 2016 worldwide, with at least 33% of it not managed in an environmentally safe manner; and under business-as-usual scenario, it is expected that this municipal solid waste generation will reach 3.40 billion tons by 2050 (Kaza et al. 2050; Pipatti et al. 2006).

India is the second-most populous country in the world after China; about 17.7% of world's population lives in India, i.e., 1 out of every six people is an Indian (United Nations 2019). In 2011, the total population of the country was 1210.2 million, out of which 833.1 million (68.85%) lived in 0.64 million villages and only 377.1 million (31.15%) lived in cities. Interestingly, the share of rural population in the total population is decreasing gradually. The percentage of rural population was 82.7% in the first census of 1951 which has declined to 68.85% in 2011. On the other hand, India's urban population share was 17.3% in 1951 which has increased to 31.15% in 2011 (Census of India 2011). This increase in urban population is mainly attributed

P. Md. Umar Ravish
Sardar Patel College of Engineering, Mumbai, India

A. R. Kambekar (✉)
Department of Civil Engineering, Sardar Patel College of Engineering, Mumbai, India
e-mail: a_kambekar@spce.ac.in

to the migration of rural people to urban areas in search of employment, better infrastructure facilities, healthy lifestyle, etc. (Bhavita and Malek 2018). The rapid and unfair growth in urban areas, along with inadequate provision of basic sanitation infrastructure, has distressed many Indian cities in solid waste management and other such public services (Annepu 2012).

With regards to municipal solid waste, estimations suggest that about 1.5 Lakhs Tons per Day (54.75 Million Tons per Year) of solid waste is generated in urban India, and the per capita solid waste generation ranges from 0.20 to 0.6 kg/day in major cities. Also, the waste collection efficiency is between 70 and 90% in major metro cities whereas it is below 50% in several smaller cities. In 2014–15, out of the total MSW, approximately 117,644 TPD (80%) was collected, while only 32,871 TPD (22%) was processed or treated (Central Public Health and Environmental Engineering Organisation (CPHEEO) 2016a). A study by The Energy and Resources Institute (TERI) suggests that by 2047 solid waste generation in Indian cities will increase to 260 Million Tons per Year, which is five times the present value. It has also been estimated that the annual rate of increase in solid waste generation in Indian cities would be about 5% per annum. Present way of municipal solid waste management in Indian cities is largely ill-functioned which has led to degradation of the environment and resulted in poor quality of life (Central Public Health and Environmental Engineering Organisation (CPHEEO) 2016b).

In rural India, due to high population, growing consumerism, changing food habits, increasing use of plastics, packaging, and use and throw items, etc. the management of solid waste generated from rural households is increasingly becoming an issue of serious concern with regards to health and environment. In rural areas, this aspect has mostly been neglected due to lack of proper infrastructure, unavailability of sustainable technology at household or community level, lack of adequate O&M infrastructure, and awareness of common people (Ministry of Drinking Water and Sanitation Government of India 2015). Though solid waste generated in rural areas is predominantly organic and biodegradable and is of the order of 0.3–0.4 Million Metric Tons per Day, it is becoming a major problem as the waste generated is not segregated in-situ and also there are no proper solid and liquid waste management systems existing in these areas (Ramesh and SivaRam 2016). This has led to the spread of vector-borne diseases such as diarrhea, malaria, polio, dengue, cholera, typhoid, and other water-borne infections such as schistosomiasis. About 88% of the total disease load is due to lack of clean water and sanitation and the improper solid and liquid waste management (Ministry of Rural Development xxxx). It is quite evident that the problem of municipal solid waste management (MSWM) has emerged as a big challenge in the urban as well as the rural areas in India.

Realizing the need for a massive sanitation drive to tackle solid and liquid waste problems at the national, regional, and local levels, the Government of India launched the Swachh Bharat Mission (SBM) on October 2, 2014, with the vision of a cleaner India. It is one of biggest ever drives undertaken in the country to accelerate efforts to achieve universal sanitation and to put focus on improving cleanliness and sanitation. This mission incorporates both rural and urban components separately as: Swachh Bharat Mission (Gramin) and Swachh Bharat Mission (Urban). The overall objective

of Swachh Bharat Mission (Gramin) is to promote cleanliness and accelerate sanitation coverage in rural areas by motivating village people and administration bodies and encouraging them to undertake cost-effective and appropriate technologies for ecologically safe and sustainable sanitation (Guidelines for Swachh Bharat Mission (Gramin) 2018). In order to scale down the load on the urban solid waste treatment infrastructure and also to handle the rural solid waste in a responsible manner thereby providing healthy lifestyle along with maintaining the ecological and environmental balance, it is imperative to provide an efficient and fully functional solid waste management system in rural areas itself.

Solid waste management (SWM) includes all activities that seek to minimize health, environmental, and aesthetic impacts of solid waste (Zhu et al. 2008). An effective functional waste management system comprises six elements: (a) waste generation; (b) waste handling and sorting, storage, and processing at the source; (c) collection; (d) sorting, processing, and transformation; (e) transfer and transport; and (f) disposal (Manual on Municipal Solid Waste Management 2000). Each of these elements has its own characteristics and requires different levels of planning and decision-making to make the entire management process effective. However, selection of an efficient and appropriate solid waste treatment method for a particular area is one of the important considerations for the success of a waste management system. Selection of a wrong waste treatment method can lead to the failure of entire waste management system, apart from economic and environmental losses (Selection Criteria for Waste Processing Technologies 2016). Hence this study focuses only on the decision-making problem related to selection of a solid waste treatment method for a village.

A large number of solid waste treatment methods are available worldwide. Selection of an appropriate technology for an area is an onerous task as decision-makers have to trade-off between a pool of conflicting economic, environmental, social, and technical criteria. Hence in modern challenging environment, decision-makers often need fast and effective tools to quickly model and optimize several decision alternatives and then compare them according to various preconditions or performance criteria (Vučijak et al. 2016). In recent decades Multi-Criteria Decision Analysis, a branch of operations research, has emerged as an important and convenient tool to support decision-makers in finding optimal results for complex decision-making problems involving various indicators, conflicting objectives, and criteria (Kumar et al. 2017). A large number of MCDA techniques and approaches have been developed over the years with the purpose of improving the quality of decisions by creating the development more efficient, rational, and explicit; and each one has its own merits and demerits (Mardani et al. 2015). The ability of MCDM to handle complex and controversial information, which forms the basis of a decision-making process and then to integrate it with human aspirations by involving multiple stakeholders, has attracted the applications of MCDA in the field of environmental decision-making as well (Kiker et al. 2005).

2   Literature Review

According to Belton and Stewart (Valerie and Stewart 2002), "MCDA is an umbrella term used to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". Multi-Criteria Decision Analysis (MCDA) serves as an aid to decision-making by disintegrating the decision-making problem into manageable fragments to make judgments based on relevant data and then reassembling these fragments to have a logical and rational solution to the problem (Analysis 2009). In recent years MCDA has become a very fertile and popular branch of the Operational Research, with an ever-increasing application to a very diverse set of problem scenarios (Bruno and Genovese 2018). MCDA is a discipline that has a wide range of applications in mathematics, management, informatics, psychology, social science, economics, etc. It has flourished in all areas where a significant tactical or strategic decision is to be made depending on the time perspective of the consequences (Alessio and Nemery 2013).

Several review studies have been conducted pertaining to application of MCDA in solving environmental problems which help in knowing the suitability of a particular MCDA technique. Achillas et al. (Achillas et al. 2013) presented an extensive review of the literature on MCDA in waste management problems. Research papers were classified based on waste stream assessed, date of publication, MCDA method used and the specific topic addressed. It was found out that AHP and ELECTRE are mostly used in both location and strategy problems, whereas PROMETHEE is mostly preferred in identifying optimal waste management alternative strategies. Apart from this, it was also found that the concept of sustainable waste management is gaining importance in recent compromising models.

Huang et al. (2011) reviewed past studies in the field of multi-criteria decision-making in environmental science, conducted from 1990 to 2010. The study showed that the number of MCDA papers published in the environmental field has grown significantly during these two decades. A total of 312 papers were reviewed and it was found that AHP is the most commonly used MCDA technique. AHP/ANP was used in 48% of the papers followed by MAUT (16%) and Outranking methods (13%). It was also observed that AHP is widely used, at 80%, in spatial/GIS papers. However, in air quality/emissions studies, PROMETHEE is used more widely than AHP.

Similar study was conducted by Soltani et al. (2015) in which applications of MCDA in solving MSWM problems specifically were reviewed. A total of 68 studies were reviewed to analyze the trend in MSWM problems with multiple stakeholders. It was found that 38% of reviewed studies involved multiple stakeholders in decision-making process. Stakeholders were involved to assign criteria weights in majority of the studies while in few studies only stakeholders evaluated alternatives on their own. Most of the studies combined various MCDA methods with other popular decision-making tools. AHP and Graphical Information System (GIS) is one of the most popular combinations used in the reviewed papers. This study also showed

that AHP (65%) is the dominant technique used in solving MSWM problems while PROMETHEE is an emerging method.

MCDA has been applied to address different types of solid waste management problems in urban as well as rural areas. Since the amount of waste generated in urban areas is large it requires a robust waste management strategy that can lead to safe disposal of solid waste. In the study carried out by Madadian et al. (2013), AHP method has been applied to select the best urban waste management strategy for Tabriz city in Iran. Four waste management strategies comprised of several solid waste treatment practices such as Source Separation (SS), Biological and Mechanical Treatment (BMT), Refused Derived Fuel (RDF), Incineration and Landfilling were evaluated based on eight criteria. The findings of the research showed that the strategy comprising SS, Compost production, BMT, RDF, and Lanfilling is the best one for urban waste management. Antonopoulos et al. (2014) examined three treatment alternatives viz. mechanical–biological aerobic treatment without RDF energy recovery, mechanical–biological anaerobic treatment, and incineration with energy recovery, in the capacity range of 70–90 kT, for solid waste treatment of a medium-sized town using AHP. The alternatives were compared based on their environmental, social, and economic performance and it was found that for such an area Incineration with energy recovery would be the most suitable option. Jovanovic et al. (2016) applied SAW and TOPSIS methods to choose the optimal municipal solid waste (MSW) management system for Kragujevac city in Republic of Serbia.

Due to growing health and environmental concerns, it has become essential to treat the solid waste scientifically in rural areas as well. It is crucial to choose the most appropriate treatment method depending on the local conditions of the village. MCDA has the advantage of involving several qualitative and quantitative factors in the assessment process which guides the selection of a particular treatment method. This has been highlighted in the study conducted by Alfons and Padmi (2018). In the study, a multi-criteria approach has been adopted for selecting the most solid waste management approach for rural areas in Indonesia. A four-level AHP hierarchy was modeled comprising of a goal, five general criteria, 20 sub-criteria, and three alternatives. The results highlighted the importance of integrated solid waste management in rural areas as integrated treatment facility initiated by household-scale waste handlings was reported to be the most optimal solid waste management concept.

One of the key features of MCDA is that it can be combined with other decision-making systems such as Life Cycle Assessment (LCA) or with some spatial analysis tool such as GIS. One of the shortcomings of LCA is that it does not take into account the economic and social factors. Kermani et al. (2014) highlighted this shortcoming of LCA and combined it with TOPSIS to find out the optimum urban waste management system for a city generating 1000 Tons/day of waste having high organic content. Aguilar et al. (2018) in their study presented a multi-criteria-based methodology for the emplacement of solid waste management infrastructure with the help of spatial analysis tools available in the GIS software. The study highlighted the use of multi-criteria evaluation technique AHP along with GIS, which helped in taking into account several criteria while reducing time and cost in decision-making. Jaiswal

et al. (2018) carried out a suitability analysis for waste disposal site selection for a urban area using geospatial multi-criteria decision-making. GIS software along with AHP based Weighted Linear Combination and TOPSIS was used which generated sophisticated spatial outputs which were quite accurate, practical as well as visually appealing to the decision-makers. It was mentioned that such types of scientific approaches lead to more efficient planning.

Regional features play an important role in the decision-making process of solid waste management problems. These features vary from country to country and also from region to region within a country. Therefore by using the regional features in establishing the criteria for assessment of alternatives, this study highlights the application of MCDA to find most suitable solid waste treatment method for a rural area.

3   Materials and Methodology

3.1   Problem Definition

In this study three most commonly used solid waste treatment methods sought to be feasible at rural level viz. Anaerobic Digestion (AD), Vermicomposting (VC), and Windrow Composting (WC) are compared and ranked using Analytic Hierarchy Process (AHP) since it is one of the simplest and most widely used MCDA techniques. The alternatives are evaluated against ten criteria to find the final priorities. In AHP, the final priorities of alternatives can be determined by adopting two different modes: Distributive mode and Ideal mode. In this study also, the final priorities are determined using both the modes. A sensitivity analysis has been done in the end to check the robustness of the results obtained from the decision-making process. The methodology adopted for the study is shown in Fig. 1.

3.2   Study Area

Palsoli village (19.3639 °N, 73.2773 °E), located in Shahapur Tehsil of Thane district in Maharashtra is selected as the study area. It is approximately situated 30 km away from sub-district headquarters of Shahpur and about 70 km away from district headquarter. The nearest railway station is Vasind. It is about 5.4 km away from this village. The village location is shown in Fig. 2. Several site visits were done to know about the existing solid waste management practices in the village. From the visits, it was found out that there was no proper system of solid waste collection, transportation, and disposal in the village. The solid waste was neither treated at individual level nor at village level. People were either simply dumping or burning the solid waste. Therefore this study had been undertaken to provide a suitable solid
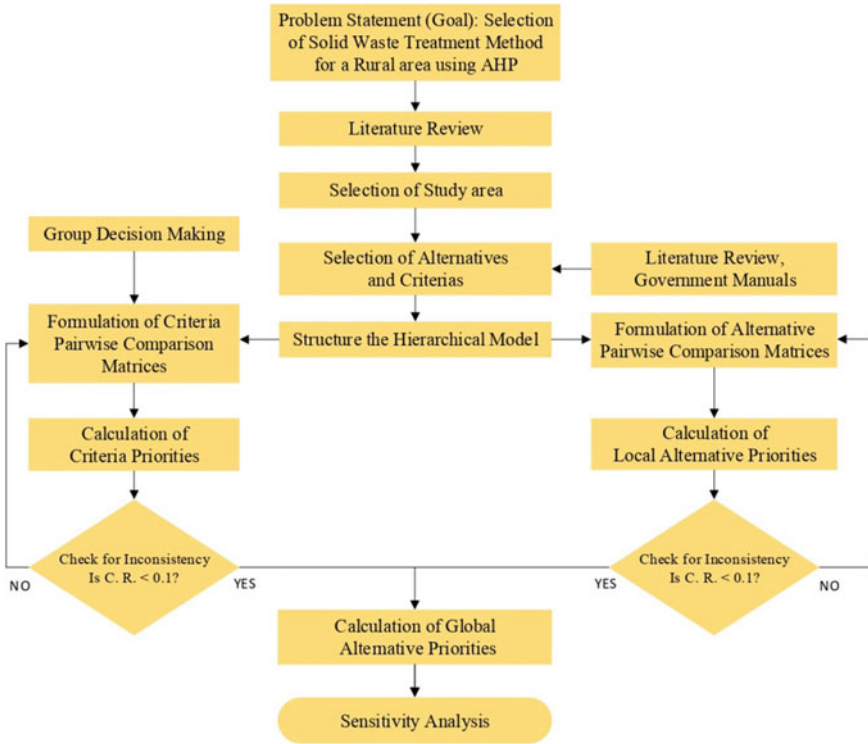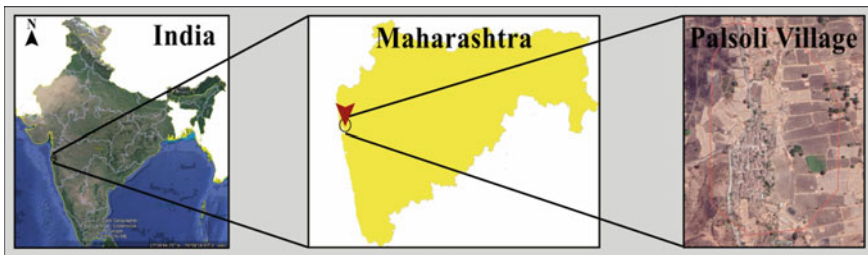
Fig. 1 Study methodology flowchart

Fig. 2 Palsoli village. *Source* Google Earth

waste treatment method for the village which will help the local authorities to develop and implement a sustainable solid waste management system in the village.

3.3 About Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process is a theory of relative measurement which was developed by Saaty during 1971–75 (Saaty 1987). It is a comprehensive framework which is designed to make multi-objective, multi-criterion, and multi-actor decisions involving finite number of alternatives (Harker and Vargas 1987). It reduces a multi-dimensional problem into a one-dimensional one and determines decisions by a vector of priorities which gives an ordering of the different possible outcomes (Saaty 2006). There are three major concepts behind AHP: analytic, hierarchy, and process, as described by Harker (1989). Analytics refers to the use of numbers and mathematical/logical reasoning involved in the AHP; Hierarchy refers to the structuring of decision problems into levels based on one's understanding of the problem. By breaking the problem into various levels, the decision-maker can easily focus on smaller sets of decisions, and the Process term signifies the natural process of decision-making which involves decision-makers' meetings, debating, revision of priorities, etc. AHP is based on a set of axioms that provide the theoretical basis for the method. These axioms are given by Saaty and Kułakowski (2016) and are briefly described below:

- **Axiom 1**: Reciprocal Judgments—The pairwise comparison matrix is formed based on this axiom. As per this axiom, if an element of a comparison matrix (A) belonging to ith row and jth column is given as a_{ij} then the element belonging to jth row and ith column a_{ji} is given as, $a_{ji} = 1/a_{ij}$. This results in the formation of a positive reciprocal matrix.
- **Axiom 2**: Homogenous Elements—According to this axiom elements present in a particular level of hierarchy must be comparable. Infinite preferences are not allowed when comparing alternatives or criteria.
- **Axiom 3**: Hierarchic or feedback dependence structure—This axiom sets the basis for the formulation of a decision problem into a hierarchy. A set of elements in a particular level are to be compared with respect to an element in the immediate next higher level.
- **Axiom 4**: Rank order expectations—All the criteria and alternatives which are significant in solving the decision problem must be included in the hierarchy. Addition or deletion of any criteria or alternative should be avoided as this could give different order of ranking.

Due to its ability to solve a complex decision-making problem hierarchically, and quantify intangible criteria, AHP is one of the most widely used MCDA methods and has been used extensively where the evaluation of alternatives is mostly subjective (Tarmudi et al. 2010; Emrouznejad and Marra 2017). The steps involved in AHP as given by Saaty (1994) are enlisted below:

- **Step 1**: Problem Definition.
- **Step 2**: Structure the decision problem into a hierarchical model by establishing goals, criteria, and alternatives and showing their relationships.
- **Step 3**: Formulate pairwise comparison matrices and check for consistency ratio.

- **Step 4**: Determine criteria weights and local alternative weights.
- **Step 5**: Synthesize these results to determine global alternative weights and obtain the ranking of alternatives.
- **Step 6**: Perform sensitivity analysis.

The problem definition step has already been covered in Sect. 3.1. In the subsequent sections, the above steps have been described briefly and applied to the case study.

3.4 Structure the Decision Problem into a Hierarchical Model by Establishing Goals, Alternatives, and Criteria

The hierarchy disintegrates the decision problem into various levels with homogenous elements such as goal, criteria, sub-criteria, and alternatives occupying a specific level in the model. Elements that have a global character, i.e., goal, can be placed at the top level of the hierarchy, followed by a criterion level, then a sub-criteria level (if any), and finally the alternatives at the bottom. The purpose of forming this hierarchy is twofold: (i) It gives overall view of the relationships between these elements and (ii) It helps the decision-maker check whether the issues in each level are of the same order of magnitude, so that comparison can be made only between homogenous elements (Saaty 1990).

Selection of Alternatives

A wide range of methods is available to treat municipal solid waste with each method having its own merits and demerits. Out of the feasible options available for rural areas, three methods viz. Anaerobic Digestion (AD), Vermicomposting (VC), and Windrow Composting (WC) are selected as alternatives for this study. The alternatives are briefly described in the subsequent paragraphs:

Anaerobic Digestion/Biomethanatiom

Anaerobic digestion, also known as Biomethanation, consists of anaerobic digestion of organic matter present in the solid waste by microorganisms that break down the biodegradable material in the absence of oxygen. In this method, there is considerable amount of volume and mass reduction of the input material. The decomposition of the waste mass by microbial activity results in the generation of an odorless and colorless biogas which mainly comprises 55–60% methane and 30–40% carbon dioxide (CO_2). The biogas has high energy value and hence can be used either for cooking/heating applications or for the generation of electricity. The nutrient-rich sludge obtained from anaerobic digestion can be used as manure-based on its composition. Due to the high organic content of the rural solid waste, this method can be considered a viable option for solid waste treatment (Varma 2012; Gupta et al. 2015; Sharholy et al. 2008; Government of India 2016).

Vermicomposting

Vermicomposting is the process of decomposing the biodegradable fraction of solid waste with the help of particular species of earthworms. The end result of the process is the production of vermicompost which is a nutrient-rich, natural fertilizer and soil conditioner. The earthworm species that are efficient in conversion of waste are Pheretima elongate, Eisenia fetida, Lampito mauritii, Perionyx excavatus, Lumbricus rubellus, Eudrilus eugeniae, etc. When compared with normal composting, vermicompost is richer in plant nutrients and has better market price. Along with this, sale of worms can also bring additional revenue. Vermicomposting is typically suited for managing smaller waste quantities. Also the ideal feedstock for vermicomposting is vegetable market waste, kitchen and garden waste, cow dung and agricultural waste which make this technique suitable for rural areas (Varma 2012; Gupta et al. 2015; Sharholy et al. 2008; Government of India 2016).

Windrow Composting

Windrow composting process consists of placing the pre-sorted solid waste in long narrow piles called windrows. The windrows are turned on a regular basis for mixing of composting materials and enhancing the passive aeration process. The size, shape, and spacing of windrows depend on the equipment used for the turning operation. Since waste generated is not huge in rural areas and also due to financial constraints, manual labor can also be used for windrows in place of machinery. At the end of one composting cycle, the finished product is dark brown in color with an earthy smell, fragile, and rich in organic matter content and nutrients, which can be used as manure (Government of India 2016).

Selection of Criteria

The MCDA problem of solid waste treatment methods involves a set of finite number of criteria which govern the prioritization of the alternatives. These criteria are either quantitative or qualitative in nature. Quantitative criteria are objective criteria based on cardinal scales whereas qualitative criteria are subjective criteria based on ordinal scales. In case of subjective criteria, the performance of alternatives has been measured using a five point rating scale of worst, poor, good, very good, and best corresponding to numerical values of 1, 2, 3, 4, and five respectively. In MCDM criteria are also classified as Benefit criteria or Cost Criteria. Benefit criteria are the ones which are to be maximized, i.e., more the performance value of an alternative for the criteria, more will be its priority whereas a cost criteria are the ones which are to be minimized, i.e., lesser the performance value of an alternative for the criteria, more will be its priority. Based on the literature review, ten criteria have been selected which are broadly categorized into four groups: economic, technical, environmental, and social.

Economic criteria represent the cost aspect of the treatment methods. The economic criteria considered in this study are construction cost and annual operation cost. Construction cost is the cost incurred in the construction of the main treatment plant. Annual operation cost includes the salaries of employees, electricity

charges, etc. Technical criteria represent the technical information about the treatment methods. Three technical criteria selected for this study are Land requirement, Cycle Time, and End product benefits. Land requirement is the area of land required for the main treatment plant alone. Cycle Time is the time required for conversion of solid waste into a beneficial end product. End product benefits indicate the types of beneficial products obtained after the completion of cycle time of the treatment method. Environmental criteria represent the threats and harmful effects of a treatment method on the environment and on the health of local people. The environmental criteria considered in this study are Fly nuisance, Odor problems, and Leachate problems. Fly nuisance is the aesthetic trouble caused because of presence of birds, flies, etc. over the waste. Odor problem is one of the serious threats to human health since in certain treatment methods various types of gases are evolved which may cause several diseases. Leachate is the byproduct of solid waste treatment which contaminates the soil as well as the groundwater thereby degrading the environment. Social criteria include the attitude of people toward a particular treatment method. Public acceptance and Employability are the two social criteria selected for this study. Public acceptance indicates the interest of local people in the acceptance of a treatment method. Employability indicated the number of job opportunities created due to the adoption of a treatment method. Table 1 gives information about the criteria used in this study. The technical specifications or the performance values of all the alternatives with respect to each criteria are summarized in Table 2.

The hierarchy model for selecting the best solid waste treatment method is shown in Fig. 3. The model comprises three levels with the goal of the decision-making problem at the top level, followed by the 10 criteria at the intermediate level, and finally the three alternatives at the bottom-most level. All the three alternatives are linked to each criteria and all the 10 criteria are linked to the goal of the problem.

Table 1 Criteria information

General criteria	Specific criteria	Notation	Units/scale	Benefit (B)/cost (C)
Economic	Construction cost	C1	INR	C
	Operation cost	C2	INR	C
Technical	Land requirement	C3	sq. m	C
	Cycle time	C4	Days	C
	End product benefits	C5	5 point scale	B
Environmental	Fly nuisance	C6	5 point scale	C
	Odor problem	C7	5 point scale	C
	Leachate problem	C8	5 point scale	C
Social	Public acceptance	C9	5 point scale	B
	Employability	C10	5 point scale	B

Table 2 Technical specifications of alternatives with respect to each criteria

Alternatives Criteria	Anaerobic digestion (AD)	Vermicomposting (VC)	Windrow composting (WC)
C1	22,09,000[a]	26,83,230[a]	25,98,030[a]
C2	3,88,080[b]	4,33,705[b]	3,88,080[b]
C3	265	654	688
C4	40	75	50
C5	Best (5)	Good (3)	Good (3)
C6	Best (5)	Best (5)	Worst (1)
C7	Poor (2)	Best (5)	Poor (2)
C8	Poor (2)	Best (5)	Good (3)
C9	Poor (2)	Best (5)	Worst (1)
C10	Good (3)	Good (3)	Good (3)

Note
[a]Construction cost is calculated for treatment plant of capacity 0.5TPD and has been calculated using State Schedule of Rates 2019–20, PWD, Government of Maharashtra (2019)
[b]The salaries for employees have been taken from https://paycheck.in and price of earthworms have been taken from https://www.indiamart.com/. Minimum and Wage (2020), Eathworms and for Composting (2020)
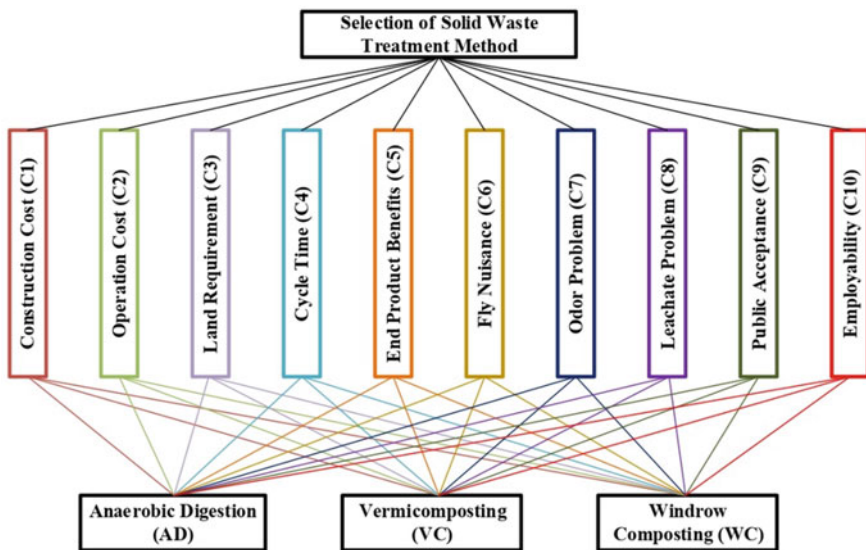

Fig. 3 AHP hierarchy for selection of SWT method

3.5   Formulation of Pairwise Comparison Matrices

Making pairwise comparison lies at the heart of AHP. The manner in which elements of different levels are compared is based on the principle as given by Saaty (2008): The elements of lower level are compared with respect to each element in its immediate upper level only. This indicates that in a three-level hierarchy, all the alternatives lying in the bottom-most level will be compared with respect to each criteria lying in the immediate level above. Similarly, all the criteria will be compared with respect to the goal of the problem. A judgment or comparison is the numerical value expressing relationship between two elements that share a common judgment-making aspect. These pairwise comparisons are made with the help of a fundamental scale of absolute numbers known as Saaty's scale given by Saaty (2008) which is shown in Table 3. Each judgment reflects the importance of one element with respect to another element with which it is compared (Fig. 4).

The judgments can be made either by an individual decision-maker or group of decision-makers. The set of pairwise judgments is represented in a square matrix called the Pairwise Comparison Matrix or Judgmental Matrix (*A*). The order of matrix *A*, represented as *n*, will be equal to the number of elements present in a level

Table 3   Saaty's fundamental scale of absolute numbers (Saaty 2008)

| Intensity of importance	Explanation
1	Element *A* and *B* are of equal importance
3	Element *A* is more moderately important than *B*
5	Element *A* is strong important than *B*
7	Element *A* is very strong or demonstrated more important than *B*
9	Element *A* is extremely more important than *B*
2 or 4 or 6 or 8	Indicates intermediate importance between 1 and 3, 3 and 5, 5 and 7, 7 and 9, i.e., Weak or slight, Moderate plus, Strong plus, and Very, very strong importance, respectively
1.1–1.9	If the importance of elements is very close to each other
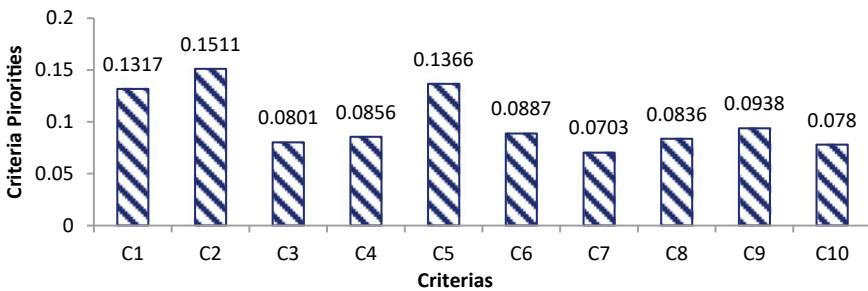
Fig. 4   Graph of criteria weights

of hierarchy. The judgmental value of ith row and jth column is denoted as a_{ij}. The entire matrix A is filled based on axiom 1. Hence the total number of comparisons to be made to fill the judgmental matrix is $\{[n \times (n-1)]/2\}$.

Pairwise Comparison Matrix or Judgmental Matrix (A)

$$= \begin{bmatrix} a_{11} & \ldots \ldots & a_{1n} \\ \vdots & \ddots \quad \cdots & \vdots \\ \vdots & \cdots \quad \ddots & \vdots \\ a_{n1} & \ldots \ldots & a_{nn} \end{bmatrix}_{n \times n}$$

Since the case study involves three alternatives and 10 criteria, 10 judgmental matrices would be formulated with alternatives as to the elements for comparison with respect to each criteria; and one judgmental matrix would be formulated with criteria as the elements for comparison with respect to the goal. Hence a total of 11 judgmental matrices will be formed. In the study, the criteria judgmental matrix and hence criteria weights have been obtained using group judgment-making process. A group of 10 decision-makers was formed comprising of academia professionals, industry experts, and local administrative heads. The pairwise comparisons were collected and aggregated through AHP Online System (AHP-OS) (Goepel 2018). However, since filling up these matrices is a time-consuming task, the alternative judgmental matrices were filled by authors alone based on the technical specifications.

3.6 Calculation of Criteria and Local Alternative Weights

Once the pairwise comparison matrices are formed, the next step is to calculate the priorities (weights) of criteria with respect to goal and alternative weights with respect to each criterion, also called the local alternative weights. This leads to the formation of respective priority vectors. The priority vectors are found using column normalization method (Saaty and Hu 1998). First, normalized values (r_{ij}) of all the performance values in a matrix are calculated using Eq. (1) and then simple arithmetic mean is taken along the row using Eq. (2) to get the priority (w_i).

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

$$w_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} \tag{2}$$

where n is the order of the square matrix; i is the row number; and j is the column number. The criteria priority vector is denoted as $W = (w_1, w_2, \ldots, w_p)^T$, where w_1, $w_2, \ldots, w_p$ are the criteria priorities or weights and p is the total number of criteria.

The local priority vector of alternatives for a criteria C_q is given as $L_q = (L_{1q}, L_{2q}, \ldots, L_{mq})^T$, where $L_{1q}, L_{2q}, \ldots, L_{mq}$ are the local alternative priorities or weights, m is the total number of alternatives and q is the criteria number. Hence for p number of criteria there will be p number of local priority vectors formed. The local alternative priorities in the priority vector can be represented in two modes: (i) Distributive mode and (ii) Ideal mode. In distributive mode, the priorities of alternatives for each criterion are kept in the same form as obtained after using Eqs. (1) and (2). In Ideal mode, the priorities of the alternatives for each criterion are divided by the largest value among them. The Ideal mode eliminates the problem of rank reversal which exists in distributive mode, which may occur due to addition or deletion of an alternative (Saaty and Hu 1998). In this study, the local alternative priorities have been used in both the modes to determine the global alternative priorities.

3.6.1   Check for Consistency

Once the priority vectors are determined for respective pairwise comparison matrices, a crucial step in AHP is to check the consistency of judgmental matrix. Consistency is the correctness of pairwise comparisons. A matrix is said to be consistent when $a_{ik} = a_{ij} \times a_{jk}$ for i, j, and k = 1, 2, …, n. However, inconsistency is inevitable in judgments, especially when number of elements to be compared is more. In AHP an inconsistency of lower order of magnitude of 10% is considered a tolerable error. Saaty proposed an eigenvalue approach to measuring the level of inconsistency in a pairwise comparison matrix. According to this approach, a consistent pairwise comparison matrix A of order n will have its principal eigenvalue equal to the order of matrix n. However, when the matrix is inconsistent, the principal eigenvalue will always be more than equal to n. This principle eigenvalue is denoted as $\lambda_{\max}$. The difference between $\lambda_{\max}$ and n measures the deviation of the judgments from the consistent approximation. This difference is used in the formation of a Consistency Ratio (C.R.) which indicates level of inconsistency of the matrix. The Consistency Ratio (C.R.) is given by:

$$C. R. = \frac{CI}{RI} \tag{3}$$

where CI is the Consistency Index and RI is the average Random consistency Index. The Consistency Index (CI) is given by $(\lambda_{\max} - n)/(n - 1)$. The average Random Consistency Index (RI) value is obtained from Table 4 based on the order of the matrix, as given by Saaty. The principal eigenvalue is obtained by solving the linear

Table 4 R. I. Values based on order of matrix (n) (Saaty 1994)

n	1	2	3	4	5	6	7	8	9	10
R. I	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

algebra problem of $A \times w = \lambda_{\max} \times w$, where A is the judgment matrix and w is the respective priority vector. The value of $\lambda_{\max}$ is calculated as:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{A \times w}{w_i} \tag{4}$$

where w_i is the criteria weight. The value of Consistency Ratio (C. R.) must be less than 10%. If this value is not less than 10% then the decision-maker needs to revise the judgments and find the priority vectors again.

3.7   Calculation of Global Alternative Weights

After the inconsistencies in criteria priority vectors and local alternative priority vectors are found to be within permissible limits, the local alternative priority vectors are synthesized to find the global alternative priority vector by combining all the local alternative weights in one matrix and multiplying that matrix with the criteria weights. The global alternative priority vector is represented as $G = (g_1, g_2, \ldots, g_m)^{\mathrm{T}}$, where $g_1, g_2, \ldots, g_m$ is the global alternative weights. The global alternative priority vector is determined as follows:

$$G = \begin{bmatrix} g_1 \\ g_2 \\ \ldots \\ g_m \end{bmatrix}_{m \times 1} = \begin{bmatrix} L_{11} & L_{12} & \cdots & L_{1p} \\ L_{21} & L_{22} & \cdots & L_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ L_{m1} & L_{m2} & \cdots & L_{mp} \end{bmatrix}_{m \times p} \times \begin{bmatrix} w_1 \\ w_2 \\ \ldots \\ w_p \end{bmatrix}_{p \times 1} \tag{5}$$

The ranking of alternatives is obtained based on the global alternative weights. The alternatives are ranked in the decreasing order of their weights. The alternative having the highest weight is ranked first and is considered the most suitable solution while the alternative having the lowest weight is be ranked last and is considered the least suitable solution.

3.8   Sensitivity Analysis

According to Dantzig (1963), "Sensitivity analysis is a fundamental concept in the effective use and implementation of quantitative decision models, whose purpose is to assess the stability of an optimal solution under changes in the parameters". The goal of sensitivity analysis is to determine the robustness of the results obtained through decision-making process by examining the effect on the ranking of the alternatives by modifying the criteria weights (Babalola 2015). The advantage of sensitivity

analysis can hardly be overlooked in applications of MCDM techniques to real-life problems as it helps the decision-maker to effectively focus more on the sensitive parts of a given MCDM problem (Triantaphyllou and Sánchez 1997). In this study, sensitivity analysis is carried out by taking different scenarios into consideration. In each scenario, the criteria weights are varied to check for variation in the final rankings of the alternatives. Based on the ranking of the criteria priorities obtained from the group decision-making results, six scenarios have been established which are described below:

- **Scenario 1**: The topmost criteria have been assigned criteria weight of 1.000 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 2**: The top two criteria have been assigned criteria weight of 0.500 and all remaining criteria have been assigned criteria weight 0.000.
- **Scenario 3**: The top four criteria have been assigned criteria weight of 0.250 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 4**: The top five criteria have been assigned criteria weight of 0.200 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 5**: The top eight criteria have been assigned criteria weight of 0.125 and all remaining criteria have been assigned criteria weight of 0.000.
- **Scenario 6**: All criteria have been assigned equal criteria weight of 0.100.

4 Results and Discussions

4.1 Criteria Priorities and Local Alternative Priorities

The result of group decision-making process for the calculation of criteria weights is shown in Table 5. The graphical representation of criteria weights is shown in Fig. 5.

The economic criterion of Operation Cost (C2) has been considered the most important criteria by the group in the selection of most suitable SWT method and has the highest priority of 0.1511. It is followed by End Product Benefits (C5) and Construction Cost (C1) having priorities of 0.1366 and 0.1317, respectively. On the other hand, Odor Problem (C7), an environmental criterion, has the least priority of 0.0703. However, this is not the case with other environmental criteria of Fly nuisance (C6). It has a priority of 0.0887 and ranks fifth in the list whereas Leachate Problem (C8) ranks seventh in the entire list. Public Acceptance (C9) which is a social criterion has been considered the fourth most important criteria in determination of alternative priorities whereas Employability (C10) has been ranked last but one in

Table 5 Criteria priorities

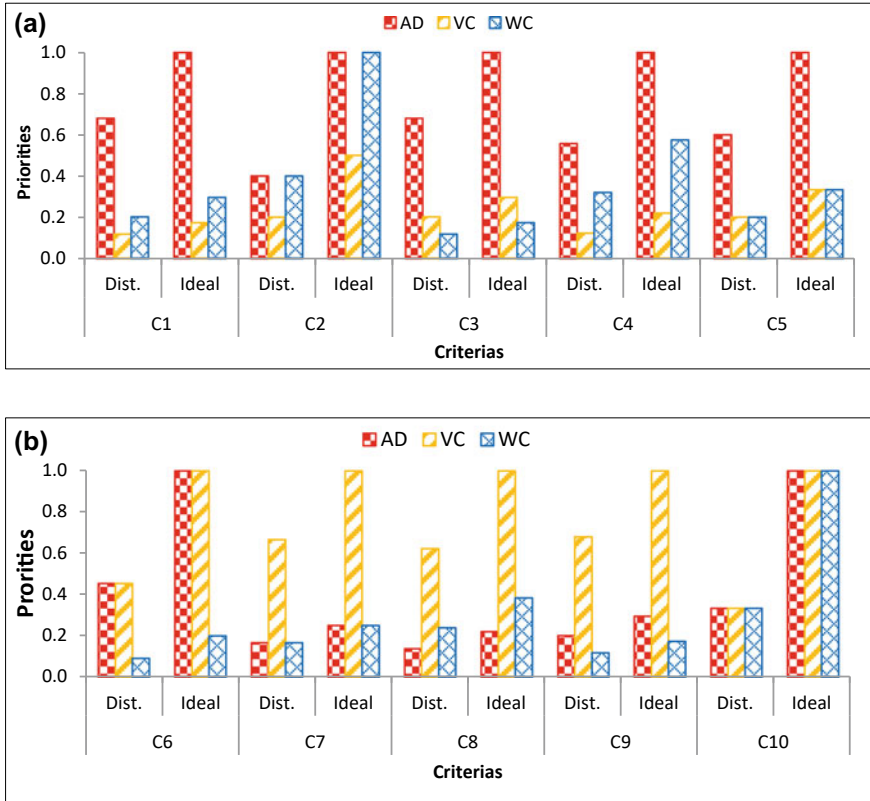| Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Priorities	0.1317	0.1511	0.0801	0.0856	0.1366	0.0887	0.0703	0.0836	0.0938	0.078

C. R. = 0.0271

Fig. 5 **a** Comparison graph of Local alternative priorities in distributive and ideal mode for criteria C1 to C5. **b** Comparison graph of local alternative priorities in distributive and ideal mode for criteria C6 to C10

the list. Cycle Time (C4) and Land Requirement (C3), both technical criteria, have been considered of moderate importance as they have been ranked sixth and eighth on the list. The Consistency Ratio (C. R.) of the pairwise comparisons of entire group is 0.0271 which is less than 0.1 and hence these criteria priorities have been used to find the final rankings of the alternatives.

The pairwise comparison matrices for alternatives with respect to each criterion are shown in Tables 6 and 7. All the comparison matrices have C. R. less than 0.1 which indicates that the inconsistencies are within the acceptable limits.

Tables 8 and 9 show the local alternative priorities with respect to each criterion in distributive mode and ideal mode, respectively. Based on technical specification of alternatives with respect to each criterion, the preferences of local alternative priorities are also obtained in the same manner. For all the cost criteria, alternatives having minimum performance value have the highest priority whereas, for all the benefit criteria, alternatives having maximum performance value have the highest priority. The ideal mode gives a much better understanding of the preferences when

Table 6 Pairwise comparison of alternatives with respect to criteria C1 to C5

Ct	C1			C2			C3			C4			C5		
Alt	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC
AD	1	5	4	1	2	1	1	4	5	1	4	2	1	3	3
VC	1/5	1	1/2	1/2	1	1/2	1/4	1	2	1/4	1	1/3	1/3	1	1
WC	1/4	2	1	1	2	1	1/5	1/2	1	1/2	3	1	1/3	1	1
	C.R. = 0.0238			C.R. = 0.0000			C.R. = 0.0238			C.R. = 0.0176			C.R. = 0.0000		

Table 7 Pairwise comparison of alternatives with respect to criteria C6 to C10

Ct	C6			C7			C8			C9			C10		
Alt	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC	AD	VC	WC
AD	1	1	5	1	1/4	1	1	1/4	1/2	1	1/4	2	1	1	1
VC	1	1	5	4	1	4	4	1	3	4	1	5	1	1	1
WC	1/5	1/5	1	1	1/4	1	2	1/3	1	1/2	1/5	1	1	1	1
	C.R. = 0.0000			C.R. = 0.0000			C.R. = 0.0176			C.R. = 0.0238			C.R. = 0.0000		

Table 8 Local alternative priorities with respect to each criterion in distributive mode

Crit	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Alt										
AD	0.6806	0.4000	0.6806	0.5571	0.6000	0.4545	0.1667	0.1373	0.2014	0.3333
VC	0.1179	0.2000	0.2014	0.1226	0.2000	0.4545	0.6667	0.6232	0.6806	0.3333
WC	0.2014	0.4000	0.1179	0.3202	0.2000	0.0909	0.1667	0.2395	0.1179	0.3333

Table 9 Local alternative priorities with respect to each criterion in ideal mode

Crit	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Alt										
AD	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.2500	0.2203	0.2959	1.0000
VC	0.1733	0.5000	0.2959	0.2201	0.3333	1.0000	1.0000	1.0000	1.0000	1.0000
WC	0.2959	1.0000	0.1733	0.5748	0.3333	0.2000	0.2500	0.3843	0.1733	1.0000

compared to distributive mode since the best value will always have priority 1 and the subsequent values will have priorities less than 1. Figure 5a, b shows the comparison of local alternative priorities in Distributive and Ideal mode for Criteria C1 to C5 and Criteria C6 to C10, respectively. Since criteria C1 is cost criteria and Anaerobic Digestion (AD) has the least cost of construction it has the highest priority with respect to criteria C1 whereas Vermicomposting (VC) has the highest cost of construction has the least priority with respect to criteria C1. Anaerobic Digestion (AD) has the highest priority for criteria C2, C3, C4, and C6. For other cost criteria

Table 10 Global Alternative Priorities and Preference for both the modes

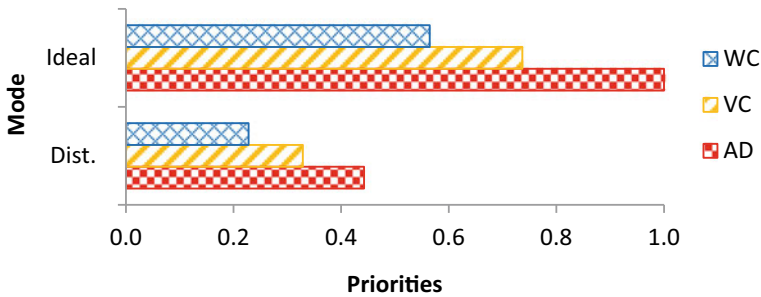| Mode	Alternatives			Preference
	AD	VC	WC	
Distributive	0.4427	0.3288	0.2280	AC ≻ VC ≻ WC
Ideal	1.0000	0.7367	0.5645	AC ≻ VC ≻ WC

Fig. 6 Comparison graph of global alternative priorities

C7 and C8, vermicomposting has the least performance value and hence has the highest priority. For Benefit criteria C5, since Anaerobic Digestion (AD) has the highest performance value, it also has the highest priority. Similarly for criteria C9, Vermicomposting (VC) has the highest priority. Since the performance value of each alternative is same for C10, all the alternatives have same priority.

4.2 Global Alternative Priorities

The global alternative priorities obtained after multiplying the criteria weights with local alternative priorities are shown in Table 10. The priorities have been found separately for both distributive mode and ideal mode. In both the modes, Anaerobic Digestion (AD) has the highest priority while Windrow composting (WC) has the least priority. Vermicomposting (VC) ranks second in both the modes. Figure 6 shows the global alternative priorities as obtained in both the modes.

4.3 Sensitivity Analysis

To check the robustness of the results obtained using AHP, a sensitivity analysis has been performed by adopting a scenario-based approach. Six different scenarios have been constituted in which the criteria weights have been varied to check the variation in the final preferences of the alternatives. The assignment of priorities to criteria

in each scenario is done as per the explanation in Sect. 3.8. Table 11 shows criteria priorities for different scenarios. The result of sensitivity analysis for distributive and ideal mode is shown in Fig. 7a, b and is explained in subsequent paragraphs.

The final preference of alternatives is same for both the modes for each scenario. Also for each scenario in both the modes, Anaerobic Digestion (AD) has the highest priority which is the same as for the group decision-making process. Only for scenarios S1 and S2, the final preference of Vermicomposting (VC) and Windrow Composting (WC) is different from the final preference of group decision-making process. For both these scenarios, WC has more preference than VC. The reason for such variation is the assignment of criteria weights of 1.000 and 0.500 to criteria C2

Table 11 Criteria weights for different scenarios

| Scenario Criteria	Group criteria weights	S1	S2	S3	S4	S5	S6
C1	0.1317	0.000	0.000	0.250	0.200	0.125	0.100
C2	0.1511	1.000	0.500	0.250	0.200	0.125	0.100
C3	0.0801	0.000	0.000	0.000	0.000	0.125	0.100
C4	0.0856	0.000	0.000	0.000	0.000	0.125	0.100
C5	0.1366	0.000	0.500	0.250	0.200	0.125	0.100
C6	0.0887	0.000	0.000	0.000	0.200	0.125	0.100
C7	0.0703	0.000	0.000	0.000	0.000	0.000	0.100
C8	0.0836	0.000	0.000	0.000	0.000	0.125	0.100
C9	0.0938	0.000	0.000	0.250	0.200	0.125	0.100
C10	0.0780	0.000	0.000	0.000	0.000	0.000	0.100
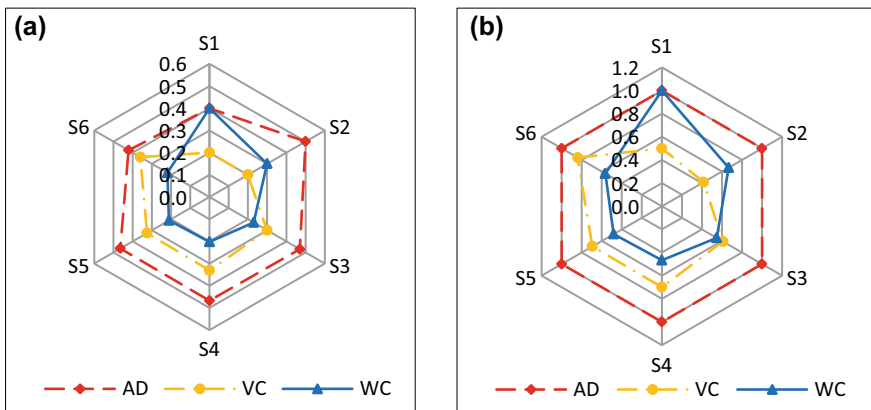
Fig. 7 **a**, **b** Global alternative priorities for different scenarios in distributive mode and ideal mode, respectively

for which the performance value of WC is better than VC. But as the number of non-zero criteria increased in remaining four scenarios S3, S4, S5, and S6 the preference of alternatives appeared exactly same as that for the group decision-making process. Hence the robustness of the decision-making process undertaken is well verified.

5   Conclusion

The problem of solid waste management is increasing day by day in the rural areas due to the growing consumerism, changing lifestyles, etc. Due to this, the need for an effective solid waste management (SWM) system in rural areas can hardly be overlooked. It is crucial to select the most suitable solid waste treatment method for efficient functioning of SWM system. But due to the availability of large number of treatment methods and the involvement of large number of criteria in selecting the most suitable option for a particular area, the decision-making problem becomes challenging. In recent decades, MCDM has emerged as a convenient tool to overcome such challenges in decision-making process. Many MCDM techniques have been developed with each one having its own merits and demerits. AHP is one of the MCDM techniques which is simple to use and hence has been widely used to solve decision-making problems across disciplines including environmental problems. This study highlighted the application of AHP in the selection of the most suitable solid waste treatment method in the context of rural areas. From the application of AHP it has been found that Operation Cost is the most important criterion in the selection of alternatives and the most suitable method for the study area among the options selected is Anaerobic Digestion. Vermicomposting emerged as the second-most suitable option followed by Windrow Composting. A sensitivity analysis has been performed to check the robustness of the decision-making process. From the analysis, it has been found that the most suitable solid waste treatment method for the study area is Anaerobic Digestion only even after the alteration of criteria weights. Hence the robustness of the decision-making process is well verified.

References

Achillas C, Moussiopoulos N, Karagiannidis A, Banias G, Perkoulidis G (2013) The use of multi-criteria decision analysis to tackle waste management problems: a literature review. Waste Manage Res 31(2):115–129. https://doi.org/10.1177/0734242X12470203

Annepu RK (2012) Sustainable solid waste management in India. M.Sc. thesis. Earth Engineering Center, Columbia University, New York

Alessio I, Nemery P (2013) Multi-criteria decision analysis: methods and software, 1st edn. Wiley, West Sussex

Antonopoulos IS, Perkoulidis G, Logothetis D, Karkanias C (2014) Ranking municipal solid waste treatment alternatives considering sustainability criteria using the analytical hierarchical process tool. Resour Conserv Recycl 86:149–159. https://doi.org/10.1016/j.resconrec.2014.03.002

Alfons AB, Padmi T (2018) Multi-criteria analysis for selecting solid waste management concept case study: rural areas in Sentani Lake Region, Jayapura. Indonesian J Urban Environ Technol 2(1):88–101. https://doi.org/10.25105/urbanenvirotech.v2i1.3557

Araiza Aguilar JA, Nájera Aguilar HA, Gutiérrez Hernandez RF, Rojas Valencia MN (2018) Emplacement of solid waste management infrastructure for the Frailesca Region, Chiapas, México, using GIS tools. Egypt J Remote Sens Space Sci 21(3):391–399. https://doi.org/10.1016/j.ejrs.2018.01.004

Babalola MA (2015) A multi-criteria decision analysis of waste treatment options for food and biodegradable waste management in Japan. Environments 2(4):471–488. https://doi.org/10.3390/environments2040471

Bhavita S, Malek SS (2018) A recapitulation on exigency of smart villages in Indian ambience. Int J Adv Eng Res Dev 5(03):1–8. https://doi.org/10.21090/ijaerd.nace19

Bruno G, Genovese A (2018) Multi-criteria decision-making: advances in theory and applications—an introduction to the special issue. Soft Comput 22(22):7313–7314. https://doi.org/10.1007/s00500-018-3531-0

Census of India (2011) Provisional population totals. Office of the Registrar General and Census Commissioner, New Delhi. https://censusindia.gov.in/2011-prov-results/paper2/data_files/india/paper2_1.pdf

Central Public Health and Environmental Engineering Organisation (CPHEEO) (2016) Municipal solid waste management manual, part III. Ministry of Urban Development, Government of India, New Delhi. http://cpheeo.gov.in/upload/uploadfiles/files/Part3.pdf

Central Public Health and Environmental Engineering Organisation (CPHEEO) (2016) Municipal solid waste management manual, part I. Ministry of Urban Development, Government of India, New Delhi (2016). http://cpheeo.gov.in/upload/uploadfiles/files/Part1(1).pdf

Central Public Health and Environmental Engineering Organisation (CPHEEO) (2000) Manual on municipal solid waste management. Ministry of Urban Development, Government of India, New Delhi

Central Pollution Control Board (CPCB) (2016) Selection criteria for waste processing technologies. Ministry of Environment, Forest and Climate Change, Government of India, New Delhi. http://cpcb.nic.in/SW_treatment_Technologies.pdf

Central Public Health and Environmental Engineering Organization (CPHEEO) (2016) Municipal solid waste management manual, part II. Ministry of Urban Development, Government of India, New Delhi. http://cpheeo.gov.in/upload/uploadfiles/files/Part2.pdf

Dantzig GB (1963) Linear programming and extensions. RAND Corporation, Santa Monica, CA. https://www.rand.org/pubs/reports/R366.html

Emrouznejad A, Marra M (2017) The state of the art development of AHP (1979–2017): a literature review with a social network analysis. Int J Prod Res 55(22):6653–6675. https://doi.org/10.1080/00207543.2017.1334976

Goepel KD (2018) Implementation of an online software tool for the analytic hierarchy process (AHP-OS). Int J Anal Hierarchy Process 10(3):469–487. https://doi.org/10.13033/ijahp.v10i3.590

Government of India, Solid and liquid management in rural areas: a technical note. Department of Drinking Water Supply, Ministry of Rural Development, New Delhi. https://swachhbharatmission.gov.in/sbmcms/writereaddata/images/pdf/technical-notes-manuals/SLWM-in-Rural-Areas-Technical-Note.pdf

Guidelines for Swachh Bharat Mission (Gramin) (2018) Ministry of Drinking Water and Sanitation, Government of India, New Delhi. https://jalshakti-ddws.gov.in/sites/default/files/SBM(G)_Guidelines.pdf

Gupta N, Yadav KK, Kumar V (2015) A review on current status of municipal solid waste management in India. J Environ Sci 37:206–217. https://doi.org/10.1016/j.jes.2015.01.034

Harker PT, Vargas LG (1987) Theory of ratio scale estimation: Saaty's analytic hierarchy process. Manage Sci 33(1):1383–1403. https://doi.org/10.1287/mnsc.33.11.1383

Harker PT (1989) The art and science of decision making: the analytic hierarchy process. In: Golden BL, Wasil EA, Harker PT (eds) The analytic hierarchy process. Springer, Heidelberg, pp 3–36. https://doi.org/10.1007/978-3-642-50244-6_2

Huang IB, Keisler J, Linkov I (2011) Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. Sci Total Environ 409(19):3578–3594. https://doi.org/10.1016/j.scitotenv.2011.06.022

Indiamart Live Eathworms for composting. https://www.indiamart.com/proddetail/vermiculture-earthworm-11265286812.html. Last Accessed 12 July 2020

Jaiswal AK, Satheesh TA, Pandey K, Kumar P, Saran S (2018) Geospatial multi-criteria decision based site suitability analysis for solid waste disposal using topsis algorithm. ISPRS Ann Photogramm Remote Sens Spatial Inf Sci 4(5):431–438. https://doi.org/10.5194/isprs-annals-IV-5-431-2018

Jovanovic S, Savic S, Jovicic N, Boskovic G, Djordjevic Z (2016) Using multi-criteria decision making for selection of the optimal strategy for municipal solid waste management. Waste Manage Res 34(9):884–895. https://doi.org/10.1177/0734242X16654753

Kaza S, Yao L, Bhada-Tata P, Van Woerden FV (2018) What a waste 2.0: a global snapshot of solid waste management to 2050. Urban Development Series. World Bank, Washington. https://doi.org/10.1596/978-1-4648-1329-0

Kermani M, Nouri J, Omrani GA, Arjmandi R (2014) Comparison of solid waste management scenarios based on life cycle analysis and multi-criteria decision making (case study: Isfahan City). Iran J Sci Technol (Sci) 38(3):257–64. https://doi.org/10.22099/ijsts.2014.2271

Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, Bansal RC (2017) A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew Sustain Energy Rev 69:596–609. https://doi.org/10.1016/j.rser.2016.11.191

Kiker GA, Bridges TS, Varghese A, Seager TP, Linkov I (2005) Application of multicriteria decision analysis in environmental decision making. Integr Environ Assess Manag 1(2):95–108. https://doi.org/10.1897/IEAM_2004a-015.1

Madadian E, Amiri L, Abdoli MA (2013) Application of analytic hierarchy process and multicriteria decision analysis on waste management: a case study in Iran. Environ Prog Sustain Energy 32(3):810–817. https://doi.org/10.1002/ep.11695

Maharashtra Gram Panchayat Minimum Wage. https://paycheck.in/salary/minimumwages/18640-maharashtra/18851-gram-panchayat. Last Accessed 12 July 2020

Mardani A, Jusoh A, Nor KMD, Khalifah Z, Zakwan N, Valipour A (2015) Multiple criteria decision-making techniques and their applications—a review of the literature from 2000 to 2014. Econo Res Ekonomska Istraživanja 28(1):516–571. https://doi.org/10.1080/1331677X.2015.1075139

Ministry of Drinking Water and Sanitation Government of India, New Delhi (2015) Technological options for solid and liquid waste management in rural areas. https://www.susana.org/_resources/documents/default/3-2322-7-1442317620.pdf

Multi-criteria analysis: a manual (2009) Department for Communities and Local Government, London. http://www.communities.gov.uk/documents/corporate/pdf/1132618.pdf

Pipatti R, Sharma C, Yamada M (2006) Chapter 2: Waste generation, composition and management data. IPCC Guidelines for National Greenhouse Gas Inventories, Kanagawa. https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_2_Ch2_Waste_Data.pdf

Public Works Department (PWD) (2019) State schedule of rates 2019–20. Government of Maharashtra, Mumbai

Ramesh R, SivaRam P (2016) Solid waste management in rural areas: a step-by-step guide for Gram Panchayats. Centre for Rural Infrastructure (CRI), National Institute of Rural Development and Panchayati Raj (NIRD&PR), Hyderabad. http://nirdpr.org.in/nird_docs/sb/doc5.pdf

Saaty RW (1987) The analytic hierarchy process-what it is and how it is used. Math Modell 9(3–5):161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty TL (2006) The analytic network process. Archive of SID. Network 1(1):1–26. http://www.springerlink.com/index/p9r45787g7u914n9.pdf

Saaty T, Kułakowski K (2016) Axioms of the analytic hierarchy process (AHP) and its generalization to dependence and feedback: the analytic network process (ANP), pp 1–12. http://arxiv.org/abs/1605.05777

Saaty TL (1994) How to make a decision: the analytic hierarchy process. INFORMS J Appl Anal 24(6):19–43. https://doi.org/10.1287/inte.24.6.19

Saaty TL (1990) How to make a decision: The analytic hierarchy process. Eur J Oper Res 48(1):9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Saaty TL, Hu G (1998) Ranking by eigenvector versus other methods in the analytic hierarchy process. Appl Math Lett 11(4):121–125. https://doi.org/10.1016/S0893-9659(98)00068-8

Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1):83–98

Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities—a review. Waste Manage 28(2):459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Soltani A, Hewage K, Reza B, Sadiq R (2015) Multiple stakeholders in multi-criteria decision-making in the context of municipal solid waste management: a review. Waste Manage 35:318–328. https://doi.org/10.1016/j.wasman.2014.09.010

Tarmudi Z, Abdullah ML, Tap AOM (2010) Evaluating municipal solid waste disposal options by AHP-based linguistic variable weight. Matematika 26(1):1–14. https://doi.org/10.11113/MATEMATIKA.V26.N.554

Triantaphyllou E, Sánchez A (1997) A sensitivity analysis approach for some deterministic multi-criteria decision-making methods. Decis Sci 28(1):151–194. https://doi.org/10.1111/j.1540-5915.1997.tb01306.x

United Nations (2019) World population prospects 2019, Online edn, Rev 1. Population Division, Department of Economic and Social Affairs. Retrieved from: https://population.un.org/wpp/Download/Standard/Population/

Varma RA (2012) Technology options for treatment of municipal solid

Vučijak B, Kurtagić SM, Silajdžić I (2016) Multicriteria decision making in selecting best solid waste management scenario: a municipal case study from Bosnia and Herzegovina. J Clean Prod 130:166–174. https://doi.org/10.1016/j.jclepro.2015.11.030

Valerie B, Stewart TJ (2002) Multiple criteria decision analysis: an integrated approach. Springer, Boston. https://doi.org/10.1007/978-1-4615-1495-4

Zhu D, Asnani PU, Zurbrügg C, Anapolsky S, Mani S (2008) Improving municipal solid waste management in India : a sourcebook for policy makers. World Bank Institute Resources. World Bank, Washington. https://doi.org/10.1596/978-0-8213-7361-3