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Selection of the optimal medical waste incineration facility location: A challenge of medical waste risk management

Izbor optimalne lokacije postrojenja za spaljivanje medicinskog otpada: izazov u upravljanju rizikom od medicinskog otpada

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Abstract

Background/Aim. Among the other challenges of the 21st century, medical waste (MW) has become an arising problem for both the environment and people because of its increasing amount, variety, and complexity. That is way MW management has become one of the very important ecological imperatives. Serbia with no potential for appropriate disposal of all MW is forced to export MW to countries with MW incineration facilities. Incineration lowers the possible risks of inappropriate disposal and the emission of environmental pollutants, but leads to the need for a "clever" choice of the incinerator facility location which has to meet diverse environmental, economic and technical criteria **Methods.** The criteria for the choice of optimal locations for a MW incinerator facility were as follows: the amount of MW that needs to be transported, the transport time from other locations, the current pollution of the location, the unemployment rate and the location safety in terms of natural disasters and accidents. By using the obtained results for seven efficient locations gained by Data Envelopment Analysis (DEA), we used a goal programming for the analysis of the most suitable location for a MW incineration facility. **Results.** In the proposed methodology on the chosen scenario and analysing the criteria relevant for selecting the most suitable location, using the DEA method, seven efficient locations for MW incineration facility were obtained. The optimal location was location 13. **Conclusion.** Based on the obtained results, we demonstrated that by the use of goal programming it is possible to develop a methodology for selection of optimal MW incineration facility location as one of the necessary activities of MW risk management.

Key words:
environment; incineration; medical waste; medical waste disposal; risk control.

Apstrakt

Uvod/Cilj. Među izazovima 21. veka, medicinski otpad (MO) je, imajući u vidu povećanje njegove količine, raznovrsnost i kompleksnost, postao rastući problem kako za životnu sredinu, tako i za ljude. Zbog toga je upravljanje MO postalo jedan od veoma važnih ekoloških imperativa. Srbija nema potencijala za adekvatno odlaganje celokupnog MO i mora da ga izvozi u zemlje koje imaju postrojenja za njegovo spaljivanje. Spaljivanje MO smanjuje moguće rizike prouzrokovane njegovim neodgovarajućim odlaganjem kao i emisije zagađivača životne sredine, ali rezultira potrebom za „pametnim" izborom lokacije za postrojenja za spaljivanje da bi bili ispunjeni različiti ekološki, ekonomski i tehnički kriterijumi. **Metode.** Za izbor optimalne lokacije postrojenja za spaljivanje MO korišćeni su sledeći kriterijumi: količina MO koja mora da se transportuje, vreme transporta između lokacija, trenutno zagađenje lokacije, stopa nezaposlenosti i bezbednost lokacije u odnosu na njenu izloženost prirodnim nepogodama i nesrećama. Korišćenjem rezultata za sedam efikasnih lokacija dobijenih metodom *Data Envelopment Analysis* (DEA), upotrebili smo model ciljnog programiranja za dalju analizu izbora najpogodnije lokacije za postrojenje za spaljivanja MO. **Rezultati.** Primenom metode DEA za izabrani scenario i analize kriterijuma relevantnih za izbor najpogodnije lokacije, nađeno je sedam efikasnih lokacija za postrojenje za spaljivanje MO. Optimalna lokacija je bila lokacija 13. **Zaključak.** Na osnovu dobijenih rezultata, pokazali smo da je primenom ciljnog programiranja moguće razviti metodologiju za selekciju optimalne lokacije za postrojenje za spaljivanje MO, kao jedne od neophodnih aktivnosti za upravljanje rizikom od MO.

Ključne reči:
životna sredina; spaljivanje; medicinski otpad; medicinski otpad, odlaganje; rizik, kontrola.

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Introduction

Over the past two decades, medical waste (MW) has become one of the most important topics, having in mind its negative impact on the health of the population and the environment [1–4]. Several terms are used for MW both in literature as well as practice: “hospital waste”, “health care waste”, “infectious waste” or “pharmaceutical waste” [2]. Since there is no single universal term for this type of waste, there is also no universally accepted definition of MW. The reason for this lies in the fact that MW is determined by various laws and regulations, resulting in the evidence that different countries, even different regions of the same country, imply different types of waste as MW [2, 5, 6]. Knowing this, MW can be defined as: “waste resulting in the provision of health care services, which includes a variety of materials, of used needles and syringes, body parts, diagnostic samples, blood, chemicals, pharmaceuticals, medical devices and radioactive materials” [7]; “all medical, liquid or gaseous wastes which are generated from healthcare facilities, medical laboratories, research centers, pharmaceutical and veterinary factories, veterinary clinics, home nursing institutions; human and animal remnants, body fluids; blood and derivatives, human excreta, contaminated clothing, wipes, injectors, contaminated sharp tools, expired medicines and chemicals” [8]; “heterogenous mixture of communal waste, infectious, pathoanatomical, pharmaceutical and laboratory waste, disinfectants and packages, as well as chemical waste from health care institutions and veterinary organizations” [9].

Having in mind that all of the various types of MW can imply different negative impacts, special attention has been given to appropriate treatment and disposal of MW, as well as necessary MW management (MWM) [10, 11]. Consequently, all types of health care institutions must be “in standby mode” in situations that include the possible creation of MW [12], especially when the generated MW can cause potential injuries to medical staff and the general public (directly in contact with MW or indirectly) [5, 12, 13]. This is especially important given that according to the World Health Organization (WHO) and the USA Environmental Protection Agency, 10–25% of MW falls into the category of hazardous MW [14], and that “the global trend in rising healthcare usage will result in more medical waste” [5]. Besides, inadequate MWM can lead to the risk of this waste, too [5, 15–19]. That is why research in the field of risks related to MW began in the 1990s. These MW risks include: “environmental pollution, such as water, air, soil, result in unpleasant odors, promoting the growth and multiplication of insects, rodents and vermin, and can lead to the transmission of diseases such as typhoid, cholera, human immunodeficiency virus (HIV) and hepatitis (B and C)” [20, 21].

For these reasons, some authors use the general division of MW into medical general waste (or nonhazardous waste) and medical hazardous waste. The second type of waste is considered as medical risk waste [22]. Also, it is concluded that MWM, and medical waste risk management (MWRM) must be necessary parts of the management of any healthcare institutions/facilities, bearing in mind that “healthcare organizations are routinely in a state of crisis management” [23]. Interestingly, the modern concept of crisis originates from medical literature in which it indicates a dangerous state of health of the organism from which it can not recover without permanent damage, external intervention or without fundamental restructuring since the body's defense (immune) mechanisms are not enough to pull the organism out of the crisis. Social scientists have borrowed this basic medical metaphor to describe the crisis in economic, political, social, and cultural systems [24]. Crisis management can be defined as an activity aimed at planning and implementing measures to resolve dangerous situations. As an area of action in the field of crisis resolution, whose goal is to overcome the crisis, crisis management has recently become a dominant area of interest in all organizations, including health institutions. Taking measures of crisis management in health care as an important area of functioning of human society is a specific subject of crisis management. The foundations of crisis management in healthcare are based on the creation of knowledge and the ability to respond to a crisis, and one of the goals of crisis management is both MWM and MWRM.

The main goal of health crisis management is to reduce the risk to the life of the population that has been imposed on potential crisis situations. The secondary goal is to reduce damage, ensure public safety during the crisis and the consequences of the crisis, and care for survivors and victims. It is certainly necessary to mention here the risk analysis, i.e. the assessment of vulnerability and risk that are complementary aspects of the same phenomenon; interactions of physical forces with human or environmental systems. Therefore, risk analysis and management in the MWM process include identification, hazard analysis as well as taking measures related to exposure to these hazards to prevent a crisis. This is extremely important because medical institutions have a special responsibility for making quality decisions based on quantitative methods, the results of which provide a comprehensive and exact basis for efficient MWM (where efficiency can be defined “by the phrase ‘do things right’” [25]). Some of the most commonly used methods include Risk matrix, Failure Mode Effects Analysis (FMEA), Root Cause Analysis (RCA), Event tree analysis (ETA), Data Envelopment Analysis (DEA), Preliminary Hazard or Risk Analysis (PHA/PRA), Hazards and Operability Study (HAZOPs), Fault Tree Analysis (FTA), goal programming and others whose task is to identify, quantify, and mitigate the risks of MW [22]. Thus, obtained quantitative indicators in the process of crisis management, allow to align organizational resources with the goal of carrying out the mission of the organization as well as to improve the awareness of all involved stakeholders about the importance of MWM.

This is crucial nowadays, having in mind the current global COVID-19 pandemic and its rapid progress [26, 27] with the consequential rise of the amount of infectious MW and the need for improvements in the field of MW disposal, MWM, and MWRM to reduce the further spread of COVID-19 as well as other diseases.

Unfortunately, for the time being, there is no method of optimal MWM, treatment, or disposal of MW that eliminates all of the risks caused by MW to humans or the environment [28]. This is especially the case in Serbia, which produces a large amount of MW and there is no systematic presentation of data on the amount of MW generated in health care institutions. It is estimated that 48,000 tons of MW are generated annually in clinics and hospitals in Serbia, of which 9,600 tons are hazardous MW (of which 5,300 tons are generated in hospitals, 2,410 tons in health centers, 1,700 in other dispensaries, and 200 tons in health protection institutions) [9, 29].

In health care facilities, where there was no possibility of sterilization of used syringes and needles, swabs, bandages, and other infectious waste, typical waste was mixed with municipal waste and referred to the city dump [30]. Besides the installed autoclaves and shredders for sterilization of MW in Serbia, there are no other modern facilities for MW treatment, especially its incineration [9]. Knowing all that, it is no surprise that establishing MWM and incineration facilities is included within the goals of Waste Management Strategy for Serbia for the period 2010–2019 [9]. The incineration of MW is one of the methods to reduce and remove MW. The main advantages of this type of MW treatment include a significant reduction in the quantity of waste, eliminating dangerous pathogens and organic matter, transforming waste into ash. A downside to this method of MW disposal is emissions of pollutants such as dioxins and furans [e.g. polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF)], toxic metals, as well as particulate matter, which have negative impacts on the environment and human health [30–32] because they “have been associated with a range of adverse health effects” [7].

Under the framework of the European Commission's Guidelines for Waste and the National Strategy of the Republic of Serbia for waste management, the treatment of MW by incineration is carried out concerning all defined rules and regulations regarding possible emissions to air, water and land [9, 33]. Nevertheless, the fact that waste incineration creates energy must be considered in the context of an integrated approach to waste management, which should include reduction, reusing, and recycling [9].

These are the reasons why this study emphasizes adequate MWM, which involves solving the optimal location, routing and scheduling problems of MW collection, and incineration, as it is shown as good practice in other countries [32–42]. This is especially significant today when authors like Yu et al. [43] prove the importance of MW and optimization of its disposal as one of the key tools in searching for possible solutions during the COVID-19 pandemic. Therefore, the aim of this study was to develop an appropriate methodology for selecting the optimal location for a MW incineration facility as one of the necessary activities of MWM and MWRM. For these reasons and due to the availability of data, the region of Šumadija and Western Serbia and one scenario were selected.

Methods

One of the long-term goals of the Strategy on Waste Management of Serbia is defined as the provision of capacity for MW incineration. This implies the necessary choice of most favorable location for it. The methodology presented in the study shows that it is first necessary to determine a region from which potential locations and criteria will be selected, which will then lastly provide us with the optimal location for the MW incineration facility. Selected efficient locations used in this research were obtained from the results of previous research of Stanojević et al. [44]. The final results refer to the application of the DEA method and are used further on for choosing an optimal location by goal programming. The location selection process is presented in Figure 1

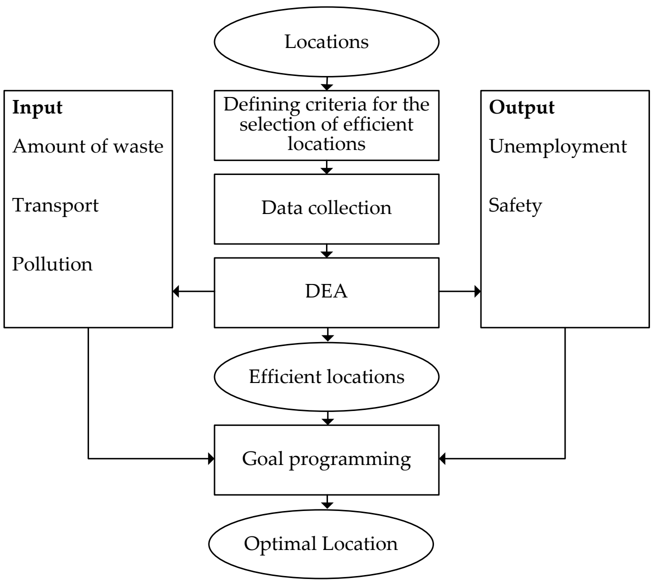

Fig. 1 – The selection procedure for an efficient and optimal location. DEA – Data Envelopment Analysis.

(the results of Stanojević et al. [44] were complemented).

The first step of choosing a location was to consider the geo-economic map of Serbia, which is divided into 30 administrative areas, 29 cities, 30 urban municipalities, 149 municipalities, 6,158 villages, and 193 urban settlements [45]. Regions according to the number of cities, population, area, the number of cities/municipalities with more than 40,000 inhabitants (this number is determined based on the city with the smallest population in Serbia, which is Prokuplje with 44,000 inhabitants [46]) and the number of health facilities [47] are given in Table 1.

Table 1

Regions according to the number of cities, population, area, number of cities/municipalities with more than 40,000 inhabitants and the number of health facilities [44–47]

Parameter	Vojvodina	Belgrade	Šumadija and Western Serbia	South and Eastern Serbia	Kosovo and Metohija
Number of cities	8	1	10	9	1
Population	1,659,440	1,931,809	2,031,697	1,563,916	-
Area (km^2)	21,614	3,234	26,493	26,248	10,910
Population density per 1 km^2	89.40	513.10	76.70	59.60	-
Number of cities/ municipalities with more than 40,000 inhabitants	13	17	14	12	-
Number of health institutions	92	54	101	93	-

Šumadija and Western Serbia occupy a central place in Serbia: the most registered medical institutions are located there, it is the largest area, with the most inhabitants, and with the most cities and the most towns/municipalities with more than 40,000 inhabitants. That is why it was elected as the region in which the efficient locations for the treatment of MW should be defined. Šumadija and Western Serbia, within the eight areas, have 14 towns/municipalities with more than 40,000 inhabitants [46]. Featured cities are regarded as possible locations for effective MW treatment. In regions of Zlatibor and Kolubara, there is a city that has more than 40,000 inhabitants, while in other areas we have two potentially efficient locations. MW from municipalities and cities that are located within the same area, but have less than 40,000 inhabitants, "belong" to the city which is the closest to them.

Criteria for the selection of efficient locations within the region and determination of an optimal location were [44]: the amount of generated MW that needs to be transported to a given location; duration of transport from all other locations to given locations; current pollution of each location; the unemployment rate; the safety of the location from natural disasters and accidents. The descriptions of criteria are given respectively: the amount of MW is in direct relation with the increase of the consequences of possible risk of the spillage of MW which can produce pollution of air, land, and water; duration of transport has impact to traffic and wherefore significant negative effects on the quality of air [emissions of CO_2, NO_x, CH_4, O_3, greenhouse gases (GHG) and their consequentially responsibilities "for acid deposition, stratospheric ozone depletion and climate change"]; this criterion is very important, having in mind that "incineration of medical waste involves the creation of certain gases such as CO_2, NO_2, CO and other gases, it is necessary to choose locations that have the least air pollution, specifically have the lowest risk of crossing the permissible limits of pollutants" [48]; the unemployment rate has great importance as chosen criteria having in mind that this rate represents an important indicator in the evaluation of "socioeconomic development and welfare of countries" [49]; consequences of natural disasters and accidents beside their devastating influence on people and material goods (infrastructure, households, firms, and plants) in the affected area with medical waste incineration facility, could be especially dangerous having in mind possible catastrophic emissions of MW of which 10–25% presents hazardous waste with infectious, radioactive, or toxic characteristics [14].

Accordingly, in the contest of the DEA method, inputs for given scenario were: the amount of generated MW, duration of transport, and pollution, while outputs were: the unemployment rate, and safety of the location from natural disasters and accidents. In the scenario of the methodology presented in this paper, all input and output criteria were equal (for the decision-makers). In other scenarios, weights of input and output criteria can be different according to the decision-makers' opinions. Consequently, efficient locations could be different.

Based on the chosen criteria, values, descriptions, and results obtained by using the DEA method, we further analysed gained efficient locations. To determine the optimal location, a model of goal programming, that integrates the same multiple criteria as the DEA method is created. Charnes and Cooper [50] illustrated how that deviation could be minimized by placing the variables that represent the deviation directly in the objective function of the model. This allows multiple (and sometimes conflicting) goals to be expressed in a model that will permit a solution to be found.

Let us suppose that N is a subset of efficient locations ($|N| \leq n$).

The parameters and variables used in a mathematical model of the proposed problem are following:

b_{rj} - normalized value r-th output for j-th location ($b_{rj} = y_{lmax}$, $r \in \{1, 2\}$, $j = 1, \ldots, n$),

a_{lj} - normalized value l-th input for j-th location ($a_{lj} = x_{lj} / x_{lmin}$, $l \in \{1, 2, 3\}$, $j = 1, \ldots, n$),

$$z_j = \begin{cases} 1 & \text{if insineration facility is on the } j\text{-th location} \\ 0 & \text{otherwise} \end{cases}$$

d_l^+ - deviation from the best value l-output,

d_r^- - deviation from the best value r-output.

The mathematical model of this problem has the following notation (1-5):

$$\min f(x) = \sum_{l=1}^{3} d_l^+ + \sum_{r=1}^{2} d_r^- , \quad (1)$$

s.t.

$$\sum_{j=1}^{n} a_{lj} \cdot z_j - d_l^+ = 1,\ l \in \{1,2,3\}, \quad (2)$$

$$\sum_{j=1}^{n} b_{lj} \cdot z_j + d_r^- = 1,\ r \in \{1,2\}, \quad (3)$$

$$\sum_{j=1}^{n} z_j = 1, \quad (4)$$

As it was mentioned before, it was assumed that all of the criteria (inputs and outputs) are equally important for the decision and that the only negative deviation is permitted, i.e. decreasing the input criteria:

$$(d_l^+ \geq 0, d_l^- = 0, i \in \{1,2,3\},\ j = 1,...,n)$$

and the positive deviation, i.e. increasing output criteria:

$$(d_r^- \geq 0, d_r^+ = 0, i \in \{1,2\},\ j = 1,...,n).$$

Results

Efficient locations determined by the DEA method representd potential locations for the MW incineration facility and they are presented in Table 2.

The obtained results showed that there were seven efficient locations (the efficiency is equal to 1).

These locations were further analysed with aim to get an optimal solution which should have a minimal total deviation from an ideal location. The ideal location was obtained using the best input and output values, i.e. all criteria values of all observed locations. None of the selected locations had such values, so the goal was to find the location that deviates the least from the ideal one. The obtained values of inputs and outputs are given in Table 3.

After solving the above presented mathematical model, only for efficient locations (n = 7), the obtained values are shown in Tables 4 and Table 5.

The real deviation from the obtained ideal values and results of the authors Stanojević et al. [44] are given in Table 5.

According to the obtained results, Location 13 was chosen as the optimal location for the building of MW incin-

Table 2

Efficiency of locations considered for medical waste incineration [44]

Location	Efficiency	Rank
Užice	1	1
Valjevo	0.9012	14
Loznica	0.9901	9
Šabac	0.917	13
Gornji Milanovac	1	1
Čačak	1	1
Jagodina	0.9832	10
Paraćin	0.9804	11
Kruševac	0.9945	8
Trstenik	1	1
Kraljevo	0.9225	12
Novi Pazar	1	1
Aranđelovac	1	1
Kragujevac	1	1

Table 3

Values of inputs and outputs for various locations considered for medical waste incineration [44]

Location	Inputs			Outputs	
	Amount of waste (kg)	Transportation time (min)	Pollution	Unemployment	Safety
Užice	5,017.73	9,291	0.805	0.1894	0.9792
Valjevo	5,339.86	9,749	0.56333	0.1724	0.8939
Loznica	5,486.32	14,292	0.5975	0.3322	0.9459
Šabac	5,337.43	11,742	0.602	0.2126	0.9067
Gornji Milanovac	5,713.94	7,201	0.24044	0.1534	0.9387
Čačak	5,358.02	7,274	0.42333	0.1994	0.9441
Jagodina	5,468.85	9,260	0.3253	0.2634	0.8995
Paraćin	5,597.55	9,723	0.6675	0.2768	1.0000
Kruševac	5,316.27	9,829	0.43333	0.3006	0.8246
Trstenik	5,671.17	9,001	0.2263	0.2094	0.9898
Kraljevo	5,401.67	7,720	0.8775	0.2241	0.8922
Novi Pazar	5,392.39	13,514	0.26873	0.3687	0.9011
Aranđelovac	5,644.52	8,910	0.24044	0.2439	0.9457
Kragujevac	5,195.40	7,636	0.6725	0.2829	0.9387

Table 4

The values of variables z_j for 7 most efficient locations considered for medical waste incineration

Location	z_j
Užice	0
Gornji Milanovac	0
Čačak	0
Trstenik	0
Kraljevo	0
Aranđelovac	1
Kragujevac	0

Table 5

The values of deviations and objective function

Parameter	Amount of waste (kg)	Transport time (min)	Pollution	Unemployment	Safety
Deviation	626.79	1,709.00	0.01	-0.12	-0.04
Aranđelovac	5,644.52	8,910.00	0.24	0.24	0.94
Ideal	5,017.73	7,201.00	0.23	0.36	0.98

eration facility. Regarding total transportation time, Location 13 was not the best solution (since it required more time than was calculated ideal value of 7,201 minutes). Even though Location 13 did not have an ideal value for any of the other criteria observed, it still proved as the most efficient location, given the reasons that the amount of MW (5,644.52 kg) which has to be transported to this location is much larger than the quantity that the other locations required, but the transportation time (8,910 minutes) and pollution (0.24044) are considerably lesser than at the other locations, namely, they are closer to the best values of these criteria. Safety (0.9457) and unemployment rate (0.2439) of this location were characterized by a relatively small deviation from the best value, so the minimum value of the objective function was equal to 0.807768.

Discussion

To reduce the risks that MW carries, developing countries, such as Serbia, must focus on solving this problem as soon as possible. The previous practice of sterilization and shredding MW and its disposal in a landfill or export abroad is a short-term solution. The consequences that may occur due to possible adverse events during MWM can be dangerous not only for human health but also for the entire ecosystem of the region. Therefore, the location, where it is possible and appropriate to dispose and treat MW, should be considered through the integration of different elements that meet environmental, social, economic, and technical criteria.

This study take into consideration the amount of waste that needs to be transported, the time of transport, the current pollution of the location, the unemployment rate, and the safety of the location of possible natural disasters and accidents. By the proposed methodology, these criteria were analyzed using the DEA method, and as the results, seven efficient locations for MW incineration facility were obtained on the case of Serbia. In the presented research, it was used a goal programming model for further formulation and analysis to achieve an optimal location for the incineration of MW. In the chosen scenario, the location was Location 13.

The problem of MW and its disposal is growing rapidly throughout the world as a direct result of fast urbanization and population growth, requiring specialized treatment and management [51]. As it is mentioned before, poor MWM can potentially cause hazards such as exposed "health care workers, waste handlers, patients and the community at large to infection, toxic effects and injuries" [7], as well as risks of environmental pollution and degradation. Bearing in mind that the limitation of the present research is related to the lack of adequate database on the amount of MW generated by each health institution, the future directions of research should include the promotion and creation of a single database of health facilities, their capacity, and resources at their disposal, which would allow better management of the health facilities, and would lead to an improvement of the process of MWM, as well as problems with which every institution of this type meets. Another limitation is related to the obtained location itself, which is the result of the assumption that all of the criteria (inputs and outputs) are equally important for the decision-makers. Namely, when it comes to the location of MW incineration, it must be noted "that selected sites should be located away from sensitive land uses, e.g. residential areas, educational and health services, etc." [52]. This, consequently implies that the obtained location has to be carefully qualitatively reviewed to avoid unnecessary possible increase in pollution. Also, future research must consider different scenarios, with relation to different weights all of the criteria (inputs and outputs) for a goal programming model which in that case can give different results. Besides, cost-benefit analysis would show the long-term financial effects of such a decision.

Conclusion

The importance of MWM is reflected in the reduction of all possible negative impacts of MW both on the people and the environment. This problem can be solved by the right investment in the incinerator facility at the adequate location which will meet diverse multiple environmental, social, economic, and technical criteria to adequately manage the final processing of MW, and provide proper MWRM. This adequate location, i.e. optimal location, can be obtained by methodology presented in this study using the DEA method and the goal programming.

Disclosure statement

All authors declare no conflicts of interest.

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