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Assessment of Environmental and Economic Impacts of Municipal Solid Wastes Management System: A Case Study

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ABSTRACT
In pursuance of the Saudi vision 2030, the Al-Hasa municipality has been allocating a total of US$ 60.1 million since 2018 to the implementation of a modern Municipal Solid Wastes (MSW) management system. In addition to the improved old components, the system involves six new-engineered cells, five of which will be gradually implemented in progresses, two waste sort-out lines station, and LFG energy recovery. The present research aimed at investigating the environmental and economic impacts of this MSW management system. For this purpose, the authors applied the Life Cycle Analysis (LCA) and Life Cycle Costs Analysis (LCCA) approaches. The main results showed that the air quality was not affected. For instance, gas emission, like carbon monoxide, was less than 0.1 ppm. However, soil and groundwater were contaminated due to leachate infiltration from the uncontrolled cell in which Chloride, Nitrate, and Sulfate exceeded the maximum limits. As for noise, it was found to be high near the sorting-out station at 71.1 Leq dBA. In terms of the financial aspect, the improved MSW management was relatively feasible despite its high costs over its revenues. Thus, the negative cash-flow could be supplemented by setting household taxes at US$ 29 per capita per year, which makes the project cost-effective. Thus, the research recommends continuing the MSW management project.

Keywords: environmental impact, economic impact, MSW management, LCA&LCCA, Saudi Arabia.

INTRODUCTION

According to the Environmental Program Report – "Greening the Blue Report" [UNEP, 2019] – which was issued by The United Nations, global awareness of environmental crisis is growing, as the high pollution levels in air, soil and water are considerably high. This is due to the emission of both hazardous and non-hazardous wastes, like the Municipal Solid Waste (MSW). Thus, officials were forced to choose between several options for managing their MSW and reducing their negative impacts on the environment.

For many decades, Saudi Arabia has suffered from the pollution resulting from oil extraction and consumers' consumption of goods [Khalil et al., 2016], which have caused harmful side effects on human health, including skin and respiratory diseases, cancer, and various disabilities. According to Saudi General Authority Statistic [GAS, 2018], the government decided to implement a national MSW Management strategy, which involves renovation and modernization of the traditional network of open dumps to reduce their harmful environmental impacts on air, soil, and groundwater.

Moreover, the municipality of Al-Hasa conducted a pilot project in 2018, in which it invested US$ 60.13 million in order to implement a modern MSW management system, and from which a US$ 19 million will be incrementally disbursed in the future. Nearby the old dump, the municipality launched an extensive program to establish a new controlled landfill site with the area of 89 acres, composed of a modern cell with a capacity of 1.62 million m^3 and five other cells aimed to be involved gradually in the future. In addition, the new site comprises a compaction equipment, a weighbridge, two waste sorting-out lines, a landfill gas (LFG) collection system, an energy recovery unit, and an office building for landfill management.

Considering the cost of the MSW management system project, the Al-Hasa municipality officials pointed out that it is substantially expensive, which requires a mid-term assessment regarding its environmental and economic impacts. This will assist them in rectifying, reorienting activities and reallocating funds if necessary. For this reason, our study aimed to investigate the environmental and economic impacts of the new MSW management system on improving the quality of air, soil, groundwater, and noise, as well as to identify the extent to which this system can justify its high level of expenditure.

In order to achieve this aim, the present study applied ecological economics theory crossed with systemic approach, which suggests that MSW management based on the landfilling option is composed of six fundamental elements: generation, storage and handling at the primary source, collection and transport, treatment and recycling, and the waste deposition process [Singh et al., 2011].

As the option of the MSW management system, the landfill is the oldest and the most widely practiced of disposing of waste [Koda et al., 2015]. According to Li et al. [2017], the main reasons are a number of advantages which include simplicity, low investment expenditures, large processing capacity and low operating cost.

According to the United States Environmental Protection Agency [US-EPA, 2021], the MSW landfill is a discrete zone or excavation used to discharge household waste and other types of nonhazardous wastes. Moreover, regarding the evolution of open dumps into controlled and sanitary landfills [also known as engineered or scientific landfills], the US-EPA [2016] recommended using of well-engineered disposal facilities that are implemented effectively to protect the human health and cause the minimum impacts to the environment from various pollutants that are involved in the solid waste stream.

Regarding the cost of waste disposal, open dumps are simpler and less expensive than the controlled landfills [Singh et al., 2011]. They also provide more accurate alternatives for accommodating society's wastes [Ross et al., 2011]. These two studies in particular highlight that the controlled landfill costs are subject to significant economies of scale, suggesting the smaller the landfill, the more expensive it is to design, construct and operate on a unit cost (per ton) basis. Landfilling MSW is considered a costly public service provided by the municipal government. In 2010, for instance, the expenses of running MSW management in the United States of America reached US$ 7.824 million. Then, it increased to 9.112 million in 2013, and 9.496 million in 2019 [Statista, 2021].

Furthermore, uncontrolled landfill process causes gas emissions, so it becomes a source of greenhouse gas (GHG) and leachate infiltration into the groundwater and the downstream soil [Bogner et al., 2007]. Therefore, several modern management options which are based on 3Rs operations (reduce, reuse, or recycle) could initially complete the landfilling process in order to make the MSW management system more cost-effective and to minimize the amounts of wastes in landfills [Zhu et al., 2008]. Moreover, Zhu et al. [2008] noted that the 3Rs reduce the emissions produced by the landfills as well as save energy and natural resources. In addition, the 3Rs operation process requires LFG recovery and either flaring of the gas or using it as a fuel to generate energy in internal combustion or other similar units. Kossakowska and Grzesik [2019] evaluated the potential environmental impacts of a mixed MSW management system, which involves MSW collection and transportation, mechanical and biological treatment, landfill, as well as LFG collection system and gas combustion in flare. They found that uncontrolled landfill leachate emitted several organic substances to surface waters [Nitrates and Phosphates]. Conversely, when the landfill itself is engineered, the results could highlight no effects on soil and water [Vaverková et al., 2018], but it is very costly. In many cases, municipalities resort to tip-fees to collect fund supports from households. The amount of fees could be determined by using different methods such as flat rate or quantity based charge [Petryk et al. 2019].

MATERIALS AND METHODS

The present study applied two methods of analysis, namely the Life Cycle Analysis (LCA) and the Life Cycle Costs Analysis (LCCA), which were previously used by Bahor et al. [2010], Deng et al. [2016], Navarro et al. [2020], and Tenodi et al. [2020]. According to the international standards ISO 14044 [2006], International Solid Waste Association [ISWA, 2011], QPO-LS [2012], US-EPA [2012] and the Saudi National Standards of Royal Commission Environmental Regulation [RCER, 2015], as a normative approach, LCA consists of a compilation and assessment of the inputs, outputs, and the potential environmental impacts during the life cycle of the product system, which runs through four phases:

a) The goal and scope definition phase.
b) The inventory analysis phase.
c) The impact assessment phase.
d) The impact interpretation phase.

The most common form of LCCA is the Benefit-to-Cost Ratio, which includes the concept of net present value (NPV) procedures [Ghinea & Gavrilescou, 2016; Richa et al. 2017]. It can be used to determine the Internal Return Ratio (IRR) indicating if the landfill system is viable and profitable. The Benefit-to-Cost Ratio also determines to what extent the Household Tax could refund the landfill system. The NPV is determined as follows in Eq. (1):

$$NPV = \frac{\sum_j^n [TRj - TCj]}{[\,1 + r\,]^j} \tag{1}$$

where: *TRj* - total revenue generated by the MSW system in year *j*; *TCj* - total cost paid by the Municipality in year *j*; *r* - the discount rate (DR); *j* - the given year; *n* - the number of years indicates the age of the landfill.

The NPV could be written as follows in Eq. (2):

$$NPV = \frac{\sum_j^n \sum_i^m [\,Rij - Ckj\,]}{[\,1 + r\,]^j} \tag{2}$$

where: *Rij* - revenue of component *i* of the system in year *j; Ckj* - cost of the activity *k* in year *j.*

According to the US-EPA regulations, the questionnaire is designed to collect data from different sources, such as the landfill bureau and Gulf Energy & Environmental Consultants (GEEC) in February/March 2020. The data includes all components of costs, revenues, and descriptions of activity parameters, gas emission in air, organic and inorganic residuals of leachate infiltration in groundwater and soil, as well as noise level in different stations.

RESULTS AND DISCUSSION

The goal and scope

The research aimed to evaluate the environmental and economic impacts of the MSW management system. Thus, it described the MSW handling process, measured the environmental parameters (air, soil, groundwater, and noise qualities) and tested their compliance with International and National standards. In addition, the research simulated the economic parameters of the MSW management system (NPV, DR, cash flow, and IRR), and it ended by determination of the tax-fees that could be imposed on household to refund MSW management.

Life cycle inventory and conformity of MSW management system components

It is noteworthy that in Saudi Arabia, the Saudi Ministry of Municipality and Rural Affairs (SMMRA) nationally governs the MSW management. At region levels, it is organized, planned, and managed by municipalities. In the Al-Hasa, region, the SMMRA [2020] highlighted a generation of household waste per capita per day equal to 1.72 kg in 2018, which represents roughly two times and half of the world level 0.72 kg per day [World Bank, 2018]. It contained organic materials 84.75%, inorganic metal 7.63%, paper 3.77%, plastic 2.23%, metal 1.6 %, and wood 0.03%.

The second step includes MSW collection and transportation (Table 1). The MSW collection involves two stages: the first is an on-site collection system, and the second is an MSW gathering into four collection points (North and South Mubarrez, and North and South Hufuf) located at 32, 27, 24, and 21 km from the landfill site, respectively.

The on-site collection system is provided with containers, storage areas, trucks, and compactor vehicles. The application of RCER [2015] regulations showed that the MSW collection is acceptable, meeting most of the required conditions

Table 1. Evaluation of MSW collection and transport conformity to regulations

Criteria according to Royal Commission Environmental Regulation [2015]	Evaluation	
	Acceptable	Not acceptable
Containers, on-site selection system, and storage areas for municipal waste shall prevent the: - Accumulation of refuse - Health and fire hazards or nuisance		X
Containers for MSW shall be in adequate size, in sufficient numbers	✓	
Containers shall be selected for the specific service intended, equipped by tightly fitting lids, reusable, constructed by material not absorb water, grease or oil	✓	
Residents shall provide suitable containers and be responsible for maintenance and cleanliness		X
The minimum MSW collection frequency specifically for putrescible food wastes	✓	
The generator shall ensure that all wastes are placed compatible containers		X
All vehicles and containers used to transport wastes shall be operated and maintained	✓	
The transporter shall deliver all wastes to the designed treatment or disposal facility	✓	
Upon delivery of the waste, the transporter shall follow regulations.	✓	

except for the two criteria related to the accumulation of refused waste on-site selection and the non-participation of the residents in waste collection, maintenance, and sanitation.

The second stage consists of transporting the on-site MSW to the collection points and then to the landfill. The municipality has a large number of conventional waste compaction trucks with a capacity of 1200 tons per day, from which only 900–1100 tons per day are used. In general, the transportation criteria were compatible with standards. However, the elevators did not have the required documentation for non-hazardous waste, the containers were not compatible with different wastes type and the vehicles were not suitable for specific materials.

The landfill site was intended to potentially receive 10000 tonnes per day, but the MSW quantity is provided only at 1500 tonnes of MSW and 3000 tonnes of construction wastes in reality. As

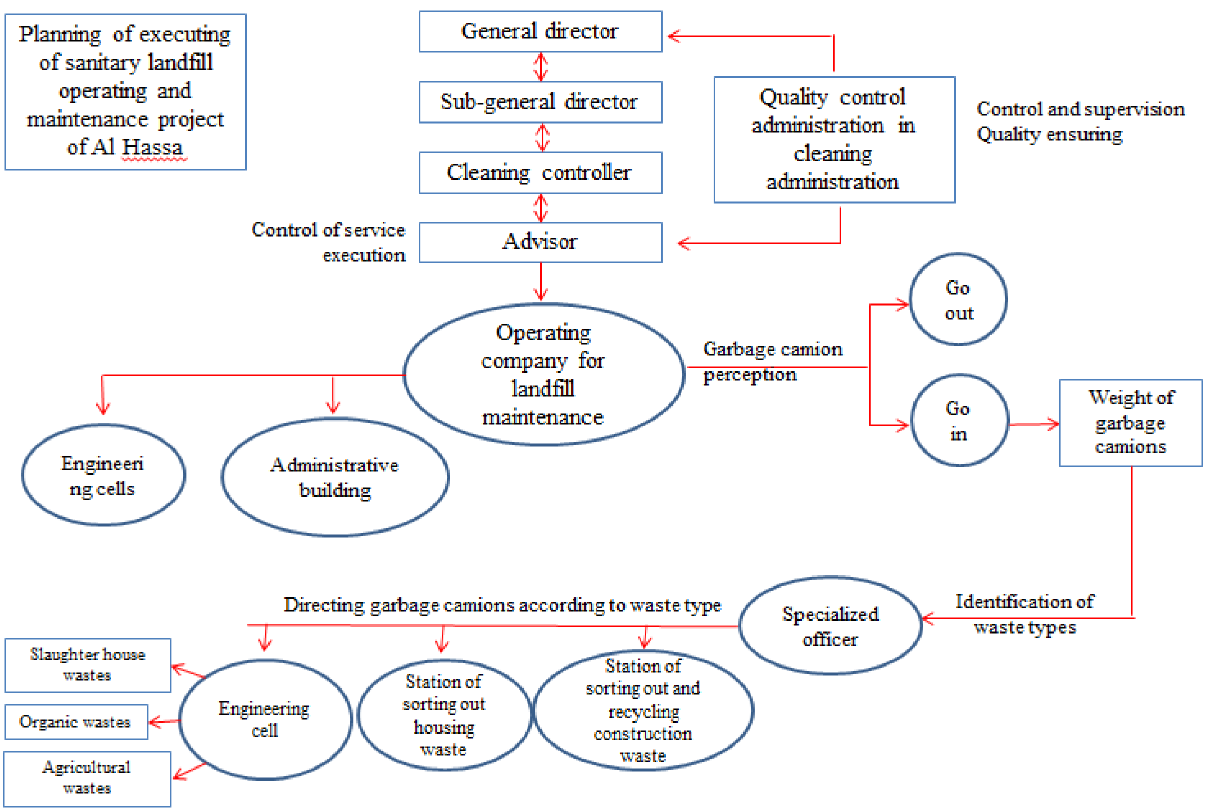

Figure 1. Executing planning of the sanitary landfill operating and maintenance project of Al-Hasa

Table 2. Air emission and quality measured by Gulf Energy & Environmental Consultant

S. No	Time	Location	NO (ppm)	CO (ppm)	H_2S (ppm)	SO_2 (ppm)	VOCs (ppm)
1	08:00	Gas monitoring sensors around the cell	0.01	0.1	0.01	0.01	0.02
2	9:00	Sort out station	0.01	0.1	0.01	0.01	0.03
3	10:00	Dead parts filling cell	0.01	0.1	0.01	0.01	0.07
4	11:00	Leachate pond	0.01	0.1	0.01	0.01	0.09
US EPA Limits & RCER standards (maximum concentration)			0.35 ppm	35 ppm	0.14 ppm	0.28 ppm	-

for the structure of the landfill, the design is compatible with the national planning of the Saudi Arabia MSW management system (Figure 1).

The landfill site location can be described as human-friendly. It requires complying with the Saudi and international regulations. Moreover, the status of the Al-Hasa landfill complies with the international guidelines developed by ISWA [2011], mainly involving beautification, safety of residents, health of on-site workers, surface water protection.

Life cycle impact analysis: environmental quality measurement

In March 2020, GEEC measured the air emission, water and soil contamination, and noise level in various landfill stations. The results revealed that air emissions, in terms of methane and non-methane organic compound (NMOC) include acceptable levels of volatile organic compounds (VOC) and organic Hazardous Air Pollutants (HAP) at all stations (Table 2). In addition, the air analysis at all stations showed an average of 0.01 ppm of nitrogen oxides (NOx), 0.1 ppm of carbon monoxide (CO), 0.01 ppm of H_2S, and 0.01 ppm of sulfur dioxide (Sox). Thus, according to the US-EPA [2012]-CFR 40-part 96.1 and RCER [2015] standards, the air pollution resulting from the landfill was sustainable.

The results of soil analysis of a sample taken from the landfill of the Al-Hasa municipality (Table 3) showed that inorganic parameters, especially pH, electrical conductivity, oil, and grease, were acceptable. However, the anion concentrations exceeded standardized limits, thus becoming potentially hazardous if the level of Chloride equals to 13 mg/kg (>0.5), Nitrate 2.8 mg/kg (>0.2) and Sulfate 3400 mg/kg (>0.2). In addition, the total organic carbon existed at a level of 0.1% without upper level limit. Then, these results suggest that the old landfill is the main cause of soil contamination due to the absence of a liner protecting it against leachate infiltration.

Moreover, the groundwater quality was evaluated using a well water sample in the landfill. All tests showed that the inorganic indicators were acceptable, according to RCER [2015]. For instance, the pH, the total dissolved solids, the oil and grease, the residual chlorine were 7.2, 1400 mg/L, <10 mg/L, and <0.02 mg/L, respectively. Concerning the concentrations of anions, the nitrates and sulfates, they were pollutants, exceeding the safe limits with 2.6 (>0.1) and 250 mg/L (> 0.1), respectively. The groundwater was also contaminated due to the absence of old landfill protection (Table 4).

In terms of the noise, five stations were used to measure its average level (Table 5). The results were found to be acceptable for all stations except for the sorting-out station, where the noise level was high (71.1 Leq dBA), reaching the limit level for

Table 3. Soil quality at specific site location measured gulf energy and environmental consultant

Test name	Results	Standards limit of detection
Inorganic parameters		
✓ Ph	6.4	-
✓ Electrical conductivity (μS cm^{-1})	2300	-
✓ Oil and Grease (%)	<0.001	-
Anions		
✓ Chloride (water soluble) (mg kg^{-1})	13.0	0.5
✓ Nitrate (water soluble) (mg kg^{-1})	2.8	0.2
✓ Sulphate (water soluble) (mg kg^{-1})	3400	0.2
Chemical analysis		
✓ Total Organic Carbon (%)	0.1	-

Table 4. Groundwater quality measured by Gulf Energy & Environment Consultant

Test name	Results	Standards limit	RCER maximum concentration	
			JBEIL standards (24 h average period)	YANBU standards (24h average period)
Inorganic parameters				
✓ pH	7.2	-	5-11	5-9
✓ Total dissolved solids (mg L^{-1})	1400	5	2000	2500
✓ Oil and grease (mg L^{-1})	<10	10	120	100
✓ Residual chlorine (mg L^{-1})	<0.02	0.02	1000	4000
Anions				
✓ Nitrates (mg L^{-1})	2.6	0.1	120	80
✓ Sulphates (mg L^{-1})	250	0.1	800	150

Table 5. Average of noise measurements by location measured by Gulf Energy & Environmental Consultancy

Date	S. No	Time	Location	Min dBA	Max dBA	Leq dBA AlHassa
17/2/2019	1	08:00	Gas monitoring sensors around the cell	55.4	62.5	60.5
	2	09:00	Sort out station	67.1	72.5	71.1
	3	10:00	Dead parts filling cell	54.6	60.8	58.8
	4	11:00	Leachate pond	53.6	58.9	56.8
	5	12:00	Engineering cell	54.4	60.5	58.5

both standards: 72.5 Leq dBA for a landfill and 75 Leq dBA for an industrial zone. Therefore, the noise was harmful to the citizens and the environment.

Life Cycle Costs Assessment (LCCA) results

According to the standards, a landfill will be financially feasible as disposal facility when the average waste per capita is 0.3 Kg per day in a city with 8.10^5–10^6 inhabitants. Consequently, the Al-Hasa MSW management can be costs-effective, because it includes a landfill implemented for a city population over 1 million, with an average waste of more than 1.7 kg per capita per day.

The benefits of costs assessment include the costs and revenues generated by the MSW management system, which estimates its Internal Return Ratio (IRR). For instance, as seen in table 6, the results highlighted that the cost of site development in Al-Hasa MSW management system costs reaches US$ 3.4 million per acre, which is three-times higher than the suggested value by KYSWB [2012], US$ 0.75–1.2 million. Fitzwater [2012] estimated that a designed sanitary landfill costs per acre US$ 1 million to implement, operate, and close an MSW landfill, which is in accordance with the US-EPA [2016] standards.

The construction cost of the first cell of the Al-Hasa landfill is estimated about US$ 9.6 million, i.e. US$ 108 thousand per acre, representing 21.6% of the amount suggested by Ensol [2010] which was US$ 0.5 million per acre, whereas all other cells will cost US$ 144.4 thousand per acre. The construction costs include land clear and grub, excavation of liner, Bernell handheld disc perimeter, clay liner, geomembrane liner, geocomposite drain, granular interim cover soil, leachate collection system, and Quality assurances and control system. Excavation of the Al-Hasa landfill costs US$ 3.2 million.

Additionally, the operation costs US$ 3.48 million. For instance, the landfill operation expenses involve trucks, such as 2 bulldozers, 6-wheel loaders, 6 compactors, 3 water tankers, 1 car [jeep], 1 large pressure locomotive with 75 m high, 4 mini wheel loaders, and 1 excavator. The total truck cost is US$ 3.48 million. Additionally, the amount of US$ 1.64 million represents the costs of providing staff members, maintenance equipment and payments for four companies working in partnership with the municipality and maintenance fees. As for the post-closure cost, it was estimated to be US$ 0.3567 million, which should be paid in the fifth year, corresponding to the landfill closure year. Finally, the post-closure care costs are estimated to be US$ 1.16 million, which should be paid yearly, starting from the fifth year of the project until the end of the landfill period.

Considering the revenue, the Al-Hasa MSW management system is a public office with

Table 6. Estimated capital and operating costs for major components of the Al-Hasa MSW management system

Types	Components	Description	Estimated costs (US$ million)
Upstream components	Wastes Collection Transport	The system involves 163 elevators. Depreciation terms of 20 years.	17.463
Site development	Site surveys	Team of 3-4 persons during 2 years and salary of 10-12 Th SAR	0.1232
	Engineering and design studies	Consulting and study office	3.2
Construction	Cells Includes the excavation of the single liner	1st cell of 89 acres: Other 5 cells, each one will cost:	9.6 3.2
Excavation of landfill site	Leachate collection system	Performed by independent consultant during 5 years	3.2
	QA/QC	Operated by a private company, starting 2018 during 15 years,	
Operation of the landfill	Truck scale, scale house,	In terms of contract, Municipality will earn material:	3.48
Operating costs	Staffing, leachate treatment, Facilities and general maintenance	Four (4) consulting engineers (3 years contracts):	2.432
Closure	Installation of final cover and cap	Old landfill	0.3567
LFG collection and flare system	LFG collection, flare, operation and maintenance	Old landfill Investment cost:	3.7333
		Operation and maintenance annual costs:	0.00667
Post closure care	Maintenance	Exist for the old landfill, annual cost is:	0.3093

multiple sources of revenue. Currently, the municipality charges only tip fees for construction waste at an amount of US$ 9.33 per truck. The Al-Hasa MSW management system also generates revenues from household waste, which are sorted out in two ways. First, the municipality receives a payment for renting land to two specialized companies. Second, it receives 10% of their annual turnover with an annual average reaching approximately US$ 87 thousand during 15 years. Additional revenue resources will be earned in the next days by generating potential revenues from the LFG energy recovery unit, with a production capacity estimated to be 560 Kwh for 9 hours per day, which could be extended in the future.

The evaluation of the IRR estimates an incremental implementation of six cells, which can last for 5 years before closure and 30 years afterwards for each cell. In total, the MSW management system is expected to last for 45 years until 2070. The opportunity cost of the capital is estimated to be equal to the discount rate (DR) of the Saudi Arabia Monetary Authority (SAMA), i.e. 2%.

Overall, the results revealed that the total actualized cost of the MSW management system is US$ 303.15 million, and the total revenue is about US$ 104.2 million. Thus, the Net-Benefit of the Al-Hasa MSW management system is deemed to be negative, reaching about US$ 198.9 million (SAR -746 million). Consequently, refunding the system requires charging each household a minimum of US$ 28.8 tip-fees yearly to make achieve IRR of 2.72%, representing the minimum acceptable rate according to the SAMA rate.

CONCLUSIONS

The decision of the Al-Hasa municipality to improve and modernize the MSW management system costs US$ 60.13 million, 68% of which has been spent until now. The present study aimed to assess the environmental and the economic impacts of this system. For this reason, the LCA and LCCA methods were applied during the data collection phase from many sources.

The main results of LCA highlighted several important findings. First, the air quality is acceptable, like gas emission level, specifically carbon monoxide amount (CO) is less than 0.1ppm where the maximum limit is 35 ppm. Conversely, soil and water are contaminated due to leachate infiltration from the old cells in which the concentrations of chlorides, nitrates and sulfates exceed the standards. As for noise, the level is acceptable except for the sorting-out station where the noise level reaches 71.1 Leq dBA.

Considering the economic impacts of the MSW management system, the main results of

LCCA indicate that the system generates a negative cash-flow of US$ 198.9 million. This can be supplemented when households pay tip fees of US$ 28.8 per capita per year, thus increasing IRR to 2.72%.

The research recommends involving residents in the process of collecting and sorting-out wastes at home, using suitable containers and maintaining them, as well as participating in refunding the MSW management system.

For future research, the impact of COVID-19 pandemic on the MSW management systems across the Saudi municipalities will be analyzed to clarify its environmental and economic effects.

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