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Utilizing Local Natural Pozzolan as Partial Replacement of Cementitious materials and Sand in Cement Mortar Cubes

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Abstract. The concrete is considered a versatile construction material. The concrete comprises of fine aggregate, coarse aggregate and cement paste (cement and water). The cement paste is the binding material for aggregates in concrete. Local natural pozzolan (LNP) is found in Almadinah Almunawara, KSA. LNP can be used as partial substitution for cement and fine aggregates in lightweight concrete. This paper presents an investigation of the effect of partial replacement of cement with LNP powder in cement mortar cubes to reduce the harmful environmental impact of carbon dioxide emission resulting from cement manufacturing and the effect of partial replacement of fine aggregate in cement mortar cubes with LNP on the mechanical properties of mortar cubes. It was recommended by Saudi Building Code to add pozzolan with cement of special type in the production of concrete exposed to severe sulfate. A fifty-four cement mortar cubes of 50 mm were made (six cubes as control specimens, twenty-four cubes with cement replacement by weight with local natural pozzolan powder at replacement levels of 10, 20, 30 and 40%, and twenty-four cubes with sand replacement by volume with local natural pozzolan at replacement levels of 10, 20, 30 and 40%). The cement mortar cubes were tested at 28 and 180 days. The replacement of sand by volume with local natural pozzolan showed a notable effect on the mechanical properties of cement mortars when compared with the replacement of cement by weight with local natural pozzolan powder.

Keywords: Cement replacement, sand replacement, natural pozzolan, mortars, mechanical properties

1. Introduction

LNP is found in Al-Madinah Al-Munawarah in Saudi Arabia. K. Ezziane *et al.* [1] used the natural pozzolan (NP) as mineral admixtures and they found that it helped in reducing the heat of hydration of cement so it can be used in hot climate regions.

There is no bad effect on the performance of high performance concrete in case of partial replacement of cement with NP [2]. A reduction in the rate of hydration was obtained in case of addition of ferronickel slag and natural pozzolan to ternary blended cements that is beneficial for concrete exposed to sulfate [3]. The utilization of mineral admixtures as replacement for sand and silica fume in concrete had been investigated [4]. The utilization of fly ash and granulated blast furnace slag reduced the required amount of cement and silica in concrete [5]. The utilization of supplementary cementing materials as replacement for cement in concrete had been investigated by many researchers [6 to 9].

The utilization of various materials such as spent garnets, plastic waste, waste foundry, granite quarry, limestone fines … etc. as partial substitutions for sand in concrete to increase its strength had been investigated in many researches. Ghasan *et al.* [10] and Mariyana *et al.* [11] investigated the effect of sand replacement in concrete with spent garnets at levels up to 40% in addition to fly ash. They found that the replacement level of 40% gave thermal stability for the concrete and the replacement level up to 25% had no effect on its strength.

An improvement of energy absorption of concrete under impact loading was obtained in case of partial replacement of sand in concrete with plastic wastes [12]. The levels of replacement of sand in mortars up to 60% with granite quarry improved flexural and compressive strengths of concrete [13]. The 5% replacement of cement and 15% replacement of sand in concrete with limestone fines improved its compressive strength [14]. In this research, the effect of utilizing LNP powder as a partial substitution for cement and the effect of utilizing local natural pozzolan as a partial substitution for sand in cement mortars on the mechanical properties of it were investigated.

2. Materials

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The used materials are natural sand (NS), natural pozzolan (NP) and cement. The properties of the used materials are as follows.

2.1 Natural Sand

The properties of natural sand are shown in Table (1). The Particle distribution of the used natural sand is shown in Fig. (1).

Table (1). Properties of natural sand

Bulk density	1670	kg/m^3
Specific gravity	2.60	
Moisture content	0.10	%
Absorption	0.21	%

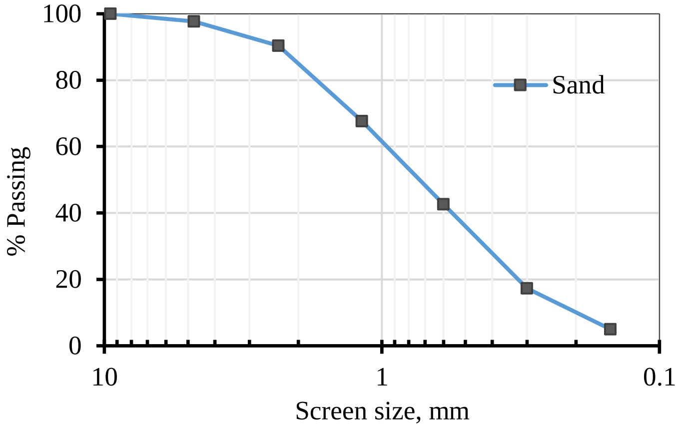

Fig. (1). Particle distribution of natural sand

2.2 Natural Pozzolan

The material properties of LNP are shown in Table (2). A quantity of the local natural pozzolan were ground to powder to reach a fineness of 2000 to 3000 cm^2/g. The Particle distribution of the used local natural pozzolan as a partial substitution for sand is shown in Fig. (2). The chemical composition of the LNP is shown in Table (3).

Table (2). Natural pozzolan properties

Bulk density (as sand)	1100	kg/m^3
Specific gravity	2.51	

Moisture content	1.33	%
Absorption	5.23	%

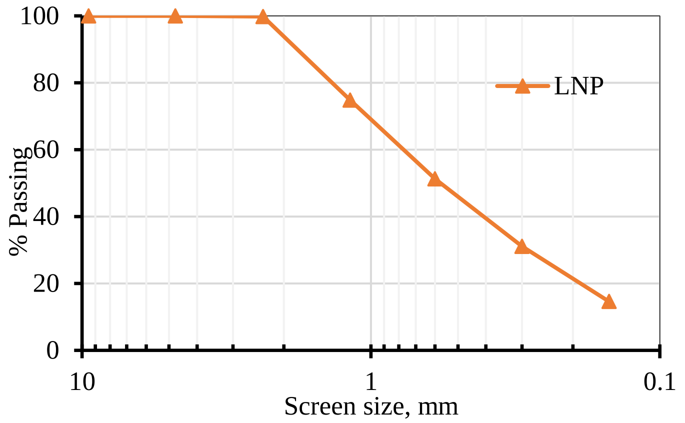

Fig. (2). Particle distribution of local natural pozzolan (sand replacement)

Table (3). Chemical compositions of (LNP)

Oxides	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**Ca O**	**Mg O**	**SO_3**	**K_2O**	**Na_2O**	**Loss on ignition**
Weight, %	41.12	15.44	17.35	11.21	4.47	0.18	1.05	0.25	2.2

2.3 Ordinary Portland Cement

Table (4) shows the chemical properties of ordinary Portland cement (OPC).

Table (4). Chemical properties of (OPC)

Oxides	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**Ca O**	**Mg O**	**SO_3**	**LOI (%)**	**Fineness (cm^2/g)**
Cement	19.97	5.85	3.43	64.13	0.6	2.8	1.6	3148

3. Experimental Program

The experimental work is divided into two parts, the first part is to study the effect of partial substitution for cement in mortars with LNP powder and the second part is to study the effect of partial substitution for sand in mortars with local natural pozzolan on the mechanical properties of mortar cubes.

Fifty-four cement mortar cubes of 50 mm were made. Six cubes as control specimens, twenty-four cubes of cement replacement by weight with LNP powder at replacement levels ranged from 10 to 40%, and twenty-four cubes of sand replacement by volume with local natural pozzolan at replacement levels ranged from 10 to 40%. The specimens were prepared in accordance with ASTM C 109. The specimens were covered with polyethylene sheets for 24 hours after casting. The specimens were demolded after 24 hours and were immersed in water storage tanks at a temperature of 22 ± 2 °C. The cubes were tested at 28 and 180 days.

The water/cementitious materials ratio was 0.49. The quantities of used materials for the prepared specimens are shown in Tables (5).

Table (5). Quantities of used materials

Type of replacement	Specimen	Cement replacement by weight, %	Sand replacement by volume, %	Natural Sand, gm	Natural Pozzolan as cement, gm	NP as fine aggregate, gm	Cement, gm
Control	CE00	0%	---	1356	---	---	490
Cement Replacement	CE10	10%	---	1356	49	---	441
	CE20	20%	---	1356	98	---	392
	CE30	30%	---	1356	147	---	343
	CE40	40%	---	1356	196	---	294
Sand Replacement	SA10	---	10%	1220	---	90	490
	SA20	---	20%	1084	---	180	490
	SA30	---	30%	949	---	270	490
	SA40	---	40%	814	---	360	490

Electrically driven mechanical mixer was used for mixing the specimens. The cement replacement levels with local natural pozzolan powder were 10, 20, 30 and 40%. The sand replacement levels with local natural pozzolan were 10, 20, 30 and 40%. Compressive strengths were measured after 28 and 180 days for specimens with cement or with sand replacement with LNP. The listed values were the averages of each three specimens tested under compression.

4. Results and Discussion

Fig. (3) shows the cement mortar cubes after compression testing for the levels of replacement of cement with LNP powder of 0, 10, 20, 30 and 40% and replacement of sand with LNP at levels of 0, 10, 20, 30 and 40%.

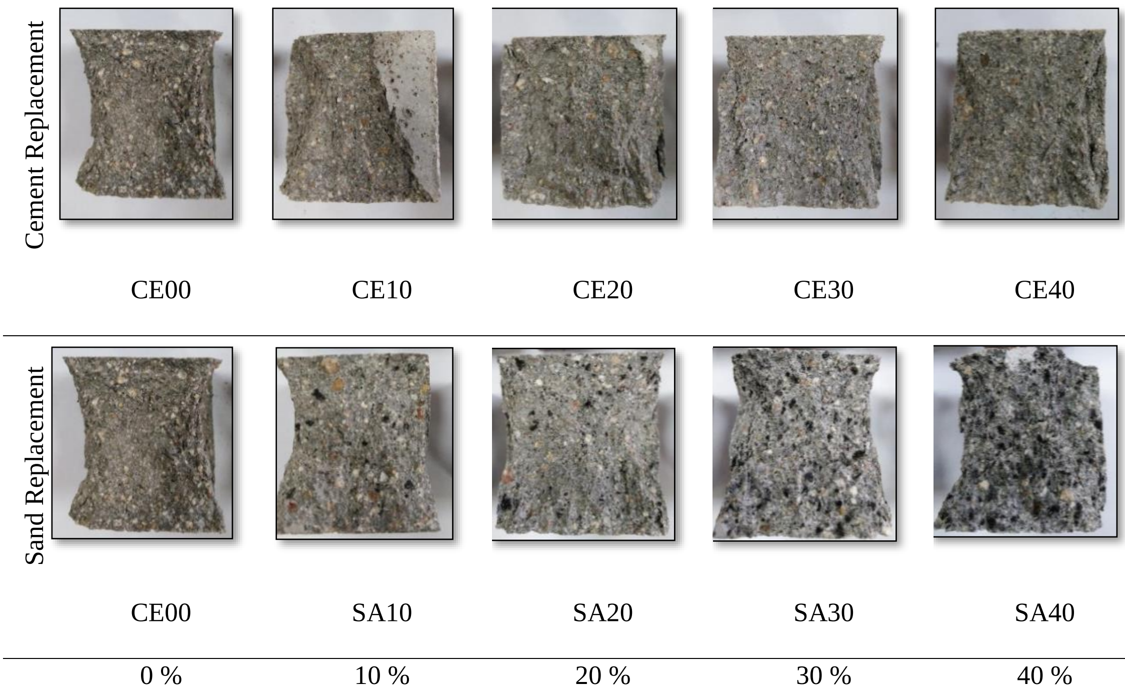

Fig. (3). Cement mortar cubes after compression testing

4.1 Effect of cement partial substitution by weight with LNP powder on compressive strength at 28 days

The compressive strength of the control specimen CE00 was 45.9 MPa. The effect of cement replacement by weight with LNP powder on the strengths of cement mortars is shown in table (6) and Fig. (4). The compressive strengths of cubes CE10, CE20, CE30 and CE40 at levels of replacement of cement with local natural pozzolan powder of 10, 20, 30 and 40% were 39.6, 37.5, 26.7 and 20.8 Mpa, respectively. The strengths of specimens at levels of replacement of cement by weight with LNP powder of 10, 20, 30 and 40% reduced by 13.8%, 18.4%, 41.9% and 54.7%, respectively when compared with control specimen. It was found that the levels of replacement of cement with LNP powder more than 20% has great reduction in the compressive strength when compared with specimens at levels of replacement less than 20%.

Table (6). Compressive strengths of specimens at 28 days (Cement replacement)

Specimen	Load, KN	Stress at, Mpa	% change of strengths to that one without LNP
CE00	114.8	45.9	control
CE10	99.0	39.6	-13.8
CE20	93.6	37.5	-18.4
CE30	66.7	26.7	-41.9
CE40	52.0	20.8	-54.7

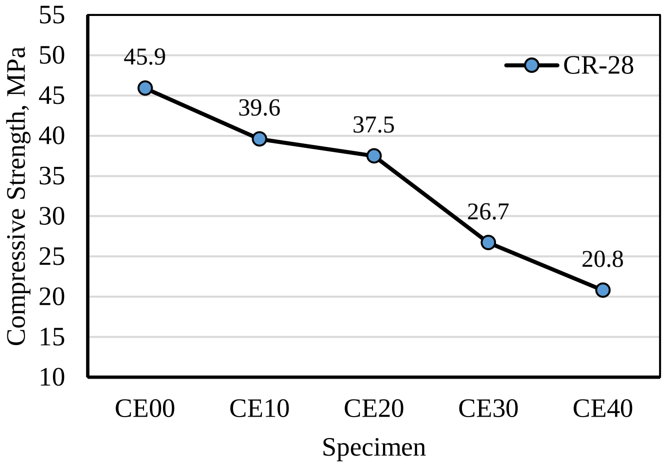

Fig. (4). Compressive strengths of mortar cubes at 28 days (Cement replacement)

4.2 Effect of sand replacement with LNP on compressive strength

The effect of partial substitution for sand by volume with local natural pozzolan on the strengths of cement mortars at 28 days is shown in Table (7) and Fig. (5). The specimens SA10, SA20, SA30 and SA40 at levels of replacement of sand by volume with local natural pozzolan of 10, 20, 30 and 40% had compressive strengths of 48.7, 47.3, 44.6 and 38.3 Mpa respectively. The effects of percentage of sand replacement of 10, 20, 30 and 40% with LNP on the compressive strengths were +6.0%, +3.1%, -2.9% and -16.7% respectively. It can be noticed that the strength of specimens with sand replacement by local natural pozzolan up to 20% showed more compressive strengths than those without local natural pozzolan at 28 days.

Table (7). Compressive strength of mortar cubes (Sand replacement)

Specimen	Average load, KN	Average stress at 28 day, Mpa	% change of strengths to that one without LNP
SA10	122.3	48.7	+6.0
SA20	119.1	47.3	+3.1
SA30	111.7	44.6	-2.9
SA40	95.6	38.3	-16.7

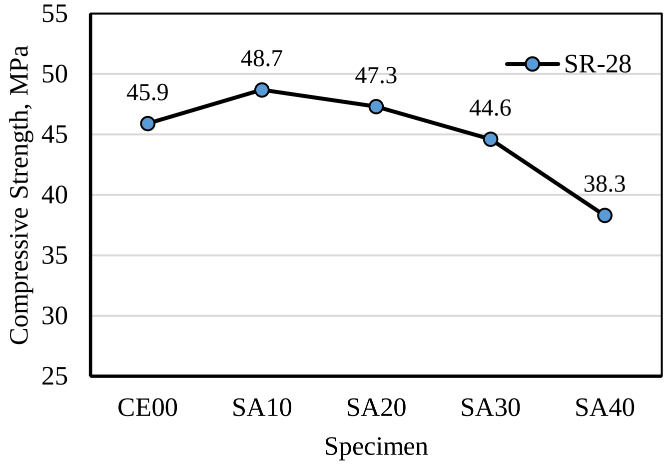

Fig. (5). Compressive strength of mortar cubes at 28 days (Sand replacement)

The compressive strengths of specimens for cement and sand replacement with LNP are shown in Fig. (6). It was found that 23% increase in the compressive strength of cement mortar was achieved by replacing 10% of sand by volume with LNP when compared with 10% cement replacement by weight with LNP powder and 6% increase in the compressive strength when compared with specimen without LNP.

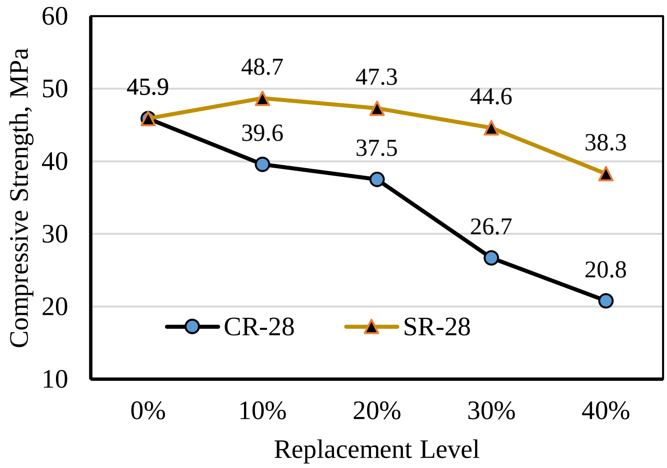

Fig. (6). Compressive strength of mortar cubes at 28 days (Cement and Sand replacement)

4.3 Curing duration effect on compressive strength

The compressive strength of specimens at 28 and at 180 days are shown in Table (8) and Fig. (7) for both cases of replacement of cement with LNP powder and replacement of sand with LNP. The compressive strengths of the specimens of cement replacement at 180 days were 48.0, 42.1, 34.2 and 27.4 Mpa for levels of replacement of 10, 20, 30 and 40%, respectively. The compressive strengths of the specimens of sand replacement at 180 days were 50.4, 53.6, 48.2 and 39.9 Mpa for replacement levels of 10%, 20%, 30% and 40%, respectively.

Table (8). Loads and compressive strengths of cement mortar cubes (28 and 180 days)

Type	Specimen	At 28 days		At 180 days	
		Average load, KN	Average stress, Mpa	Average load, KN	Average stress, Mpa
Cement Replacement	CE10	99.0	39.6	120.1	48.0
	CE20	93.6	37.5	105.2	42.1
	CE30	66.7	26.7	85.5	34.2
	CE40	52.0	20.8	68.6	27.4
Sand Replacement	SA10	122.3	48.7	125.9	50.4
	SA20	119.1	47.3	134	53.6
	SA30	111.7	44.6	120.5	48.2
	SA40	95.6	38.3	99.8	39.9

It was found that the replacement level of cement of 10% increased the compressive strength of mortars when compared with specimen without cement replacement at 28 days. It was also found that replacement level of sand of 30% with LNP increased the compressive strengths of mortars by 9.7%, 16.7% and 5% for replacement levels of 10%, 20% and 30%, respectively when compared with specimen without sand replacement at 28 days.

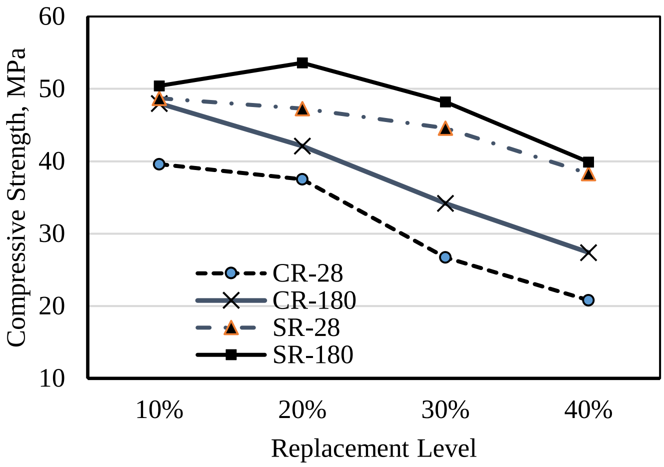

Fig. (7). Compressive Strengths of specimens (28 and 180 days)

5. Conclusions

In this research, the objective is to study the effect of utilizing LNP powder as a partial substitution for cement by weight and the utilization of LNP as a partial substitution for sand by volume in cement mortar cubes. The test results of cement mortar cubes were measured at 28 and 180 days.

The conclusions are listed as follows:

1. The partial substitution of cement with LNP powder decreased the strength of mortar cubes.
2. The replacement level of sand by volume with LNP at levels up to 20% increased the compressive strengths of cement mortars at 28 days.
3. The replacement of cement with LNP powder at replacement level of 10% at 180 days increased the compressive strength by 4.6% when compared with control specimen at 28 days.
4. The replacement of sand with LNP increased the compressive strengths at 180 days by 9.7%, 16.7%, 5% for replacement levels of 10, 20 and 30%, respectively when compared with control specimen at 28 days.
5. At long ages, the cement or sand partial replacement with LNP helped in gaining more strength.

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استخدام البوزولان الطبيعي المحلي كبديل جزئي للمواد الأسمنتية والرمل في مكعبات المونة الأسمنتية

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ملخص البحث. تعتبر الخرسانة أكثر المواد الإنشائية شائعة الاستخدام. تتكون الخرسانة من الركام الصغير، والركام الكبير ، والأسمنت ، والماء. إن خليط الأسمنت مع الماء يعتبر المادة الرابطة لحبيبات الركام في الخرسانة. يتواجد البوزولان الطبيعي المحلي في المدينة المنورة بالمملكة العربية السعودية. من المحتمل استخدام البوزولان الطبيعي المحلي كبديل جزئي للأسمنت والرمل لانتاج خرسانة خفيفة الوزن. يستعرض هذا البحث دراسة تأثير الاستبدال الجزئي للأسمنت في مكعبات المونة الأسمنتية ببودرة البوزولان الطبيعي المحلي لتقليل الأثر البيئي الضار الناتج عن انبعاثات غاز ثاني أكسيد الكربون كناتج من عمليات تصنيع الأسمنت ، وأيضا تتناول الدراسة تأثير الاستبدال الجزئي للرمل في مكعبات المونة الأسمنتية بالبوزولان الطبيعي المحلي على الخواص الميكانيكية للمونة الأسمنتية. يوصي كود البناء السعودي بإضافة البوزولان إلى نوع خاص من الأسمنت في صناعة الخرسانة المعرضة لنسب عالية من أملاح الكبريتات. تم اجراء الاختبارات على عدد أربعة وخمسون مكعباً من المونة الأسمنتية بأبعاد 50 مم ، تم تقسيمهم كالتالي: (ستة مكعبات كعينات مرجعية ، وأربعة وعشرون مكعباً تم فيهم الاستبدال الجزئي للأسمنت ببودرة البوزولان الطبيعي المحلي بنسب تتراوح من 10% إلى 40% ، وأربعة وعشرون مكعباً تم فيهم الاستبدال الجزئي للرمل بالبوزولان الطبيعي المحلي بنسب تتراوح من 10% إلى 40%). تم اجراء اختبار الضغط للمكعبات عند زمني 28 و 180 يوم. أظهرت نتائج اختبارات العينات التأثير الملحوظ على الخواص الميكانيكية لمكعبات المونة الأسمنتية التي تم فيها الاستبدال الجزئي بالحجم للرمل بالبوزولان الطبيعي المحلي عند مقارنتها بالعينات التي تم فيها الاستبدال الجزئي بالوزن للأسمنت ببودرة البوزولان الطبيعي المحلي.

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Environmental and Financial Analyses for Waste Management Options in Madinah- KSA

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Abstract. Solid waste management options require the integration of economic and environmental principles in order to select the best management method. This study analysed municipal solid waste (MSW) generation, composition and collection of Madinah region, as one of largest cities in KSA with the aim of finding a management method with minimum cost. The study aimed to provide an overview of current state of MSW management and recommendations for improving the waste treatment and management system in this area based on the significance of environmental and financial aspects. These recommendations would be not specific to Madinah region, but also would be applied to other cities in KSA or any other regions with similar features. The analysis results showed that the trend of waste generation would be increased as much as two to three folds in 2030. Approximately 30% of total generated waste is disposed to a sanitary landfill, while 70% is sent to normal dumpsites. The results of environmental and finical analyses recommended the recycling and energy recovery managements options for this type of wastes in this area. The results revealed that the worst scenario for solid waste management is just landfilling whereas the money-back is zero and the best scenario is implementation the composting process for the organic portion of the waste and recycling the other items.

***Keywords*:** Solid, Waste, Management, Environment, Financial

1. Introduction

Solid waste accumulation is one of the main life-threatening issues globally considered due to its great impact on the environment. Vast increase of consumption rate of different resources due to the population growth rate and development of different utilities, results in a massive generation rate of solid waste from household, medical, sewage, and industrial sectors. Several methods have been investigated to cope with the waste generation rates and reduce its massive impacts on both the public health and the environment. The waste management options vary from one place to another. Most urbanized cities are now struggling with the problem of a giant amount of solid waste and its proper disposal and the impact to the local and global surroundings.

Various studies have been conducted recently to find different approaches conformed toward minimizing solid waste generating rate and to increase the public awareness of solid waste management (SWM). Mendes et al. [1] inspected the management of the biodegradable solid waste fraction in Sao Paulo, Brazil to compare among composting, biogasification and landfilling. They concluded that landfilling was the scenario with the highest environmental impacts, except in the case of acidification potential, in which composting presented the highest potential. Beigl and Salhofer [2] compared the ecological effects and costs of different waste management options in the region of Salzburg in Austria. They concluded that Kerbside collection is ecologically better than collection in the bring system because the specific fuel consumption is lower for collection transports than that for individual transports. With regard to acidification and net energy use, the recycling of metals plays an important role. Özeler et al. [3] studied various SWM methods for Ankara, Turkey. The main conclusion of the study is that the scenario, which included source reduction, collection, transport and landfilling, was the one with minimum contribution in all the impact categories.

The terminology of solid waste hierarchy was initiated since 1975. It presents the order of preference of the main options for managing solid waste. The solid waste hierarchy offers a useful framework for formulating SWM regulations and policies. The European

Commission in 2007 suggested a three-step for SWM hierarchy started by placing prevention first, followed by re-use or recycling and energy recovery on the second level, and disposal at the bottom. A successful SWM policy should consider the link between growth of economic and solid waste. This suggests reducing the waste quantity by reducing the resources consumption [4].

Relationships of service-payment between the customer and the service supplier are indirect. The customer does not recognize the service that they receive due to the service is mostly under-valued or under-provided except applying policy and laws to ensure service delivery. Disposal services of solid waste and their treatment methods have different cost values. Advanced treatment of solid waste is generally costly more than sending waste to landfills when the financial costs of the service are considered only. Conversely, in view of the widespread economic costs and benefits from a social aspect, the advanced treatment options for solid waste are more complimentary than just placing wastes in landfills [5].

In this study, the various management options of the solid wastes in Madinah region, as one of largest cities in KSA have been discussed along with the plans for improving the waste treatment and management system in the area. The study also investigated the significance of financial aspects of waste generations and different waste management methods.

2. Methodology

2.1 Study Area and Data Collection

This study was applied on the western part of the kingdom of Saudi Arabia (KSA) in Madinah city. The greater Madinah comprises from several municipalities; seven main municipalities are namely Alharem, Alawaly, Qiba, Alakek, Ohed, Alouoon and Albedaa as shown in Fig. 1. Total Madinah area is 151,990 km^2 and population density according to 2010 census is 12/km^2 [6]. Monthly estimations for the waste types and amounts for these regions since 2007 were collected from Al Madinah Regional Municipally [7]. The data was analyzed to examine the best management option in view of both environmental and economy aspects.

3. Results and Discussion

3.1 Current State of SWM in Madinah

Waste Generation

The sources of waste generation of the municipal solid waste (MSW) in Madinah are household, agricultural and commercial wastes [7]. Fig. 2 presents the waste generation amounts from different sources for all regions in Madinah over the last ten years. The figure shows that the waste quantities increased yearly by 10% .

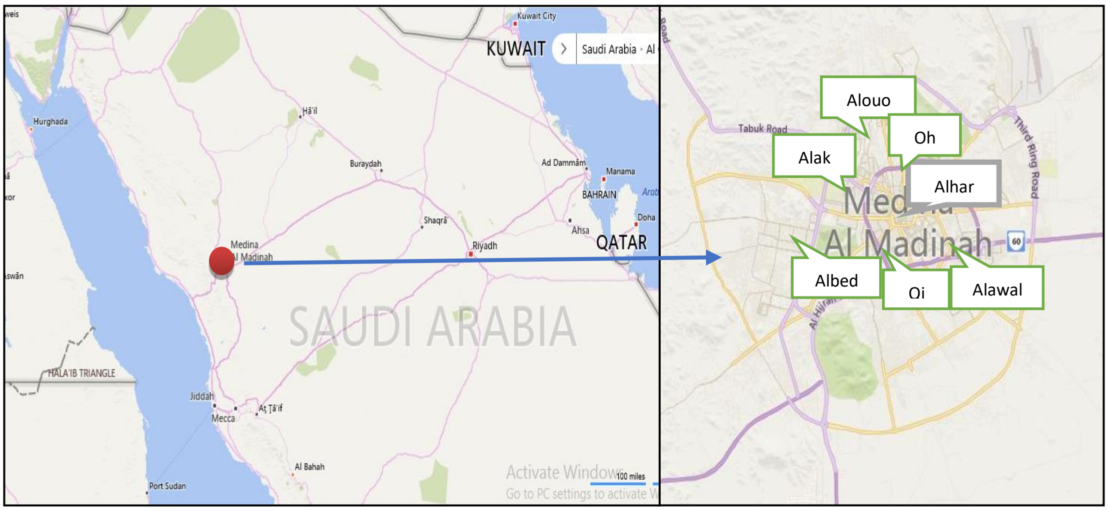

Fig. (1). Map for the studied area, Madinah in KSA (Source: Google maps)

approximately for all regions in Madinah. There was a significant increase in year 2015 in the waste amounts reached around 200% for some regions. Qiba area was the highest in waste generation among Madinah regions. In addition, Fig. 3 presents the total amounts of solid waste collected by Madinah municipally and by private commercial companies. The figure shows that the amount of waste collected by private companies was less than those collected by municipally up to 2013 and then started to increase. There was a significant increase in the waste collected by these companies in 2015. This is perhaps because there was a great construction activity in this year.

In a trial to predict the trend of waste generation progression of Madinah in the future, different relationships were examined between waste quantity per year and time. The exponential relationship showed a good correlation between the variables. Because there was a great increase in year 2015 and then back for the normal quantity generation in year 2016. Thus, two cases were studied including with and without 2015 waste quantity. Results showed relatively a good correlation in the two cases as they gave R^2 equal to 0.69 and 0.97 respectively. According to these correlations, the waste quantities were predicated for year 2030. Obviously, the prediction from the case having year 2015 was exaggerated, thus the second case might represent the actual predicated quantity of the solid waste. Figure 4 presents the predictions against actual values of the waste generation for the two cases. The results of the estimation showed a well predication for the waste quantity in the past especially for case without year 2015. Based on this result, the equation was adopted to predict the waste generation in the future such as in 2030, for instance. Waste quantity estimation in 2030 showed a high rate of waste generation as it gives three times folds in fourteen years.

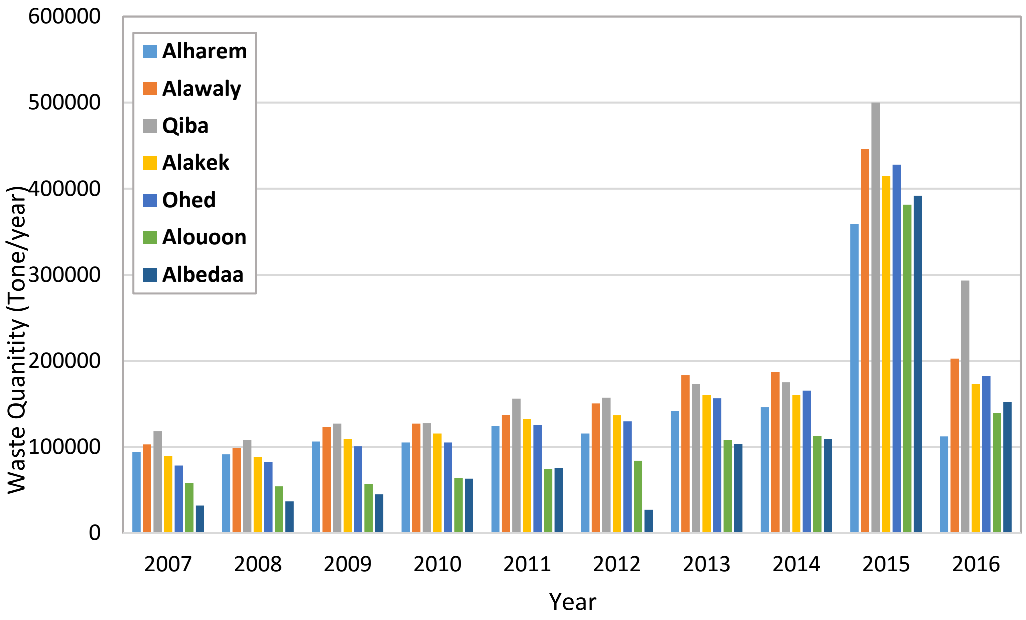

Fig. (2). Yearly waste generation for some main regions in Madinah city [7]

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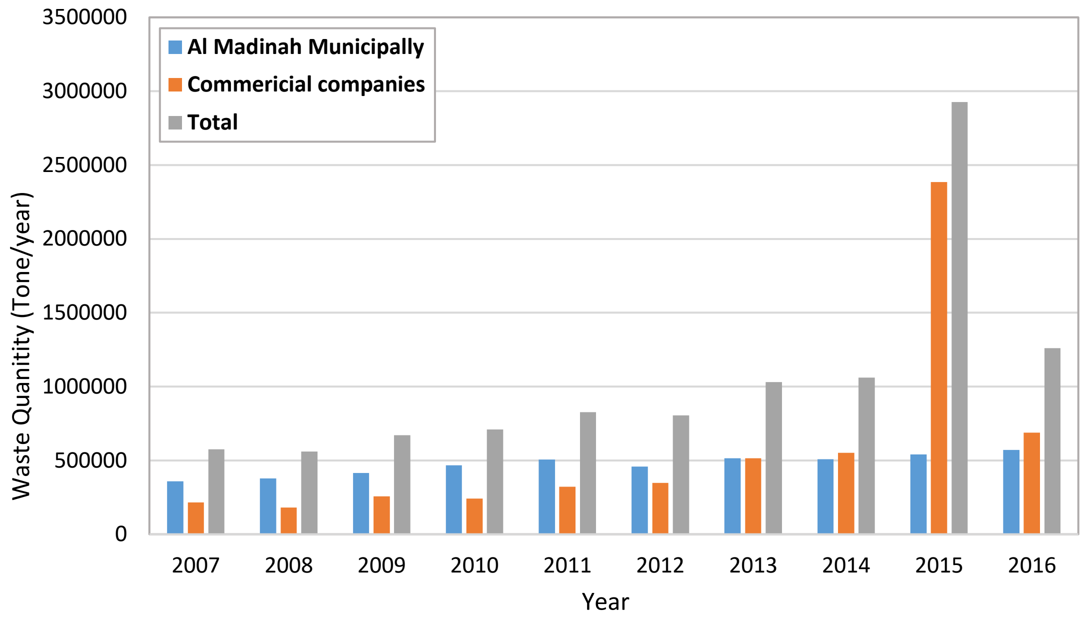

Fig. (3). Yearly waste generation in Madinah according to the collection source [7]

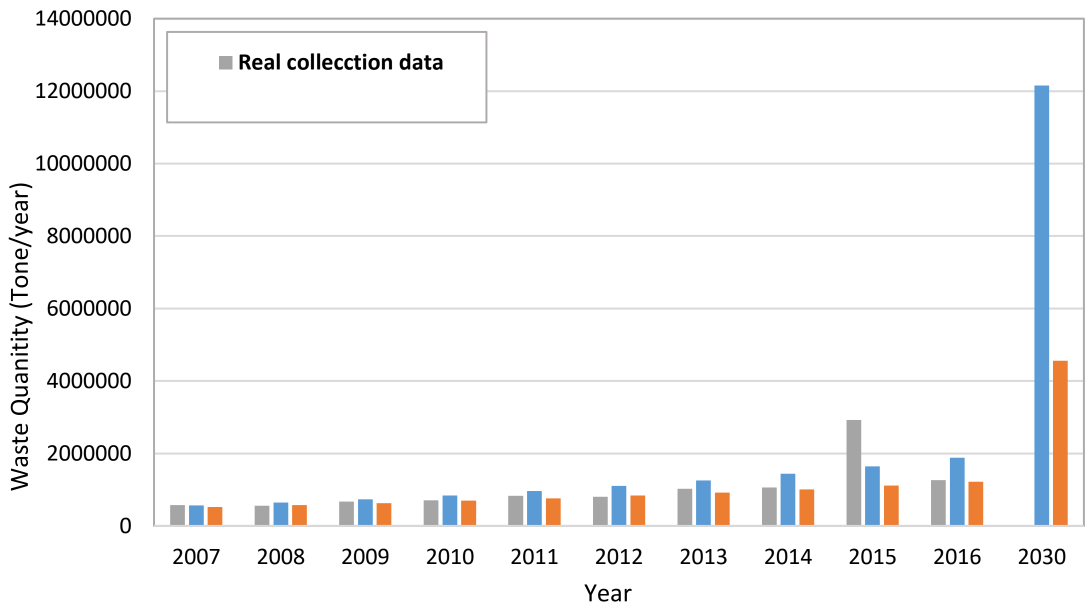

Fig. (4). Waste quantity predication based on population and time for whole Madinah

Waste Composition

The municipal solid waste (MSW) composition and their quantities majorly relay on consumers pattern and the developments in the economic and industrial sectors. The composition of the MSW comprises of different sorts of waste substance and materials, where the sorts varies depending on the sources and areas collected from. Figs. 5 and 6 present the daily average of the components of the waste collected by municipally and by commercial companies in the governorate of Madinah. The major divisions for the waste compositions are household, construction, agricultural, newspaper and cardboard; and butcher wastes. The figures show that the majority of solid waste collected is from household wastes. They show also that the majority of household waste collected by municipality and the majority of construction waste collected by the commercial companies. It is obvious that a huge amount of solid waste collection in 2015 was from construction wastes, which caused the significant increase in the waste quantity among the other collection years.

The average household waste composition included food by 13%, green waste of 2%, cardboard of 10%, paper of 13%, textile of 6%, sanitary textile of 3%, plastic bottles of 4%, plastic warps of 13%, other plastics of 2%, metal of 3%, glass of 3%, wood of 2%, other combustibles of 1%, non-combustible of 1%, electrical and electronic equipment's waste of 1%, hazardous waste of 1%, complexes of 1% and fines less than 20 mm of 20%.

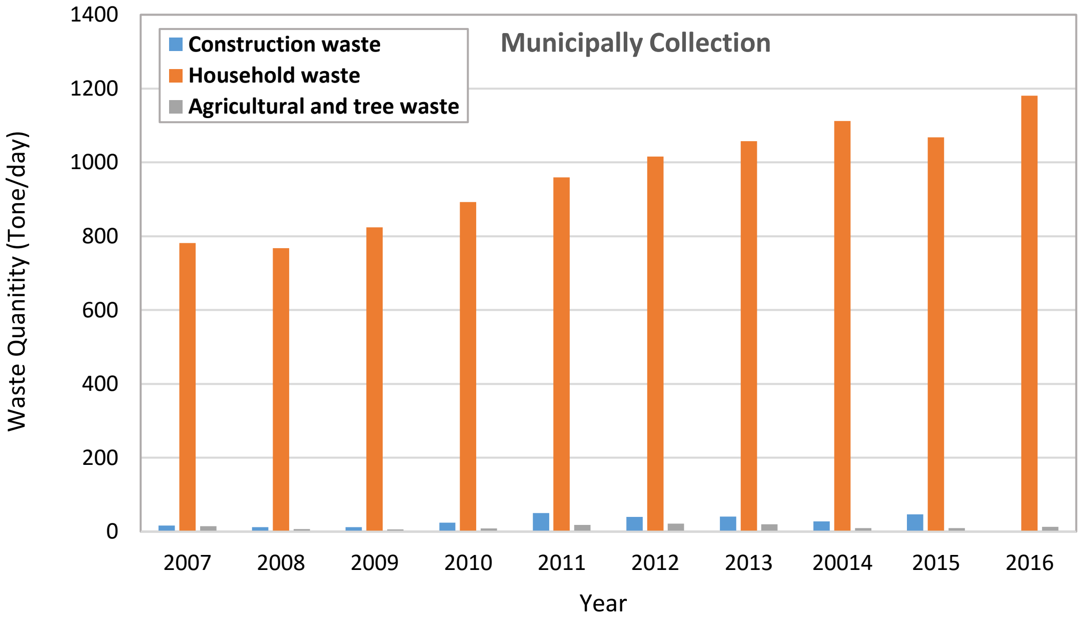

Fig. (5). Composition of waste collected by municipally

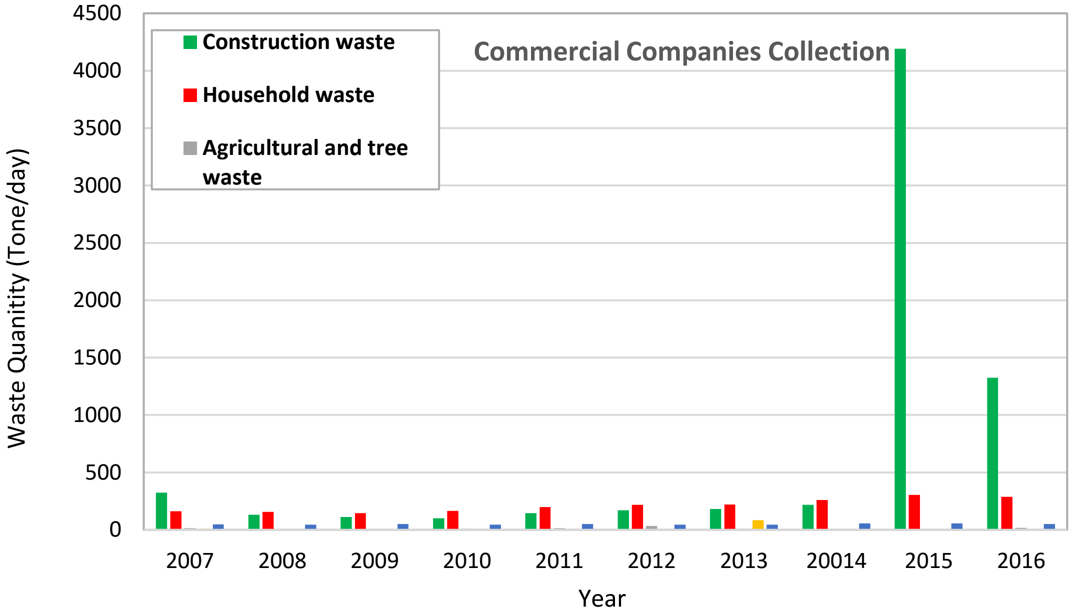

Fig. (6). Composition of waste collected by commercial companies

Waste Collection

Collection is an activity related towards gathering of MSW, transferring the collected waste and unloading the loader vehicles at transfer station or disposal site. Waste collection in Madinah is accomplished by transporting the collected waste from different storage containers at the generation point to the transfer station. Under this category of this collection system, there are two collection systems in Madinah namely, refuse collection system and commercial collection system. The refuse collection system is a system applied for collecting household waste from waste storage containers at the generation points. While the commercial collection system is a system applied for collecting commercial waste at the generation point of commercial wastes. Madinah municipality and private firms conduct the waste collection. The collection is conducted daily, twice per day for the commercial wastes, to avoid and prevent the spread of dieses that impacts the public health. Moreover, the municipality provided massive numbers of trash bins around the public space. There are two types of waste storage containers applied in Madinah located at every generation points at each area, namely large storage domestic containers on rollers and large storage commercial containers. There is no specified route for the waste collection system in Madinah. The collected waste is finally uploaded at transfer stations and then hauled to the disposal site or directly to the dump or disposal sites. The final storage of the solid waste is the process that resumes the collection process. Moreover, storage may also indicate a constructed facility that may be an excavation of an embankment or through structure fabrication used for storing waste.

Waste Disposal

Disposal is the action of getting rid of the unwanted materials or product by burial; it may be at a dumpsite or engineered sanitary landfill. Landfilling, the most widely used MSW management option has many uncertainties related to the period of the impacts [8]. Dumpsites and sanitary engineering landfills are located in the western south of Madinah, operated by the municipality. The dumpsite was used for disposal of MSW, but currently it is used for disposal of construction and demolished waste and timber waste, and also it is used for storing tire wastes and end of life vehicle wastes. Moreover, the sanitary engineering landfill has a waste leachtant collection system and the collect leachant transferred to waterproofed ponds. These ponds have a providing oxygen system to treat the leachant and disposal it in a safe way. The landfill has also a gas collection system. The sanitary landfill comprises of only municipal solid waste collected from household waste. The landfill receive around 1000 tone every day from all of the regions within Madinah , which is equal to approximately 85 % of the total waste generated from household wastes in the governorate of Madinah.

Waste management options in Madinah

Beside the landfilling options, which discussed in the previous section, there are two other waste management options practiced in Madinah namely separation and recycling. Currently, Madinah municipality does not practice other waste management options such as decomposing and incineration processes.

Separation of waste is the process of segregating waste into different sources and compositions. Separation of the municipal solid waste at the collection stage is not practiced yet in Madinah and most of KSA. The only process that may include segregation is conducted at the disposal sites to assure that none of the materials comprises of hazardous waste, medical waste, industrial waste, used tires or heavy metal commercial waste are present inside the waste delivered to the landfill. Hazardous waste from industries is stored at special containers and preserved at different locations of the KSA.

Recycling is the method conducted to turn waste into products. Recycling is one of the most important methods conducted at waste management process to assure the reduction of environmental impacts due to the waste and provide new alternates for the shortage in the natural resources. The authorities recently started practicing some of recycling measures through contracts with private firms, the recycling process include materials such as papers, plastic and used tyres transmitted abroad for recycling manufacturing. The percentage of the total recycled waste started with 2-4% from the total household wastes since 2007 and reached recently to 15%. The other 85 % of the total household wastes are landfilled as mentioned previously.

4. Financial Aspect of SWM in Madinah and KSA

4.1 Collection and landfill cost

The estimation of the cost for the collection activities of solid waste needs to calculate the direct and indirect costs. The analysis, herein, emphases entirely on the costs related to the collection process of solid waste up to reaching the landfill site. In this research, to estimate the direct costs for each unit used in the collection system such as bins, vehicles and workforce, a standard cost method was adopted based on methodology described elsewhere [9]. The estimation cost for bins and vehicles included purchase price, maintenance costs, depreciation rate, and labour hour cost for the employees. The actual data for the quantity of bins and vehicles used in the collection process in the whole Madinah governorate and the direct labour hours were obtained from annual reports of Madinah Regional Municipally [7]. Table 1 presents the estimation cost for solid waste collected from Madinah based on collection data of 2016. The table shows three types of bins adopted in collection process namely, small, medium and large; and two types of vehicles namely, small and large. Two levels of employees implemented the collection process namely, supervisors and workers. The estimation result showed that the average cost for collecting one tone of solid waste in Madinah is 67.43 Saudi Rail (SR).

Table (1). Estimation for collection cost of solid waste in Madinah

Equipment & Employee	Number	Cost/day (SR)	Total waste (tone/day)	Cost /tone (SR)
S-Bins	1798	0.438356	1150	0.69
M-Bins	9236	0.767123	1150	6.16
L-Bins	11040	1.161644	1150	11.15
S-vehicle	59	320	1726	10.94
L-vehicle	64	512	1726	18.98
Supervisors	55	80	3452	1.27
Workers	1049	60	3452	18.23
Total				**67.43**

4.2 Recycling cost

In the case of adopting recycling process as one of the most significance options of solid waste management in Madinah, the cost of collection will be assuredly increased more than the value mentioned above because there is another cost for waste separation. In this case, the cost for one tone of separated waste estimated having extra cost by 30% to become 87.66 SR. However, in this type of waste management option, there is a money-back yielded from marketing the separated waste for industrial. The separate solid wastes included paper, plastic, glass and metals. Each item has a range price according to its content and purity. The money-back was estimated based on the standard prices for the separated tone of each type of the waste mentioned elsewhere [10]. Fig. 7 presents estimation for recycling cost of available solid waste items in Madinah against the expected money back from selling theses wastes. The figure shows that money-back expected from this process covered and increased more than the cost of waste collection and separation. This emphasis on the benefits of recycling process as it removes wastes, save new resources and generate a revenue.

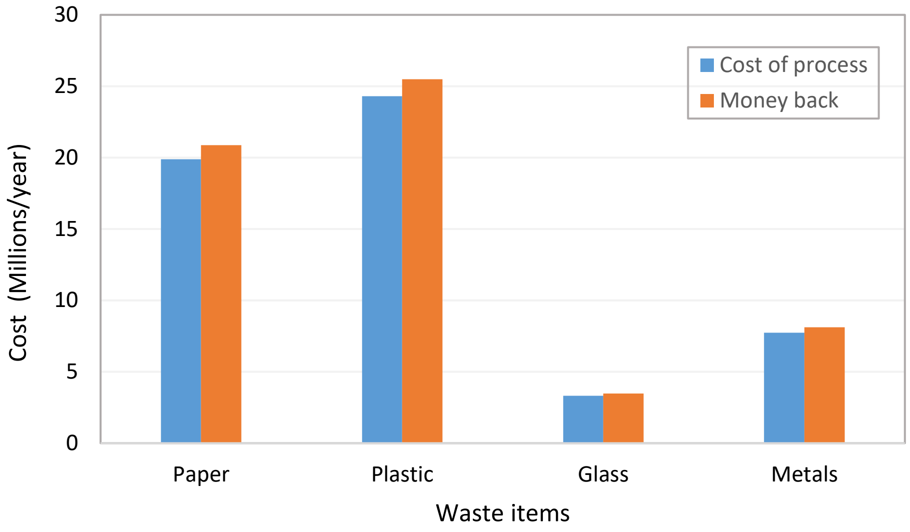

Fig. (7). Estimation for recycling cost of available solid waste items in Madinah

4.3 Composting and energy generation cost

The organic and biodegradable materials inside the solid waste of Madinah is about 65% from total household waste as mentioned earlier. The cost of composting the organic waste was estimated based on the standard production of biogas from anaerobic composting of organic waste. The calculation of the total cost is by multiply the total quantity of organic waste by methane production rate, in cubic meter, by standard price of energy of one cubic meter methane. Then the net cost will be by subtracting the expenses of composting process. Accordingly, the cost of collecting organic waste and separating it from other items is equal to 48 million SR per year for Madinah case and the money-back from energy production is almost double, equal 92 million SR per year.

4.4 Comparison between different management options

To find the best management option from the financial aspect for solid waste in this region, a combination between different types of management process was suggested. Fig. 8 presents estimation for cost and money-back of different solid waste management options in Madinah. The figure shows that the worst scenario for solid waste management is just landfilling whereas the money-back is zero and the best scenario is implementation the composting process for the organic portion of the waste and recycling the other items.

Results showed also that adopting landfilling with composting has more money-back benefits than adopting recycling with landfilling.

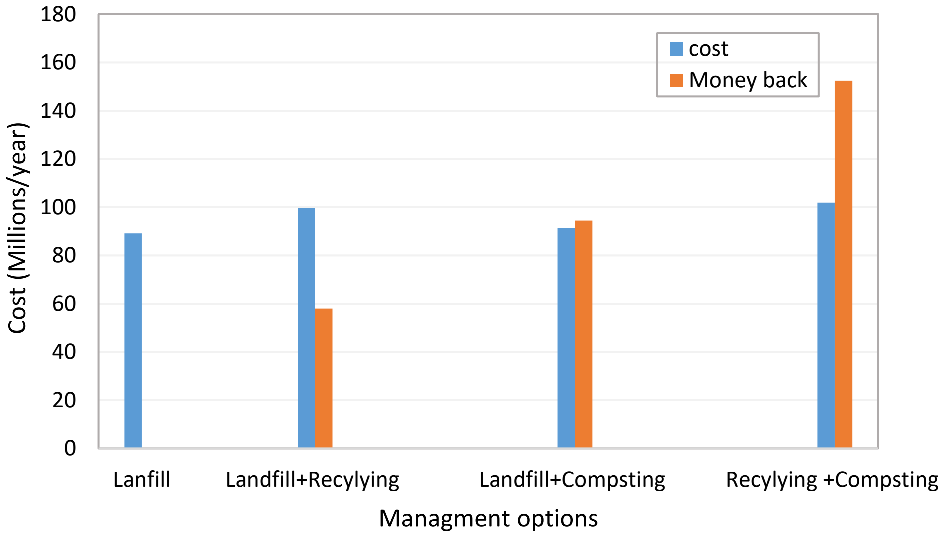

Fig. (8). Estimation for cost and money back of different solid waste management options in Madinah

5. Conclusion

The household of the waste generation in Madinah are mostly biodegradable, 65%, that comes from the household kitchen waste in the garbage and from the offices that uses cardboard and paper. Approximately 26% of total generated waste is disposed to a sanitary landfill, while 69% is sent to normal dumpsites and 5% is recycled.

The results of the regression equation for estimation the waste quantity based on time and population showed a well match with the collection data and reviled that current waste generation will be increased as much as three-fold in 2030.

The estimation result showed that the average cost for collecting one tone of solid waste in Madinah is 67.43 Saudi Rail (SR).

The results exhibited that money-back expected from the recycling process covered and increased more than the cost of waste collection and separation. This emphasis on the benefits of recycling process as it removes wastes, save new resources and generate a revenue.

The results revealed that the worst scenario for solid waste management is just landfilling whereas the money-back is zero and the best scenario is implementation the composting process for the organic portion of the waste and recycling the other items. Results showed also that adopting landfilling with composting has more money-back benefits than adopting recycling with landfilling.

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التحليلات البيئية والمالية لإدارة المخلفات بالمدينة المنورة

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قسم الهندسة المدنية- كليه الهندسة- الجامعة الإسلامية بالمدنية المنورة

(قدم للنشر في 2019/12/16 وقبل للنشر في 2020/4/1)

ملخص البحث. إدارة المخلفات الصلبة تحتاج الى دمج الجانب الاقتصادي مع الجانب البيئي لاختيار أفضل الطرق للتخلص من هذه المخلفات. هذه الدراسة تقدم تقييم عن حاله إدارة المخلفات وكمياتها بالمدينة المنورة بالمملكة العربية السعودية. يهدف البحث الى وضع توصيات لاختيار أفضل طرق إدارة المخلفات لهذه المنطقة اعتمادا على تقدير التكلفة الكلية لكل طريقة. هذه التوصيات صالحة للتطبيق على غالب مدن المملكة. الدراسة أظهرت ان ردم المخلفات هو الطريقة المستخدمة على الأغلب في منطقة المدينة المنورة وأن 30% من المخلفات تردم بمرادم هندسية بينما البقية تردم بمرادم غير هندسية. الدراسة أوضحت أن مجرد التخلص من المخلفات بالمرادم من أسوأ طرق إدارة المخلفات وأن تطبيق طرق إعاده التدوير والتخمر البيولوجي للمخلفات العضوية من أفضل الطرق من وجهة النظر الاقتصادية والبيئية.