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Case Study

Integrated solid waste management in megacities

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ABSTRACT: Rapid urbanization and industrialization, population growth and economic growth in developing countries make management of municipal solid waste more complex comparing with developed countries. Furthermore, the conventional municipal solid waste management approach often is reductionists, not tailored to handle complexity. Therefore, the need to a comprehensive and multi-disciplinary approach regarding the municipal solid waste management problems is increasing. The concept of integrated solid waste management is accepted for this aim all over the world. This paper analyzes the current situation as well as opportunities and challenges regarding municipal solid waste management in Isfahan according to the integrated solid waste management framework in six aspects: environmental, political/legal, institutional, socio-cultural, financial/economic, technical and performance aspects. Based on the results obtained in this analysis, the main suggestions for future integrated solid waste management of Isfahan are as i) promoting financial sustainability by taking the solid waste fee and reducing the expenses through the promoting source collection of recyclable materials, ii) improving compost quality and also marketing the compost products simultaneously, iii) promoting the private sector involvements throughout the municipal solid waste management system.

KEYWORDS: *Conceptual model; Compost; Integrated solid waste management; Isfahan; Recycle waste; Sustainability*

INTRODUCTION

Municipal solid waste (MSW) management is a major issue in the countries worldwide. This problem is more sensitive in developing countries, because the total amount of MSW has dramatically increased due to rapid urbanization and industrialization in the cities of developing countries (Manaf, *et al.,* 2009; Refee *et al.,* 2008). A megacity is defined by the United Nations as a metropolitan area with more than 10 million inhabitants. Some definitions also set a minimum level for population density at least 2000 persons/km^2. A megacity can be a single metropolitan area or two or more metropolitan areas which totally forms an integrated area. In 1950, there were two mega-cities with 10 million or more inhabitants, in 2012, it increased to 30. Most of these megacities are located in developing countries that the growth rate often exceeds 2% per annum. Mega-cities have to face different challenges such as environment and energy issues, and should develop new approaches, to answer to these challenges.

MSW problems in developing countries are more complex due to a number of reasons, such as urbanization, economic growth, political and cultural aspects. The conventional municipal solid waste management (MSWM) approach is reductionist, not the ability to solve the complexities caused by interaction of different parts of the system. Functional elements of waste management are considered independently, while these elements are influenced by one another, consequently one problem is solved but others remained (Marshall and Farahbakhsh, 2013;

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Seadon, 2010). These challenges promote holistic approach that considers all the aspects e.g. cultural, environmental, social and political and all stakeholders of MSWM system. Integrated solid waste management (ISWM) is a comprehensive, multi-dimensional and sustainable approach to solve the MSWM problems all over the world. The difference is the methodology of developing the ISWM concept (Asase *et al.*, 2009). ISWM strives to integrate functional elements and processes that form a waste management system (McDougall *et al.,* 2001).

This paper explores the current MSWM practices in Isfahan and then assesses MSWM system in this city according to the concept of ISWM. This could be the basis to development of ISWM in Isfahan and other major cities in Iran. In recent years, different frameworks have been introduced for explanation of ISWM (Klundert and Anschutz, 2001; Marshal and Farahbakhsh, 2013; Shekdar, 2009). In this paper the ISWM framework of Klundert and Anschutz, (2001) is used to analyze the MSW management system in Isfahan. This study has been performed in Isfahan City of Iran in 2015.

MATERIALS AND METHODS

Isfahan is the Iran's cultural capital and located about 330 km south of Tehran. According to the 2011 census, Isfahan's population is 1,834,609 and is Iran's third largest city after Tehran and Mashhad. Isfahan's economy depends on tourism and the weather is usually relatively moderate and dry.

Isfahan is introduced as a pioneer in MSW management practices in Iran. Previous studies in this area were investigated in this research. The OWM, 2015 and Abdoli *et al.,* 2013 have indicated the situation of SWM in Isfahan in recent years.

Available data demonstrates that the total MSW generation in Isfahan is 1150 tonnes per day, of which only about 150 tonnes is col-lected as source-separated recyclable materials, while the other 1000 tonnes are not separated. Therefore, the MSW generation rate is thus 0.62 kg/capita.day (OWM, 2015). Total solid waste received by the disposal center from 2004 to 2014 is shown in Table 1. Table 2 shows the composition of discarded MSW in Isfahan. Organic matter comprises 64.11% of solid waste stream. Table 1 indicates the recyclable material has been increasing gradually. The moisture content of MSW in Isfahan is 24% in November while it reaches 38% in May. In average, 20% of the weight of total generated waste in Isfahan is capable to be leachate; this percentage reaches 25% during the summer.

In Isfahan, more than 90% of the total waste is collected by the municipality and the other is collected through informal systems. At present, about 360 tonnes of recyclable waste is generated daily, but only 130 tonnes is collected by formal sector and about 20 tonnes is collected by informal sector, meaning that about 41% of the recyclable waste or 13% of the total waste is diverted from landfills via recycling. Table 3 demonstrates the amount of recyclable waste collected and its composition (OWM, 2015).

Table 1: Solid waste generated in Isfahan from 2004 to 2014

Year	Tons/day	Tons/ year
2004	810	295599
2006	856	312427
2008	870	317640
2010	914	333507
2011	1050	383250
2012	1103	402534
2013	1150	422700
2014	1140	416100

*(OWM, 2015)

Table 2: Materials discarded in the municipal waste stream (percent of total generation)

Components \ Year	1994	2005	2010	2011	2012	2013
Organic waste	83.31	73.15	68.98	65.77	65	64.11
Paper	2.34	4.19	4.87	4.34	4.5	4.59
Plastics	4.28	11.26	14.79	18.14	19	19.85
Textile fiber	2.07	4.5	4.79	3.99	4	4.08
Rubber	0.15	0.17	0.37	0.97	0.98	1
Wood	1.01	1.82	0.85	0.63	0.6	0.59
Glass	2.13	1.9	1.17	1.09	1	0.99
Metals	2.27	1.5	1.7	2.48	2.42	2.37
Others	2.41	1.51	2.5	2.6	2.5	2.43

*(OWM, 2015)

Table 3: The composition of recyclable waste*

Component	Total waste		Recyclable waste (%)
	Weight (tons)	Percentage (%)	
Polymeric materials	173	15.8	47.9
Paper	102	9.4	28.3
Glass	24.5	2.3	6.8
PET	16.5	1.5	4.7
Metal	20	1.84	5.58
Others	24	2.18	6.60
Total	360	33	100

*(OWM, 2015)

An economic benefits/potential analysis of a waste-to-energy incineration plant of 25 MW capacities in Isfahan has been carried out by Abdoli *et al.* (2013). The incineration plant is in the final stage of planning. The city's planning team identified and evaluated available technologies, and selected the best appropriated technology for the plant. For a time being, Isfahan municipality is compressing 300 metric tons of rejected material from composting plant per day and stockpiling it near the location of the future MSW incineration plant. In addition, 60% of the total waste generated used to be composted to produce a humus material, 20% is being compacted and stored it in the vicinity of incineration plant for use as fuel in the immediate future, 13% is being recycled and the remaining 7% is rejected e.g. textile fiber, wood, etc., which is landfilled.

RESULTS AND DISCUSSION

The ISWM concept distinguishes six aspects which are: environmental, political/legal, institutional, socio-cultural, financial/economic and technical and performance aspects (Klundert and Anschutz, 2001) (Fig. 1). These aspects are discussed considering the present status of MSW management in Isfahan as follows.

Technical aspects

Waste characteristics and quantities and also local conditions and limitations have significant impacts on technical aspects of waste management. Although waste incineration has been known as a suitable option in developed countries, it faces with difficulties. For example the low heat value is a prevalent barrier particularly in these countries due to the high percent of degradable organic matter in waste stream. Isfahan municipality considers the reject of compost plant for incineration which contains high heat value. Another problem is the lack of skilled workforce in the setup and operation of incinerators. Therefore, the municipality should train technical personnel in this regard.

In Isfahan, 60% of the total waste generated is being composted to produce humus material. The initial design of the compost plant was not consistent with the characteristics of the waste. Over time, retrofitting in plant design was performed. However, composting in Isfahan like as many cities of developing countries accompanies with difficulties such as:

- Lack of separate collection system of organic waste.
- Improper design of plant according to the characteristics of the solid waste input.
- Inadequate and irregular monitoring of compost quality.

These problems in the process of design and implementation of composting plant should be attended. Design and development of collection and transportation should be balanced with waste characteristics. In Isfahan dominant component of waste is organic and as a result, daily collection of MSW is an inescapable issue particularly in warm seasons. In Isfahan, more than 90% of the total waste is collected by the municipality; this rate is acceptable in comparison with many developing countries.

Environmental aspects

MSW management is a serious environ-mental problem, especially for large cities in developing countries (Abdoli, 2007; Hazra and Goel, 2009). 60% of the generated waste is being composted in Isfahan. Diversion of organic waste from landfill decreases the harmful environmental impact such as greenhouse gases (GHG) emissions, leachate production, odor and groundwater pollution potential (Nagarajan *et al.*, 2012). Moreover, compost application on soils

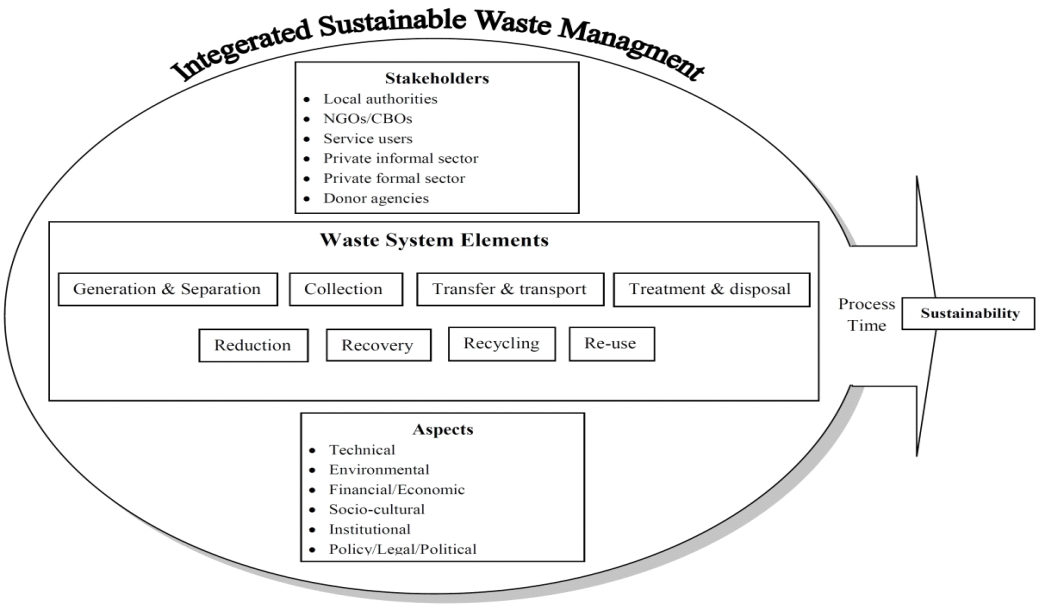

Fig. 1: The ISWM Model (Klundert and Anschutz, 2001)

improves organic matter content and at the same time prevents erosion (Zurbrügg *et al.,* 2012).

There are major concerns about the quality of the produced compost from MSW. Source separation and pre-treatment is done in the compost process, but physical, chemical and biological contaminants such as: glass shards, plastic fragments, heavy metals and endocrine disruptors are unavoidable (Farrell and Jones, 2009), which must be controlled and monitored continually. On the other hand composting plant workers are prone to respiratory and skin diseases. Therefore sanitation instruments such as hygiene masks and shoes must be prepared and distributed to the workers (Giusti, 2009; Zurbrügg *et al.,* 2012). These sanitary measures should be performed in all elements of the MSW systems.

Incineration with electricity generation is an environmental option, because this technology diverts the waste stream from landfill, eliminates the large number of pollutants and recovers energy from waste. However, MSW incineration is one of the sources of a group of persistent organic compounds known as "dioxins". These substances are non-degradable and accumulate in soil, water, and food (Giusti, 2009). Modern MSW incinerators are well equipped for dioxin control. Previous studies showed that municipalities in many developing countries cannot ability to buy modern incinerators compliance with environmental standards (Hossain *et al.,* 2011). In Isfahan, incinerator will be imported from abroad and its performance in the long term is uncertain. Since 2009, 430 acres of green space has been constructed around the future location of incineration plant. Although, this is a good step to control air pollution, it is not enough. Dioxin emissions from incineration should always be checked by air pollution control devices to protect human health and environment. This works well done in some developing countries such as Taiwan (Kuo *et al.,* 2008), that could be a promising experience for Isfahan and other cities of Iran.

Although only 5% of the total generated waste is landfilled in Isfahan, but also evaluating environmental impact of landfill is necessary. In fact, if a landfill is not properly designed and maintained, it increases concerns about environmental pollution. Landfill may pollute the soil, air and water due to leachate and biogas production (Yang *et al.,* 2014). The municipality intends to generate electricity from old landfill of the city with the help of the private sector (OWM, 2015), this work will reduce the GHG emissions dramatically. It should be noted that the transition to the sanitary landfill with leachate control is necessary for Isfahan municipality, but achieving this goal in the short-term period is unrealistic.

Table 4: Revenues of recycling through diversion from landfilling

	expense (USD/ton)	daily recycling (ton)	daily costs reduction (USD)	yearly costs reduction (USD)
Costs of collection and transportation	16	150	2400	876000
Costs of landfilling	4	150	600	219000
Total			3000	1095000

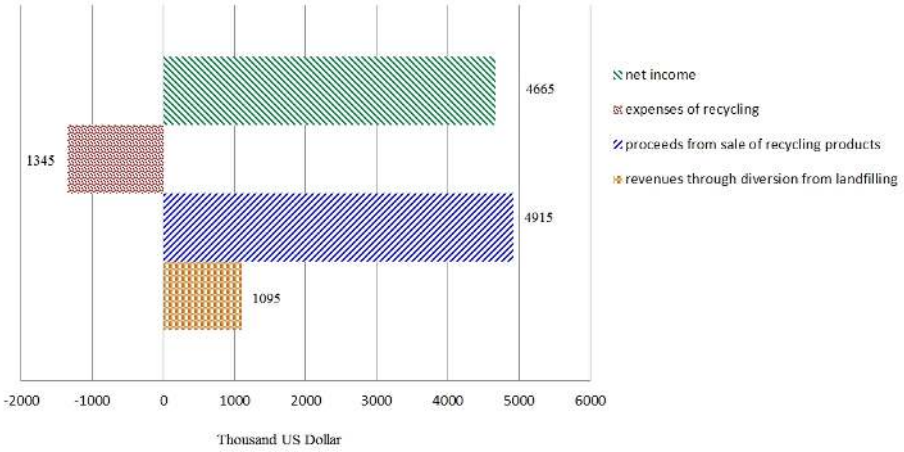

Fig. 2: Overview of total yearly costs, revenues and net income of recycling

Financial and economic aspects

The major issue in this aspect is that although the 20-50% of municipal revenues spent in developing countries to manage the waste, but it is not enough often to cover all the population (Othman *et al.,* 2013). One of the other obstacles is that although more funds is spent on collection in low-income countries but not ability for servicing of all urban areas, while in high-income countries less than 10% is spent on collection services (Memon, 2010).

In Isfahan door-to-door collection of solid waste households is done by municipality. Daily collection is an unavoidable issue in Isfahan's MSWM system and the most labor intensive and costly part of the system. The costs of waste collection and landfilling are estimated at USD 20 per ton. About 150 tons of recyclable waste is collected separately, this work reduced the annual financial burdens of transportation, collection and landfilling to USD 1,095,000. Also, yearly revenues from the sale of recycled products are calculated separately for each material in Table 4. It should be noted that the recycling process leads to fees such as human forces, motor vehicle (fuel, tire and depreciation), rewards, separation and segregation. Monthly and yearly expenses of recycling process are USD 111950 and 1343400 respectively. Fig. 2 depicts an overview of total expenses, revenues and net income of annual recycling. It shows that the annual net income of recycling process is around USD 4665000.

The initial capital required of new incineration plant is USD 21 million and the total income from the sale of 3 years electricity generated by the plant will be covered it. Therefore, the return on investment will take place over three years and the waste-to-energy incinerator plant will be self-sufficient without the need of subsi-dies. This plant operation pro-gram is expected to have a great benefit (Abdoli *et al.,* 2013).

A much more efficient and affordable way to control GHG emissions from waste is to stabilize the waste via composting (Mahmoudkhani *et al.,* 2014). Therefore the clean development mechanism (CDM) under the Kyoto Protocol could be considered as a source of income in developing countries, while Kyoto Protocol stops for registration in December 2012.

Accompanying composting with sorting equipment or manual works to separate the proper organics from mixed waste will lead to additional cost. Indeed, the compost products must have the ability to compete in price and quality with fertilizers. Thus, attention of the compost organizations should be turned to the compost marketing and consumers feedback. In Isfahan, compost is produced by open windrow which is a low-

Table 5: An opportunity/challenge analysis for current situation of MSWM system of Isfahan

Aspect	Opportunity	Challenge
Technical and performance	- More than 90% of the total waste is collected by the municipality. - There are 53 recycling stations throughout Isfahan that will increase to 60 by the end of 2015. - Composting could be a suitable option according the high component of organic matter in waste stream	- Lack of skilled workforce in the setup and operation of incinerator for a long term period - Lack of separate collection system of organic waste - Improper design of plant according to the characteristics of the solid waste input - Inadequate and irregular monitoring of compost quality - The waste transport vehicles, machinery and other equipments are damaged due to the acidic pH of the leachate
Political and legal	- Existence of national regulation related to MSWM	- Lack of law enforcement by related agencies. - Inadequate transparent of responsibility of different stakeholders in MSWM system
Institutional	- The primary strategic action plan of MSWM in Isfahan is designed in recent years	- Improper of involvement of private sector. - Lack of the technical consultant in the field of design, select and operation of different mechanism related to MSWM. - Lack of technical knowledge
Socio-cultural	- Decreasing waste generation rate by 20% according the source reduction program in the last two years - Source-separation program is improved in recent years	- Only 35 percent of citizens are committed to the program of source separation - Changing in lifestyle of the residents is a long-term process
Environmental	- Diversion of organic waste from landfill by compost decreases the harmful environmental impact - Application of compost has a positive impact on soil - Incineration with electricity generation often is an environmental option - Electricity generation from old landfill of Isfahan	- 20% of the weight of the total generated waste is capable to be leachate - Physical, chemical and biological contaminants in compost products are unavoidable - Employees of MSWM system are more prone to respiratory and dermal illnesses than the general public - MSW incineration is one of the sources of a dioxins as a non-degradable substance - Landfill may pollute the three principle media of environment (soil, air and water) - No distinct system to assess environmental impacts of MSWM system in Isfahan exists
Financial and economic	- CDM under the Kyoto Protocol could be considered as a source of income in developing countries. - Compost is produced by open windrow which is a low-cost option rather than in-vessel plants - Composting plant provides new employment opportunities specifically for adjacent citizenship - Isfahan has the first rank among other Iranian cities in compost marketing - The effective MSWM system has a positive effect on the economy of Isfahan through positive impact on tourism industry - The incinerator plant will be financially self-sufficient. - Considerable income of source separation and recycling compared to landfilling	- Collection is the most cost consuming of Isfahan's MSWM system - Accompanying composting with sorting equipment or manual works to separate the proper organics from mixed waste will lead to additional cost - No cost-benefit analyze of composting in city is done. - Accuracy of cost-benefit analysis of incineration in Isfahan is uncertain

cost option rather than in vessel plants and provides new employment opportunities specifically for adjacent citizenship. Isfahan has the first rank among other Iranian cities in compost marketing. Although 60% of the total generated waste is being composted, no cost-benefit analyze of composting in city is done. On the other hand the effective MSWM system and public cleansing have a positive effect on the economy of Isfahan through positive impact on tourism industry of city. Developing a procedure to collect the solid waste fee from users is one of the major practices in developing countries to promote the financial sustainability of system and also increasing the independence from the government. In this regard, a comprehensive effort should be considered to increase the public participation. Since the major part of annual budget is allocated to collection process, it is suggested to provide this cost from the users by an increasing rate of fee during a 20-year plan.

Socio-cultural aspects

Today it has been revealed that MSWM systems inattentive to social aspects will be defeated (Marshall and Farahbakhsh, 2013). Strategies that improve MSWM systems such as recycling, repair, reuse etc. require cultural change. Without public participation, MSWM system may become less effective. For example, source-separation efficiency and cleanliness of city strongly depend on public manner. Source-separation is a major issue, because it is an effective method to facilitate the operation of MSWM system. Desirable source-separation increases quality of compost products, reduces the cost of pre-treatment process of compost plant, provides high calorific value of waste for incineration and decreases landfilling.

Isfahan OWM has carried out some public education programs using mass media. Despite these efforts, only 35 percent of citizens are committed to the program of source-separation (OWM, 2015). A MSWM system must include a comprehensive and steady public education program to explain the benefits of citizen support and participation. As a first step residents must be familiar with types of wastes that are recyclable, compostable and combustible, and which are not (Abdoli *et al.,* 2013) and should also be informed health hazards of informal system. Because of rapid growth population in Isfahan the training of citizens for a source reduction is essential. OWM initiated some formal and informal training programs in the last two years. It is believed that these programs are the main driver to decrease waste generation rate by 20% (OWM, 2015).

In Isfahan, leachate is a major concern. At least 20% of the generated waste is leachate. Besides the negative impacts of leachate on the environment, the waste transport vehicles, machinery and other equipments are damaged due to the acidic pH of the leachate. In recent years, Isfahan municipality has initiated the activities to familiarize citizens with the negative environmental impacts of leachate. But it requires change in lifestyle of the residents that is a long-term process.

Solid waste composition is also inûuenced by cultural and socio-economic status. Recyclable wastes are more in developed countries, while degradable organic matter is high in developing countries (Othman *et al.,* 2013; Shekdar, 2009). MSWM should be proportionate to public behavior. Rapid development of economic growth will impact the composition of solid waste (Manaf *et al.,* 2009; Gupta *et al.,* 2015). In Isfahan, predominant form of waste at present is organic matter, though this condition is not stable. Noting rapid urbanization and industrialization of Isfahan, the proportion of recyclable waste has been continually growing in recent years. Therefore the MSWM system must be updated to suit the waste composition and quantity. For example, recycling services should be improved and developed gradually. At present, there are 53 recycling stations throughout Isfahan; this number will increase to 60 by the end of 2015.

Political and legal aspects

MSWM has low dependency on the political agenda in many developing countries, though this situation is beginning to change. Modification and implementation of realistic policies is a major concern in these countries. The policy should quantify the available goals in accordance with the local situation and also identify the responsibility and role of all stakeholders. Legal framework is formed on the basis of national policies and local legislations (Abdoli *et al.,* 2010). Periodical review and amendments of the policies and legislations should be considered. This makes possible to adopt feedbacks from citizens and other stakeholders in future development of MSWM policies and legislations.The national SWM law of Iran was enacted on May, 2004. All mega cities which have population more than 1 million be obligated to develop a framework

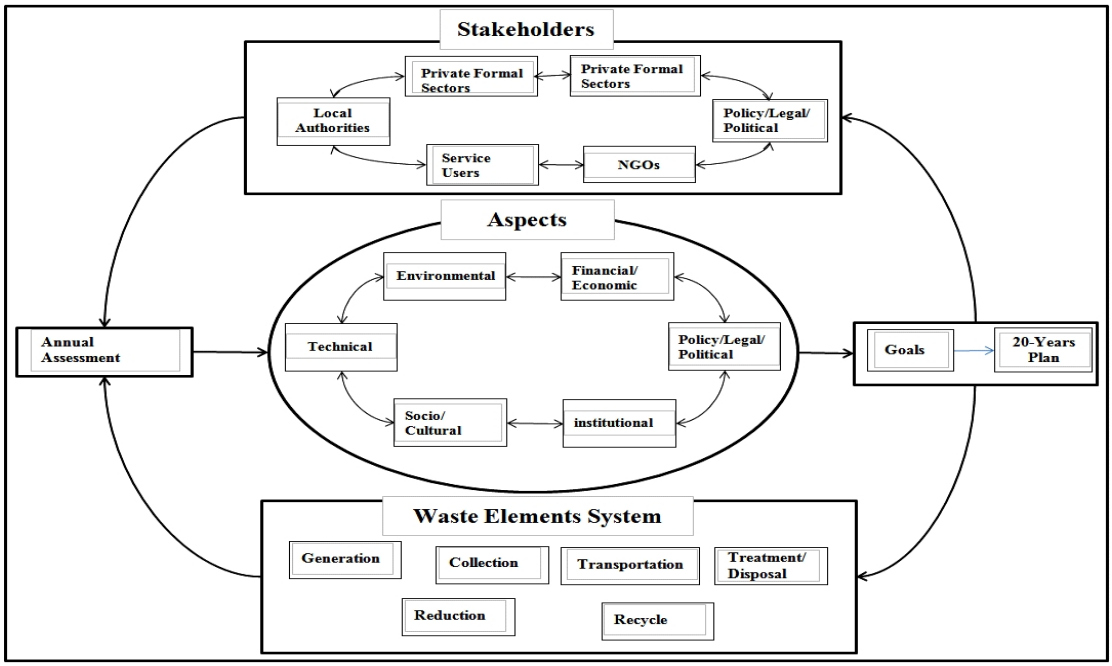

Fig. 3: Conceptual ISWM model in Isfahan

to separate the solid waste at the source by 20 March 2012. Two other regulations consider SWM fees in 2005 and electrical waste management in 2010 (Abdoli *et al.*, 2013). Even though legislation is often in place but enforcement tends to be weak. The principal challenge in Isfahan is the insufficient tendency in related organization to implement the regulations.

Institutional aspects

In developing countries, the lack of powerful institutional framework is a major issue. Increasing the transparency and also the coherency in responsible institutions are the required actions to achieve sustainable and sound governance in SWM (UN-Habitat 2010; Wilson 2007).

The municipality of Isfahan is responsible for MSWM. The first phase of a new MSWM strategic plan in Isfahan has been carried out, but also there are a lot of challenges to achieve the suitable situations. Private sector involvement is a suitable option to improve efficiency and service coverage but it is a challenging work. 10% of the generated waste is collected through informal systems, these activities must be institutionalized. The lack of technical knowledge requires establishment of a research center at the municipality which is responsible for technical training and also about the technical consultants in the field of design, selection and performance of different mechanisms related to MSWM.

CONCLUSION

Isfahan is introduced as a pioneer in MSW management practices in Iran. However, there are still several waste management problems in Isfahan that should be resolved. An opportunity/challenge analysis for current situation of MSWM system in Isfahan (Table 5) provides a comprehensive evaluation about the MSWM of Isfahan. Finally on the basis of ISWM framework, the conceptual model is presented for MSWM in Isfahan (Fig. 3). Using this model, the following recommendations are made for the future ISWM plan in Isfahan:

- At the first, municipality of Isfahan should design the 20-year plan of MSWM. Sanitary landfill with leachate control is an essential component of this plan.
- The early action plan and short-term goals must be defined. The performance of OWM should be assessed yearly according to the 20-year plan.
- Promote the financial sustainability of system through the increasing user's fee during the 20-year plan.

- Update the existing regulations and enhance enforcement of the regulations.
- The main component of waste stream in Isfahan is organic matters, so composting could be a suitable option. OWM should plan to collect organic waste separately and convince the public to take part in this program and develop market for composting materials in rural areas of Isfahan.
- Source-separation and pre-treatment in composting process should be improved. This measure could increase the quality of compost products and also have a positive effect on the performance of incinerator.
- Proper air pollution control equipments including dioxin control devices should be installed at incinerator plant.
- Personal protection equipments such as hygiene masks and shoes must be purchased and distributed among the employees of MSWM system.
- Recycling reduces expenses of collection and landfilling significantly. Therefore, expanding the source separation of recyclable waste is an essential issue.
- Promote the private sector involvements throughout the MSWM system.

Increasing the public awareness and also providing the infrastructure to facilitate the public participation.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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