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Developing an Integrated Solid Waste Management System for a Mini – Municipality in Tobruk – Libya

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Abstract:
In an attempt to solve problem of solid waste management in Tobruk, Libya, a field study of the services provided for solid waste management in 2012. Showed that these services were below the poverty level. The main objective of the study was to propose a comprehensive and sustainable solid waste management system. It was necessary to define the elements and criteria quantitively for the comprehensive design of solid waste which were as follows: a) The population 0f the city of Tobruk has reached 110,300 capita distributed over 20 neighborhoods, b) The total amount of waste to 120 ton per day c) The daily average of household waste generation reached 1.02 ± 0.29 Kg as household solid waste with a total of 111.78 ton per day; e) the estimated average household solid waste per neighborhood was 5.59±2.58 ton city is mainly urban with good roads network made of a good number of rate was 1.02 ± 0.29 Kg as household solid waste with a total of 111.78 ton per day. e) the estimated average household solid waste per neighborhood was 5.59±2.58 ton /day. a population density of 562.7. it was possible to design a sustainable comprehensive and integrated system. The proposed system consisted of the following .workforce of 831 workers and139 drivers and 38 supervisors, a managerial staff of 73, a total number of various type and capacity of containers 809, a transportation fleet of various trucks and vehicles of 55.

Keywords: Comprehensive and sustainable management, Household waste, Tobruk, Compost production, Sanitary landfill, Sterilization of hazardous medical waste.

تطوير نظام متكامل لإدارة النفايات الصلبة لبلدية مصغرة بمدينة طبرق ـ ليبيا

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الملخص
في محاولة لحل مشكلة إدارة المخلفات الصلبة بمدينة طبرق – ليبيا، أوضحت الدراسة الميدانية للخدمات المقدمة لتناول المخلفات الصلبة لعام 2012م، وتدني تلك الخدمات لمستوي الفقر، وكان الهدف الرئيسي للدراسة اقتراح نظام للإدارة الشاملة والمستدامة للمخلفات الصلبة، وكان من الضروري تعيين العناصر والمعايير كمياً لأجل تصميم الشامل للمخلفات الصلبة، وكانت كالاتي: أ- التعداد السكاني لمدينة طبرق وقد بلغ مائة وعشرة الأف وثلاثمائة مواطن موزعين علي عشرون حياً. ب- الكمية الكلية للمخلفات وبلغت مائة وعشرون طناً يومياً. ج- المعدل اليومي لتولد المخلفات المنزلية وبلغت 1,02 كجم ومدي إنحراف ±29 كجم / مواطن، وعليه فأن الكمية الكلية لتلك النوعية بلغت مائة واحدي عشر وثمانية وسبعون طناً يومياً، والمخلفات المنزلية للأحياء وصلت إلى 5,59 طن ومدى إنحراف ± 2,58 طن. د- المساحة الكلية لمدينة بلغت 294,7 كم^2 بكثافة سكانية 562.7 مواطن/كم^2، ونوعية البيئة حضرية، والتي تتميز بشبكة طرق رئيسية وفرعية جيدة. هـ- توفر مساحات لإنشاء محطات انتقالية ووحدات معالجة لإنتاج الكمبوست، وتعقيم المخلفات الطبية الخطرة وإنشاء مدفن صحي. و- طريقة جمع المخلفات المنزلية والتوقيتات المناسبة للأهالي، وبناءاً على ما تقدم من الحساب الكمي للعناصر والمعايير اللازمة لتصميم إدارة شاملة ومستدامة بمدينة، وقد أمكن وضع التصميم المناسب لمدينة كالآتي: قوة عمل مكونة 831 عامل و139 سائق و38 مشرف، وهيكل إداري ومالي مكون 73 موظف، وعدد الصناديق ذات سعات متنوعة للجمع 89 صندوق، وبراميل لسيارات النقل ذات سعة مختلفة 55 عربة، ومحطتي انتقاليتين، ووحدتين لإنتاج الكمبوست، ووحدة تعقيم للمخلفات الطبية الخطرة، ومدفن صحي، وبرنامج شامل لتوعية البيئية.

الكلمات المفتاحية: إدارة شاملة ومستدامة، مخلفات المنزلية، طبرق، إنتاج الكمبوست، محطة النقل، مدفن صحي، توعية بيئية، تعقيم المخلفات الطبية الخطرة.

Introduction

The present study started in the year 2012, addressing one of the main topics of environmental concern both globally and locally, it is the problem of municipal solid waste management (MSWM). Tobruk, a Libyan city has been suffering from such problem, and has been the case for a long time. Lack of an appropriate integrated and comprehensive MSWM system for the city is resulting from a number of factors, which will be investigated in the present research. After identifying the casual factors through field work and analyzing the obtained data on the present situation, a second phase of research included various municipal solid waste (MSW) parameters. These parameters are: number of Tobruk neighborhoods and their geographic distribution in relation to the existing roads network and distance to non- residential areas; population size and amount of MSW per neighborhood as well as the MSW generation rate; MSW composition; MSW organic fraction percent and its properties regarding composting criteria (Carbon: Nitrogen ratio and moisture content); availability of large enough land for establishing transfer stations/ composting plants and a sanitary landfill. These parameters need to be determined prior to designing a sustainable MSWM system. However, residents' preference of the type of MSW services as well as their willingness to pay for the services are considered of importance as to ensure customer satisfaction and financial viability of the MSWM system. Because of the complexity of the MSWM problem, several authors emphasized on the need to quantify such parameters before proposing a sustainable and valid MSWM system [1,2,3,4,5]. Regardless of the relatively great effort to obtain the required data in order to determine and quantify the mentioned parameters, the present study took a long time to achieve. Unfortunately, political events causing political instability accompanied with a serious degree of civil war hindered many research activities. However, with much harder effort, it was possible to come about such obstacles. Under unfavorable conditions, the problem of obtaining recent and accurate data on population size, amount of solid waste and generation rate, as well as its composition during the progress of the study was solved by using mathematical formulae to produce data of reasonable accuracy. Surveying a big number of research articles and reports, in addition of various case studies on MSWM issues, greatly helped in designing different components of the overall process of MSWM, starting from collection, transportation, sorting and segregation, re-use, recycling, treatment, and final disposal. In this context, much attention was given to public awareness and relationship between proper MSWM on one side and environmental protection, natural resources conservation, and human health and welfare on the other side. The present study, although went through handling of medical and health care solid waste, did not cover industrial waste. This is due to the fact that medical solid waste is usually and traditionally mixed with MSW generated from other sources, such as households, schools, institutions, restaurants, hotels, act. Also, industrial solid waste, apart from being hardly mixed with MSW, needs a completely different approach for its management. Different options of private sector participation in MSWM have been addressed. This thesis introduces a proposed MSWM system as general plan, hoping it could be of help to the municipality of Tobruk and if accepted all necessary executive steps and adjustments could be made before full implementation.

AIM OF the WORK**:** 1- This research is to analyses the present situation of municipal solid waste management in Tobruk. 2- Investigate several integrated municipal solid waste management systems, as to identify the most appropriate system. 3- Propose an integrated environmental management system (IEMS) for municipal solid waste for the city.

Methods

A thorough investigation of the existing situation has been conducted utilizing research data and direct assessment. Data concerning the population distribution per neighborhood and the estimated number of residential units and the amount of waste generated in each neighborhood were collected. Socio-economic level of the inhabitants of each neighborhood, the pattern of traffic and the urban morphology was considered. Furthermore, special attention was given to the existing collection and transportation equipment and the so-called transfer areas. Information on the following were obtained and analyzed as the most relevant for the design: -geographical position, topographical position, principal access roads, area extension, municipal borders, buildings topology, ambient, archeological, monumental and hydrogeological obligations, touristic, social and cultural activities, urban structure, with identification of residential (type of housing), commercial, industrial, agricultural and touristic areas roads network and traffic intensity, positioning of collected waste delivery points and road network linkages.

Municipal Solid Waste Generation

The measure of the amount of generated MSW has been carried out on the basis of records of the truck's loads collected daily both by the municipality due to the absence of any weighing scale at the open dump sites. Municipality research on various reports and some field tests has been conducted. A check of these figures has been done by multiplying the per capita waste generation parameter by the number of inhabitants, although this parameter differs from a neighborhood to another due to certain factors; almost the same values of the amount of

daily generated MSW in Tobruk was found to be about 120 tons /day. Therefore, the MSWM system was designed taking into account an average of 120 tons /day (total MSW), demolition debris sand, and dust are not included.

Municipal Solid Waste: Sources and Flow

Investigations of MSW sources and flows characteristics have been conducted in order to allow for the calculations. For every MSW generator the reference parameter has therefore been identified as follows:
for households the parameter is number of inhabitants and thus, municipality population, for commercial businesses, the number and the shop area are an adequate parameter for quantification of waste together with the type of activity, for markets, the number and area, for restaurants and canteens, the number of staff members, the area or the number of available seats for gests, the production of green waste is tied to the extension of parks or green areas and to the frequency of maintenance. After assigning an average value of each MSW source by the field investigations, MSW generation coefficients for every type of source was multiplied by such value in order to obtain the daily amount for each category. For example, in Tobruk an average generation of 1 kg MSW/m^2 per day for grocery businesses was found to be the coefficient for such activity, by multiplying it by the number and area extension of the mentioned businesses, the quantity of MSW generated by this type of activity was estimated.

Collection and Transportation Equipment Situation

The present situation of collection and transportation of MSW is poor since there are few containers (1to 2cu. Mt capacity) unloaded by means of side loaders. The loading vehicles are used as mobile containers moving on the main roads to collect waste at certain places from street sweepers' piles. Small trucks and vehicles are working in the secondary roads. Many existing vehicles are off-duty in the garages because of unavailable spare parts and because of lack of resources to fix them properly. There are few mechanical sweepers during the night service along main roads. Spray trucks for washing the roads are also very old and rarely used as the other equipment. There are a scattered number of big containers, which are usually full without collection services due to reduced number of working lift trucks. In the crowded neighborhoods, it was noticed that the use of small tipper trucks and also some pick-up vehicles to serve rough roads are used. These vehicles when reaching the full capacity, they unload the content into bigger collecting trucks. The use of special trucks equipped with a loading tipper container in the back is for removing SW from illegal dumps in the popular neighborhoods with the help of a caterpillar front loader.

Analysis and Design Data Municipal Solid Waste Composition Analysis

The examination of the composition of the waste generated in a specific area or district allows the choice of appropriate management and treatment methods. The MSW composition analysis is also of fundamental relevance for designing a system of separation at source which will be described later. For a correct analysis it is useful to remark among other factors: possible qualitative changes over a period of time, possible seasonal changes, a change in the long term in the population socio-economic conditions, for commercial waste it may be necessary to evaluate any dramatic technologies developments in the production cycles or new laws. One hundred MSW samples each of about 50 kg were collected from different neighborhoods and sorted out, each MSW component was weighed to determine its percentage.

Organic waste composting criteria Randomly collected samples (10 samples) of the organic fraction of MSW were analyzed for their carbon: nitrogen ratio and moisture content (%) (Senersi, 1989). This was carried out as to evaluate the suitability of the organic fraction for composting and determine if it needs adjusting.

Methods of Collection and Transportation

Municipal solid waste collection design parameters and definitions

In order to apply the optimum methodology for the MSW collection service the following criteria were considered:

- guarantee maximum reliability,
- guarantee an adequate hygiene level for generators and employees,
- minimize man-waste physical contact,
- obtain collaboration from all involved stakeholders,
- always maintain minimal costs.

The parameters that have to be optimized are:

- percentage of door-to-door collection,
- number and type of containers,
- emptying frequency,
- container placement in the urban network,
- number and characteristics of vehicles assigned to the service (volume and weight capacity, operating time collection speed from one container to the next, from garages to operation areas, and from operation areas to waste disposal sites),

- parameters related to the waste transportation system between transfer areas and the final waste disposal site.

Positioning of the Containers in the City

Localization of containers has been done according to service organization optimization criteria and considering the following principles:

- Hygiene regulations,
- traffic flow and clear visibility of street signs,
- five meters horizontal distance from ground floor windows and shops entrances, safety measures including distance from any inflammable device, cultural and or special sites like archeological areas monuments, museums, historical places and areas assigned to security.

Municipal Solid Waste Transportation Analysis

It is an established concept that a modern MSW transportation system must aim at maximizing the capacity of the vehicles fleet. As a consequence, compressor trucks, capable of reducing considerably waste volume and therefore allow to transport a higher weight of waste were recommended. Another basic feature of the modern vehicles is the use of the mechanical arms capable of lifting and tilting waste containers and hopper allowing big amounts of waste to be unloaded. The number and type of vehicles needed for Tobruk waste transportation has been determined according to the average amount of MSW of each neighborhood, urban structure, and travelling time to transfer station, composting plants, and sanitary landfill site. However, according to the selection of the type and number of containers, the calculation of the type and number of compressor trucks was determined, yet, in some areas it will not be possible to utilize the compressor trucks and therefore other type of vehicles was considered. To determine the optimum type and the capacities of transportation vehicles, for a specific neighborhood according to the examined situation of Tobruk other factors were considered such as:

Traffic and urban structure, container size, type, and number, peaks of waste generation, minimum and maximum distances from transfer stations and final treatment sites.

Calculation of staff needed for the collection and transportation Based on the design choices the number of workers necessary for the collection has been estimated as follows:

- door to door requires 1 worker every 300 flats, so total number of flats in Tobruk should be divided by 300 to obtain number of workers.
- container back loading compressor system requires 3 workers (1 driver + 2 workers), times the number of containers,
- tipper truck collection vehicle requires 2 workers (1 driver + 1 worker), times the number of served flats,
- small tipper collection vehicle (1 driver + 1 worker), times the number of large containers,
- lifting trucks for large containers ($20m^3$) (1 driver + 3 workers)

In addition, reserve manpower force for shifts, holydays, illness and accidents of approximately 20% of the total number of workers and drivers was added.

Calculations Of the Number of Containers

The calculation of the number and type of containers is based on the filling coefficient which depends mainly on:

- emptying frequency,
- position of the container,
- possible extraordinary peaks of waste generation.

For an optimum dimensioning the filling coefficient is never to exceed a value of 0.8 in such a way, a safety margin is provided in cases of extraordinary waste generation. On the other hand, very low values mean economic losses because of the increase of the marginal operating costs. Filling coefficient in case of low collection frequencies has to be around 0.2-0.3. The estimation of the number and size of containers to be utilized has been carried out starting from the number of flats as well as the available data relative to the amount of collected MSW per each neighborhood. For customers utilizing containers collection service, he/ she should not walk more than 100 meters in order to put his/ her waste bag in the container, with a maximum distance of 200 meters between two containers. The final calculation includes other additional factors:

- Optimization of the container positioning,
- allowance for an operational margin for replacements, maintenance or other particular requirements (extra of 10%).
-

Collection Methods Analysis

The commonly used methods for waste collection are the following:

- door to door,
- building containers,
- street containers,

- large size containers,
- pneumatic or gravity chutes.

However, door to door collection is by all means the most appropriate system for Tobruk supported by suitably situated building and street containers. The following issues should be considered regarding door to door collection method.

- Conflict of interest between the private collectors, mainly interested in the recyclable materials, and profit to be made out of it, and leaving the left- over amount of garbage on the street against the public cleanliness interest.
- the damage to the city image caused by the permanence of the waste on the ground and the degradation of road hygiene and aesthetics,
- hygienic and sanitary inconvenience for the collection workers,
- long collection time necessary for the collection from all the flats,
- higher cost of the service,

The estimated flats/shift served by each/door to door collector is about 300 units during eight-hour shift.

Buildings Containers

Usually, the average standard capacity is of 110-130 liters, capable of containing waste produced by 5-7 families. Another way is to use small plastic or metal containers, which could contain a bigger volume of waste and could be used for a building with larger number of families. This collection method is the most efficient in central areas of large cities were introduction of bigger containers conflicts with urban aesthetics. The advantages of this collection method are the following:

comfortable and easy to use, both for the inhabitants and for the collecting personnel, better flexibility allowing adaptability to waste quality and quantity variations,

The principal disadvantages are:

- bags are breakable easily when placed on exposed support,
- limited productivity output of the unloading personnel, as time needed for each unloaded operation is almost the same for unload a 10 times larger container,
- difficulty of finding an available place in all buildings.

The most commonly used materials for bags are polyethylene which is cheaper, more resistant and less polluting than polyvinyl chloride (PVC).

Street Containers

Collection in containers is the most common method due to economic reasons and service quality ones. Containers of sizes 1-2.5m^3 serve a big number of flats and allow a remarkable increase of productivity per employee if compared to the previous methods. However, the investment cost is higher and in certain areas of Tobruk they may suffer from improper use and require therefore an important education campaign for their utilization. Commercial centers and particularly big markets can instead be served by containers with a capacity 4 and 20m^3.

Table 1. Containers typologies and volume

The most common used containers are:

Type and size	No. of flats
1-Lt. 110 support	4
2- Lt. 1100 container	24
3- Lt. 1300 container	30
4- Lt. 1700 container	39
5- Lt. 2400 container	54

The choice of the containers depends on the chosen type of service and type of the served area as well as economic considerations. The financial aspects of the choice affect the entire economic management of the collection service. Also, elements such as maintenance and level of mechanization of the emptying service, which strongly affect the cost of the service, should be considered. The adopted collection system for each neighborhood is the outcome of several considerations (for example population density and habits of waste disposal of the local inhabitants) and takes into account the city structure (traffic, roads, and urban structure). For cities like Tobruk the traditional system of containers emptying (where the docking to the vehicle is carried out manually by two workers) compared to the system based on the side loaders trucks, is preferable because it is more reliable, flexible and less vulnerable to unfavorable conditions (accumulative waste, inaccessibility due to parked vehicles, etc.).

Results

It is important to identify the existing situation in order to gradually improve it and avoid problems connected with public awareness of an adopted completely new waste management system. Domestic west collection and transportation management in Tobruk is presently carried out with old vehicles and obsolete equipment and almost no tools. Furthermore, the collection is done by private collectors in most residential areas and rarely by compressor trucks from scattered containers. It is obvious that the complexity of the optimization process is a result of the many variables influencing each other. The identification of the optimum management solution is also affected by independent variables, such as political instability. Field investigations were needed to clarify the specific situation in Tobruk for, but this task must always follow a theoretical analysis which is based on available data. This was so difficult to obtain because of the unstable political situation in Libya. For this reason, more or less old data were used to provide a first theoretical solution of the type of service that should be employed (containers, vehicles, staff, etc.). Such solution could then be optimized after political stability is achieved. The system is unorganized due to the lack of a single management company or municipality and causes big amount of waste to remain on the streets (**Photo.1**).

Figure1 . MSW scattered all over various areas and streets in Tobruk

The technical approach-MSW characteristics

Estimated MSW amounts and sources generated in Tobruk

The amount and sources of MSW in Tobruk were estimated according to the methods mentioned in Materials and Methods chapter. **Tables 2 and 3** give the results of various quantification parameters.

Table 2. Some demographic characteristics and solid waste generation rate (kg/capita/day) in inhabited neighborhoods, Tobruk-Libya in 2011

S.N	Neighbou-hood	Area (Km^2)	Population size Capita)(	Density (Capita /Km^2)	Household solid waste amount ton/day)(	Generation rate (kg/capita/ day)
1	**Alsienaie**	18.20	8000	440	7.60	**0.95**
2	**Mokhtar**	10.20	5200	510	7.80	**1.50**
3	**Nasr (a,b,c)**	23.05	8500	369	7.65	**0.90**
4	**Horria (a,b,c)**	12.20	5600	459	6.72	**1.20**
5	**Hadieck**	35.65	8500	230	7.23	**0.82**
6	**Manara**	7.55	3500	464	5.25	**1.50**
7	**Andalus**	64.53	10500	163	8.93	**0.85**
8	**Matar**	7.36	6500	883	4.88	**0.75**
9	**Wasate el-madina**	5.10	5450	1090	8.18	**1.50**
10	**Kaliej**	15	5800	387	8.70	**1.50**
11	**Souq Ajaj**	6.20	3950	637	2.96	**0.75**
12	**Alhatia**	4.65	3300	710	2.81	**0.85**
13	**Zohor**	15.85	6000	379	7.80	**1.30**
14	**Jublia Estern**	2.34	2350	1004	1.65	**0.70**
15	**Kods**	22.85	8900	390	6.68	**0.75**
16	**Nour**	3.75	2450	653	2.01	**0.82**
17	**Alforjan**	2.90	2600	897	2.50	**0.96**
18	**Alsninate**	2.10	1700	810	1.50	**0.88**
19	**Cordoba**	27.29	7500	275	7.13	**0.95**
20	**Bab Derna (1,2)**	7.93	4000	504	3.80	**0.95**
Total		294.7	110300	374.3	111.78	**20.38**
Average per neigh-borhood					5.59±2.58*	**1.02±0.29***

***Standard deviation**
Source: National center department, Libya,

Table 3. Distribution of MSW sources over various activities.

Source	Number	Coefficient of MSW generation (kg/day)	Average MSW amount* (ton/day)
Households' units	22060	5.1	111.78
Commercial (shops)	60	32	1.92
Markets	3	667	2.00
Restaurants	20	95	1.90
Parks	4	150	0.60
Schools	5	60	0.30
Institutions	11	64	0.70
Health centers	5	160	0.80
Total			120

*The average is calculated on yearly basis

MSW organic fraction characterization for composting
The organic fraction separated from the MSW of Tobruk was tested for its suitability to be composted.
Composition of municipal solid waste
s mentioned in the chapter of Materials and Methods, it was rather of importance to determine through sampling the various components of MSW in Tobruk. This sorting process provides information required for the main activities of MSW management, i.e. re-use, recycling, and treatment including composting, health care waste treatment, and sanitary landfilling as final disposal. (**Table. 4)** illustrates MSW composition in Tobruk.

Table 4. Composition of municipal solid waste, excluding construction and demolition debris, sand, and dust, generated from the twenty neighborhoods of the city of Tobruk-Libya, in the year 2013.

Neighbour-hood	Sorted out materials (ton /day)								
	Organic (food waste)	**Paper& Card-board**	**Plastics**	**Glass**	**Timber**	**Metals**	**Textiles & Leather**	**Medical waste**	**Miscellan-eaous**
Alsienaie	52.3	15.2	9	4.1	2.9	5.9	3.6	0.9	**6.1**
Mokhtar	57.6	15.0	7.8	3.2	2.8	6	2.3	0.7	**4.6**
Nasr (a,b,c)	53.6	16.7	8.1	2.2	3.8	6.8	2.9	0.5	**5.4**
Horria (a,b,c)	60.1	15.9	8	3.7	2	4.2	2.8	0.6	**2.7**
Hadieck	59.8	14.1	7.2	3	2.7	5.9	1.9	0.9	**4.5**
Manara	60.8	16.2	8.1	4	2.8	5	2.2	0.5	**0.4**
Andalus	60.2	14.8	7.8	2.6	3.8	7.2	0.7	0.8	**2.1**
Matar Qadeem	57.1	13.2	8.2	2.9	3.2	6.1	1.8	0.5	**7**
Wasate el-madina	60.8	15.1	6.9	2.8	4	7.2	1.1	0.5	**1.6**
Kaliej	58.7	14.8	7.3	2.6	2.1	6.1	2.9	0.8	**2.7**
Souq Ajaj	59.2	13.5	8.6	3.4	3.8	6.8	2.2	0.6	**1.9**
Alhatia	60.2	12.7	9.1	2.8	2	6.2	1.4	0.7	**4.9**
Zohor	61.3	13	7.8	1.8	1.9	7.7	2.5	0.6	**3.4**
Jublia Estern	65.1	13.8	6.7	1.2	1.7	5.3	1.2	0.8	**4.2**
Kods	51.3	15.1	6.4	2.8	2.1	8.8	2.9	0.9	**9.7**
Nour	50.6	11.3	7.9	3	4.2	9.3	3.2	0.8	**9.7**
Alforjan	50.9	10.8	8	3.8	3.8	8.5	4.1	0.9	**9.2**
Alsninate	54.8	13.2	7.5	2.1	3.1	8.8	2.7	0.5	**7.3**
Cordoba	58.9	12.8	8.1	2.2	2.8	9	3.9	0.6	**1.7**
Bab Derna (1,2)	59.5	13.7	7.2	2.6	3.1	7.8	2.6	0.8	**2.7**
Average For Tobruk	57.64	14.05	7.79	2.84	2.93	6.93	2.45	0.7	**4.59**

According to [7], it is evident that with such values of the C/N ratio and moisture content, the recoverable organic fraction proved to be suitable for composting.

Table 5. Organic waste criteria for composting, carbon: nitrogen ratio (C/N) and moisture content %, Tobruk-Libya, 2013

Total amount of municipal solid waste (ton/day)	Organic waste **(food waste) %**	**Total organic waste (ton/day)**	**Composting criteria**	
120	57.64	69.17	**C/N ratio**	**Moisture content %**
			26.68±3.08*	52.4±5.92*

* Standard Deviation

The general work plan for the proposed sustainable integrated municipal solid waste management for Tobruk The general work plan is based on the site investigations, collected data and analysis, as well as surveying of international model. The targets of the work plan can be summarized as follows: -Increase efficiency of collection, transportation, treatment and disposal, Maximize the utilization of waste materials, design a safe sanitary landfill, Introduce appropriate solid waste, management techniques. Improve environment quality, design an environmental awareness program, emphasize safe handling in all stages of workers' activities, Introduce alternatives for private sector participation in service provision.

Table 6. List of the foreseen type and number of vehicles, equipment, and containers for MSW collection and transportation in Tobruk

Description	Size	Number
Refuse collection compaction truck	10 ton, 15m^3	**6**
Refuse collection compaction truck	2 ton, 6m^3	**10**
Septic tank emptying tankers	14m^3	**2**
Septic tank emptying tankers	9 m^3	**2**
Refrigerated medium trucks	9 m^3	**2**
Canal jet truck	9 m^3	**1**
Large open tipper trucks	18 ton, 15m^3	**2**
Small open tipper trucks	1 ton, 6m^3	**5**
Front loader	4m^3	**1**
Skid loader		**2**
Large mechanical road sweeper		**3**
Small suction sweeper		**2**
Recovery vehicle		**1**
Bin washing vehicle		**1**
Pickups double cabin		**4**
Minibus		**4**
Saloons		**3**
High pressure water truck		**2**
Lift truck		**1**
Vehicle with crane		**1**
Waste container	20m^3	**6**
Waste container	2m^3	**200**
Waste container	1.1m^3	**103**
Litter basket	0.24m^3	**500**

Waste Collection and Transportation System, Separation of Waste Streams

It is suggested to achieve such activity by collecting and managing each type of waste independently. Therefore, the construction debris shall be brought to a treatment plant for reducing and homogenizing the material for the reuse in the construction of roads as a sub-base filling. Part of the material shall be used to make artificial green hills and form the green belt at the outskirts of the city in cooperation with the governorate in order to have a natural barrier to the sand blowing from the desert. In any case this material should not be carried to the landfill in order not to exhaust its capacity earlier than foreseen. The domestic, commercial business, as well as governmental offices, and schools waste constitute the biggest stream of municipal solid waste (MSW) which ideally should be separated at source. In view of the gradual implementation of such solution the plan is to begin with the sorting of the main components by means of the utilization of an adequate system such as specified containers and vehicles (**Table. 6**) for specific types of waste, this is to say separation at source. Another sorting activity will be done at the transfer stations so that different materials which may go to recycling and reuse are not transported to the composting plants and final disposal in the sanitary landfill and. Only the small residual portion of non-recyclable materials shall be disposed in the landfill.

Organization Of the Pattern of Waste Collection and Transportation

It was clear that the existing system is basically dis-organized, therefore is unable to cope with the collection and transportation of the waste generated. It is proposed to implement a door-to-door collection system on a daily basis, in order to satisfy the inhabitant's preference, and to assure more flexibility, as most preferred a container collection service is also required to avoid garbage to be left on streets. Their use will also enable to monitor the appreciation of the residents with respect to the utilization of bins for the separation at source system, which is foreseen to be implemented. Obviously different types of containers are to be used to cope with various requirements and different situations.

Regulation Of Waste Collection and Transportation on Sustainable Basis

The frequency of collection is proposed to be daily for domestic and medical waste. Furthermore, special patrolling teams are to be employed to supervise collection and allow emergency intervention wherever it is required. The number of workers to be employed for the collection is calculated in order to allow a reasonable amount of work for each person as well as a sufficient reserve of personnel. It is estimated that a total number of 830 workers including 112 drivers is reasonable to provide the required service.

(Table. 7) gives a detailed distribution of the work force per neighborhood according to category. According to public preference the routing is to be planned in order to assure collection in the morning from 6 a.m. to 2 p.m. for the first work shift and from 6 p.m. to 2 a.m. for the second work shift. However, the time of service is to be organized per each shift according to the traffic pattern of each neighborhood.

Cleansing System

The cleansing system aims to dramatically improve the existing situation in order to reach an adequate acceptable standard. The objective can be reached through the following actions: an awareness program me to convince the population to minimize littering, provide littering baskets with a higher density in specific areas such as parks, commercial centers and big markets, schools, sport centers or public gathering sites are to be served by large containers ($20m^3$), provide highly efficient manual and mechanical sweeping systems, supported with a compatible collection and transportation system.

Table 7. Foreseen number and distribution of the work force for waste collection, cleansing and transportation*

No	Neighborhood	Drivers	Collection Workers	Supervisors	Total
1	**Alsienaie**	6	35	4	**86**
2	**Mokhtar**	6	35		
3	**Nasr(a,b,c)**	6	35	4	**85**
4	**Horria(a,b,c)**	5	35		
5	**Hadieck**	7	40	4	**85**
6	**Manara**	4	30		
7	**Andalus**	8	45	8	**201**
8	**Matar Qadeem**	4	30		
9	**Wasate el-madin**	8	45		
10	**Kaliej**	8	45		
11	**Souq Ajaj**	4	30	4	**72**
12	**Alhatia**	4	30		
13	**Zohor**	8	45	2	**55**
14	**Jublia Estern**	4	25	6	**129**
15	**Kods**	6	30		
16	**Nour**	4	25		
17	**Alforjan**	4	25		
18	**Alsninate**	4	25	6	**117**
19	**Cordoba**	8	40		
20	**Bab Derna** (1,2)	4	30		
Total		112	680	38	**830**

*Including reserve workforce

wash on adequate basis streets and squares, cooperate with the governorate to improve the conditions of roads and sidewalks in order to increase the possibility of utilizing of mechanical sweeping and reduce the dust on streets, cooperate with the government for the creation of a "Green Belt" at the outskirts of the city to minimize the dust fall-out, cooperate with the governorate for improving the street drainage system and for the installation and cleaning of public toilets. Furthermore, operating a centralized service call center in order to receive calls from the citizens for clearing off special waste such as electronic waste, bulky materials from households or objects lying on the streets such as abandoned cars or dead animals. The estimated total number of sweeping and washing vehicles is 10; the estimated number of workers employed in the cleansing service is 120 and 20 drivers.

Health Care Solid Waste Treatment

Medical waste from health care centers was estimated as 0.7 (ton/day). There was other waste material generated in the health care centers which is similar to the household waste, and it was estimated as 2.6 ton/day. The collection and sorting system was designed to collect separately different categories, of such waste. The results of the field survey and the visits to different health centers indicated the following: lack of resources for proper medical waste management, need for trained specialists, no separation of hazardous and non-hazardous waste, collection and transportation are to be upgraded, there is no proper treatment and disposal.

Categories Of Solid Waste from Health Care Centers

Following the European standards 18000 the categories of medical waste are shown in Figures 2 and 3 [6,7].

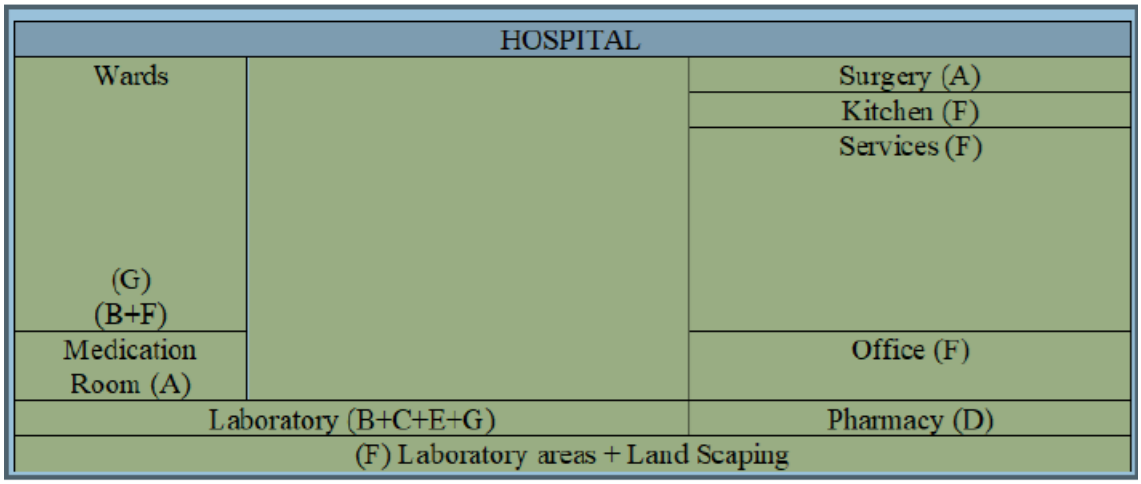

Figure2. Categories of medical waste

A: Human tissues, blood, waste of contagious illness, and bandages
B: Syringes, contaminated tools
C: Waste of labs
D: Waste of pharmacies
E: Containers of urine
F: Organic waste
G: Glass+ paper+ plastic

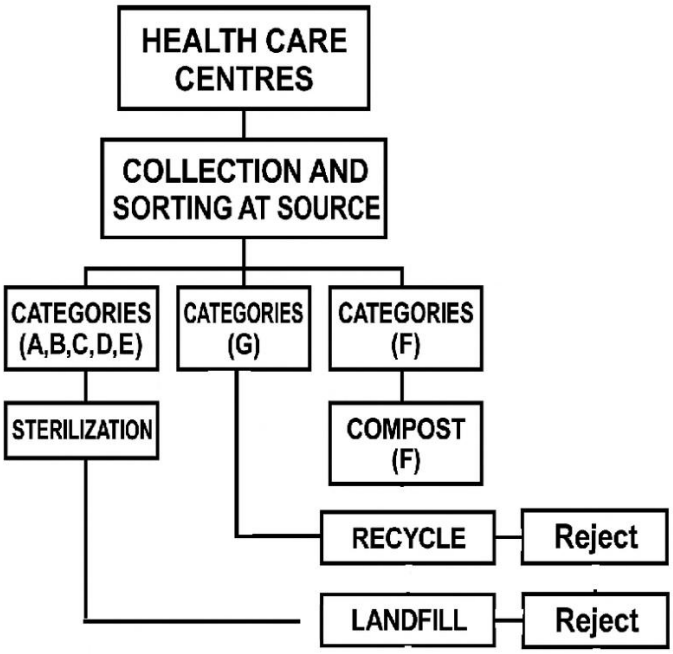

Figure 3. Health care medical solid waste segregation, collection, transportation, and treatment

Discussion

Minimum requirements to be observed in handling medical waste According to [7,9] No manual handling of waste after it is placed in the containers at collection points, All staff handling health care waste should be informed about the environmental and occupational health risk and should be supplied with the necessary preventive and protective devices, Issues on health waste management to be included in the curriculum used in the education of nurses and doctors, Other solid waste collectors shall not interfere with the collectors of the medical waste. The European standards for controlling medical waste are stated in ISO 180100, 180101, 180102, 180103, 180104, and 180105. These standards are for human hospital waste such as parts of the body, blood and other waste material which requires special attention to avoid the hazard of infections.

Collection specification Plastic bags are to be heavy-duty, having adequate mechanical strength characteristics and checked by means of both free fall strength tests, and load tests. These tests must be carried out at a

temperature of 20±5 on a number of bags specified by the standards for each lot. The maximum allowed weight for a single bag is 150 kg [8,10].

General features Several techniques are practiced such as incineration, sterilization with steam or microwave, or chemical sterilization or sterilization with gamma rays. Selecting the convenient treatment will depend on several technical/economic criteria. The most appropriate medical waste treatment in the case of Tobruk health centers is autoclaving, particularly when treating a relatively little amounts [11,12,13,14,15].

Treatment details Sterilization is the process to eliminate every form of microbial life, including the most resistant to heat. Heat is the best-known physical sterilizing agent; wet heat (saturated steam) and dry heat are the two classic means of sterilization. Pressurized steam is economic and sterilizes very quickly. Dry heat is a sterilizing process quite slow requiring high temperatures and exposure time is quite long. Nevertheless, dry heat has a very high diffusion into those materials such as oils, Vaseline, etc. The biological indicators are bacteria selected and maintained alive in special cultures. They are used as control organisms to verify sterilization of a material. Bacillus stearothermophilus is the most common used bacterium to verify the sterilization, due to its very high resistance to heat.

The following main parameters have to be considered to verify the sterilization operation of a waste:
constant temperature, exposure time, all the mass of waste is exposed to the sterilizing heat, quantity of waste to be treated at a time, due to the limited volume.

Treatment steps Plastic bags, where the solid medical waste is collected, are automatically loaded by means of a hopper or a tilting platform to an apparatus which provides bags opening and reduction of the size of waste material. This size reduction will allow the steam to have an effective deep action on the waste mass. Waste is then fed, through a sealing device, to the sterilizer, where the steam is continuously injected. After the time necessary for sterilization, according to a formerly decided programmed, waste is pressed (to reduce the water content) ready for disposal in special cells of the sanitary landfill [16]. The sterilization cycle is fully automatic and temperature, pressure, and time are recorded and kept under constant control. If during the cycle, a temperature decrease is registered, the cycle is stopped and restarted from the beginning.

Transfer stations More effective, technically viable, environmentally sound, and economically sustainable collection and transportation schemes are the target of MSW managers. The intrinsic nature of MSW collection relates to the development of effective vehicle routing models that optimize the total traveling distances of vehicles, the environmental emission and the investment costs. In order to achieve such goal, transfer stations are established and their siting within the service area is of great importance. In the case of Ghana, Kumasi metropolitan area, although there is an engineered landfill, still there was a problem of waste collection and transportation from the generation centers to the landfill. Thus, multi-criteria decision analysis incorporated into a geographic information system (GIS) was used to determine potential MSW transfer station sites. The results were to establish 11 sites located within six different sub-metros [17]. The situation in Tobruk is quite different. Only two transfer stations are adequate, since the amount of MSW is small, and the distribution of residential neighborhoods with respect to land area of Tobruk is more or less clustered. The main function of this station is to carry out sorting of various components of the waste, after receiving collected waste transported by different vehicles. At the same time this facility is used as an office and/or a starting point for workers and supervisors with dressing rooms and a storage facility for their tools. It is fitted with a belt conveyor of easily separated materials to be recycled. The separated organic fraction is transported to the composting sites and rejects to the landfill. The area is to be fitted with water, electricity, hydraulic and firefighting facilities. Beautification around these sites by means of trees and green areas is usually considered. With reference to the general solid waste flow diagram mentioned earlier, it is foreseen to have 2 transfer stations one east and one west of Tobruk, where an amount of 100 to 150 tons per day of MSW is to be sorted in order to separate the organic fraction from the inorganic fractions. The inorganic fraction is divided into different components and cleaned for recycling and reuse, while the organic fraction is transported to composting plants. The station is equipped for multifunction service: facilitate quick transportation from residential sites, increase efficiency of fleet utilization, increase sorting activity which results in efficient recycling and reuse, improve trafficking streams which leads to air pollution minimization from exhausts. Each station is a focal point for the service in Tobruk; therefore, it is equipped with all the facilities required for the workers, supervisors, and managers. In addition, it is provided with a facility for the selling of various sorted materials. From the process point of view, an area must be organized for storage of containers, separated waste, such as bulky waste, building materials, glass, plastic, etc. The sorting line will be organized in the same manner as described latter in the composting plant. The station should include weighbridges and all required utilities such as a fuel station and a maintenance workshop. Fire protection and other safety standards must be observed. Solid waste is sorted by specialized workers in the area in order to assure the selection of material with a standard of quality assuring an easy positioning on the market of recycled materials.

Detailed work plan of the transfer station the transfer station should normally be located as much as possible near a central position of the various neighborhoods. Trucks entering the station go to an elevated unloading platform after being weighed on a weighbridge and unload the waste into a hopper. A belt conveyor serves a

manual sorting station after garbage bags are opened by a special machine, organic material is immediately separated and sent by means of another conveyor to a big container to be transported to the composting plant. The inorganic material will be separated into various components. Paper, cardboard and aluminum cans are compressed, while other components are stocked in suitable containers to be brought to final destinations. A sufficient area is reserved for parking large containers for different types of material. All rejects are transported for final disposal in the sanitary landfill.

Potential environmental impacts, Construction phase Soil The soil may be affected from the construction camp due to the daily work at the site.

Ambient air quality Air quality might be affected by the movement of construction trucks, and excavation works.

Noise emissions due to construction work, and increased levels of noise from the movement of vehicles and trucks movements.

Flora and fauna at the surrounding areas, a garden was observed and need to be protected from possible contaminants migration.

Worker health and safety This may include physical hazards from falling and injuries, risks from movement of heavy machinery, physical hazards from contact with disturbances.

Local community: Inconvenience of local community might result due to the last environmental impacts (Noise, Dust, etc.).

Job creation the construction of Tobruk transfer station will create about 60 new jobs.

operation phase

Solid waste management the new transfer station will have positive impact on the solid waste management process; it will facilitate the waste management in Tobruk with less operational costs and less environmental impacts comparing with the previous situation.

Composting plants the sorting activity at the transfer stations together with some separation at source will lead to better conditions of sorting and composting in the plant. With reference to the flow diagram mentioned earlier in the general work plan it is estimated that 80% of waste generated will be treated and recycled and 20% of rejects will be disposed into a safe sanitary landfill.

Financial affairs-capability of funding and fee structuring

One of the main challenges that face a proper MSWM system to achieve its objectives is the capability of funding. Insufficient funding to cover the cost of all items of a MSWM system including wages for the adequate number of workers, drivers, supervisors, and management staff would lead to complete failure. In addition, enough funds are required to cover the capital and operation cost of all MSWM facilities and utilities, such as transfer stations, composting plants, sanitary landfill, containers, and the collection and transportation fleet. If funds are available, there should be a strict financial management system to ensure efficient utilization. More expenditure is usually incurred on waste collection and transportation rather than other activities i.e. recycling, treatment, and final disposal.

Willingness to pay, combined with proper management is a good measure to assess the feasibility of a community-based project. A service is considered affordable when a community perceives it as valuable. Ways to generate revenues from fee collection include: mode of fees collection, tariff system reflecting level of service, and different rate of different type of waste collection, i.e. communal collection points, curbside, house to house, or door to door collection. Income level and amount of waste to be collected and disposed are two factors usually used to determine fees structuring. Community meetings to review billing rates and mode of payment help in convincing residents to pay for the service, and proved to be effective in achieving financial viability.

Private sector participation Private sector participation in MSW management is increasingly being applied in many countries recently. The accepted municipal solid waste management responsibility could be completely public (governmental), public-private, or completely private. The decision is always based on country policy on which formula is appropriate, regardless of service quality, financial viability leading to sustainability, socio-economics, environmental concerns, and finally the best practice. The success of private sector participation usually depends on strict and transport contracting procedures and common understanding among the three involved parties: government/municipality, service provider (private sector), and residents. In addition, a public awareness programmed through which residents is well informed of the newly introduced MSWM system. A legal framework is required as to deal with complaints and penalties. Irregular payments by the governmental authority to the private sector causes service provision disturbance which could lead to painful disputes.

The awareness programmed an awareness programme is to be organized in cooperation with governmental authorities targeting citizens' particularly younger generation through involvement of schools. An environment day shall be organized as well as conferences and seminars. Media channels should be utilized in order to reach various population sectors. The start of a new service and the necessity to upgrade the present system of solid waste management over the years demands to carry out an information campaign to support the changes and their acceptance to the public. Citizens should be involved and informed on what is going on: involved in order to participate with motivation to the new system of environmental protection. A well-planned information campaign is the key to make a message well received by a large number of citizens. The proposed required actions are the

following: an adequate information campaign of the new management system, -introduce the new service with specific indication of the timetable of waste collection, competent authority governance, establishing a central call center.

Reducing solid waste generation rate [18] reported that the most uncontrollable phase in MSWM is waste generation rate, which is considered a challenge for local authorities. The reduction in waste generation can only happen when everybody reduces waste generation by changing purchasing and consumption patterns. There is an urgent need for a public awareness campaign in order to achieve such goal. Re-use of sorted items recovered from MSW is another reducing factor for waste generation. In such case, there should be centers which provide re-usable items collected from all sources of solid waste generation, as well as transfer stations and put it for sale. This can be the responsibility of Non-Governmental Organizations (NGOs).

Sanitary landfill with daily amount of about 120 tons of MSW generated in Tobruk, and on yearly basis, the amount is about 36,000 tons; Organic fraction is 21,600 ton producing 10,800-ton compost. The inorganic fraction will 50% re-use and or recycle activities, is 7,200 ton disposed into landfill. This significant reduction should be one of the main targets of MSWM, this could be achieved by encouraging sorting at source and transfer stations, re-use, and recycle activities, which could be done through an awareness programmed, as well as opening venues for recycling techno-economic feasibility studies and projects. For non- scavenging informal waste workers, itinerant recyclable buyers function as service providers for curbside recycling where households sell or donate recyclables to itinerant recyclable buyers. Itinerant recyclable buyers then gather those recyclables and resell them to recyclables buying centers, which is the equivalent of a drop- off recycling center in a formal recycling system. Nevertheless, the strong advantage of itinerant recyclable buyers and recyclable center buying is that they are self-funded, and the cost of running them is not a burden on the government or taxpayers, which is in contrast to the official curbside or drop-off recycling that may incur great costs to the public [19]. The research by [20]. employed an analytic hierarchical process (AHP) to nominate the best informal recycling modes. Itinerant recyclable buyers are recommended for all urban settlements as an effective, informal MSW collection activity. Reducing the amount of MSW rejects affects the choice of final disposal technologies and methods. If the best choice for Tobruk is sanitary landfilling, because of availability of vast areas of desert land, and abundant energy sources, the establishment of a sanitary landfill becomes a must. The filling capacity and longevity of the landfill are always proportional to the MSW rejects to be disposed of. Constructing a sanitary landfill with the specification and dimensions proper to Tobruk case should be planned according to international standards. Prior to construction, the process of siting should also take into consideration all criteria cited in literature.

The organization of staff and man-power in order to ensure smooth operation of the new system of MSW in Tobruk, an organizational chart is proposed for all employees, starting from to management down to collection, sweeping workers (**Fig.1**). For each job, there should be a full description, as well as a manual. Training programmers especially tailored for newly recruited staff are to be conducted prior to taking over the job. The training programmers are the responsibility of well qualified expirees. Much of the success of the proposed MSWM system to deliver high quality services depends on well conducted training. The recruitment policy of staff, drivers, and workers should allow the most appropriate system for selection, with fairness and transparency. A system of rewarding excellent performance against penalties for bad will ensure incentive based management. Personnel at all levels should be ensured medically and financially. The proposed organizational chart fits well with the municipality of Tobruk being the services provider, or a private sector, or a public-private partnership. The total employees' number is 1.076, with 831 workers, and 139 drivers, and only 106 supervisors, middle and top management staff.

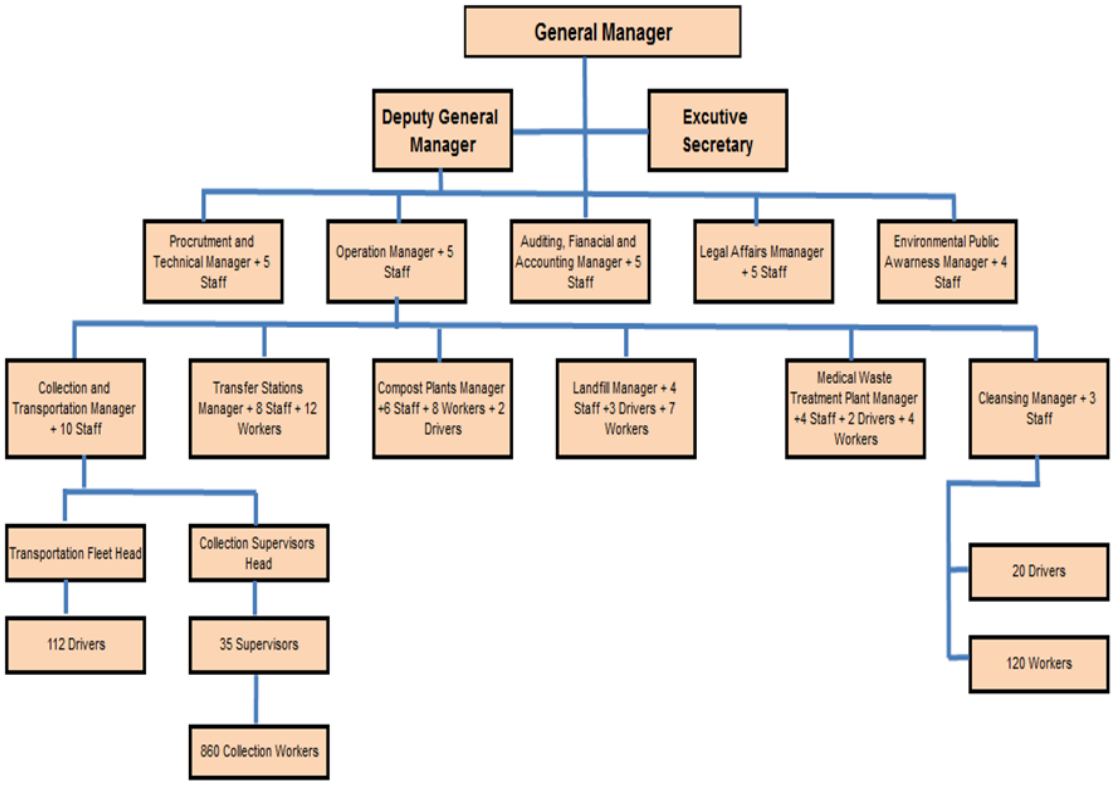

Figure 4. Organizational chart of staff and man-power

Conclusion

Environmental protection and natural resources conservation together could be achieved through proper integrated and sustainable municipal solid waste management. Although the problem of municipal solid waste management is widely spread over many of the poorly developing countries, the solution of this problem depends mainly on political will, rather than technical or socio-economic factors. Once, there is a serious political will, such factors could be easily integrated within a proper management system, which is financially viable and technically sustainable. The present thesis introduces a new system for municipal solid waste management in the city of Tobruk, with all components being addressed. A detailed general work plan has been proposed for the municipality authorities of the city to be implemented. The proposed system is flexible enough to accommodate any adjustments required upon the time of execution. Certainly, this is dependent on coming to terms with the political conflicts between and among Libyan fractions, hopefully soon is the better for the sake of Libyan citizens. Major elements of the proposed system are following.

- Conducting a comprehensive environmental public awareness program me on the issue of municipal solid waste.
- Establishing a pay for the services system acceptable to customers.
- Designing an efficient municipal solid waste collection and transportation system, with all its details.
- Encouraging separation at source for re-use, recycling, and composting of organic fraction of the waste.
- Completely separate handling of medical waste from the city health care centers.
- Establishing two transfer stations, two composting plants, and a sanitary landfill, all in appropriate locations in the desert land south of Tobruk.
- A proposed organizational structure for managerial staff, supervisors, drivers, and workers for all activities of the new municipal solid waste management system.
- Options for private sector participation in services provision have been addressed.

The final conclusion is that municipal solid waste problem in Tobruk could be solved by adopting the proposed management system, which is characterized by being comprehensive, sustainable, integrated, and flexible.

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