RES-Q an Ongoing Project on Municipal Solid Waste Management Program for the Protection of the Saniq River Basin in Southern Lebanon

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Abstract. Lebanon is currently facing an unprecedented mix of social, economic, and political crises, which exacerbate many public health and environmental health problems. Among these, solid waste management (SWM) is considered one of the biggest challenges that Lebanon has been facing for the past two decades. In the absence of national guidelines and ministerial action, SWM is a responsibility of local municipalities. In this paper, we describe the development of a technology-based Waste Management System (WMS) in an area of 43 villages in southern Lebanon. The project is inspired to the paradigms of circular economy and smart cities, and it aims to define affordable and efficient strategies to address SWM. The driving factor in defining the strategies is economic and environmental sustainability, as Lebanon imports most of its resources in hard currency, which is becoming less and less available. The lessons learned from this project can be transposed in other areas and countries with limited financial resources, representing an important paradigm for the WMSs in many areas of the world.

Keywords: Waste management · Circular economy · Sustainability · Smart governance · IoT · ICT · Lebanon

1 Introduction

The paper describes the EU-funded project RES-Q (EuropeAid/155108/DD/ACT/LB), whose objective is to implement a waste management system in the Sainiq River basin (Lebanon) according to a logic of circular economy. Since 1997 Lebanon had to face a challenging waste crisis, which led to task Municipalities and Unions with collection, treatment, and disposal often with limited and variable budgets each year, which in some instances forced municipalities to adopt quick solutions with harmful environmental consequences such as open dumps [1–3]. As the waste crisis in Lebanon continues to

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unfold, efforts to find sustainable and scalable solutions to solid waste management are being sought by various governmental and non-governmental entities, as well as by international organizations as European Commission, which realized that solving the waste crisis in Lebanon is of strategic importance for the entire area [4].

Municipalities are the local administrations charged with the day-to-day management of all public works located within their boundaries, that is why they are taking all responsibilities related to landscaping and beautification works, maintenance of water and wastewater networks, street lighting, waste disposal, internal roads, recreational facilities, as well as the urban planning in coordination with the Directorate General of Urban Planning [5].

Municipalities are considered as key players and actors in the management of municipal solid waste. In this respect, the decree no. 8735 of 1974 [6] on the maintenance of public cleanliness sets the responsibility of municipalities in the collection and disposal of household wastes, and emphasizes that the health council of the governorate should approve the location of waste disposal sites. Moreover, the municipal law no. 118 of 1977 [7] entitles the municipal councils to build solid waste disposal facilities.

The target area of the project represents the higher part of Jabal Amel in south Lebanon, where the open dumps scatter randomly, threatening the safety and integrity of surface water and ground water, as well as causing air and soil pollution. All these effects reflect negatively on the health and life of local citizens. The municipalities involved in the project fall within the scope of two governorates: Nabatieh governorate and South Lebanon governorate [8].

The main goal of the paper is to present a model of an Integrated Solid Waste Management (ISWM) which utilizes the concepts of ICT, IoT, smart city and circular economy. The paper addresses the problem by showing how an ICT platform, sensor-installed bins and algorithm-based scheduling and collection can optimize overall processes of ISWM. This paper is organized into five sections including Sect. 1, introduction. Section 2 is Lebanese context which discusses the project RES-Q, target area, problem of open dumps, and forecast the waste generation in the target area. Section 3 is current situation in the target area and shed some light on the climate conditions, human capital, waste sources, amounts of waste, waste composition, organized or unorganized method of SWM, CAPEX and OPEX. Section 4 presents the proposed WMS by the implementation of ICT, details of an ICT platform developed to address the problem and smart waste collecting system. Finally, Sect. 5 wraps up the paper with discussion, conclusion, and future advancements in the different dimensions of ISWM.

2 Lebanese Context

The EU programme ProMARE (EuropeAid/155108/DD/ACT/LB) [9], which finances the RES-Q project, comes under the umbrella of abovementioned actions. The RES-Q project is aimed at developing a model of Integrated Solid Waste Management (ISWM) system, which would preserve the environment surrounding the Sainiq River basin in the southern of Lebanon (Fig. 1). The target area covers three Unions of municipalities: Iqleem at-Tuffah (IET), Jezzine (JEZ) & Jabal Al Rihan (RIH) - encompassing a total of 44 municipalities. In the RES-Q project the unions of municipalities of IET and RIH

are involved. The union of IET includes 10 municipalities (11 villages), for 96 km^2, and RIH (6 municipalities, 43 km^2), in addition to Kfar Melki, a municipality that is out of any union. IET is the most populated region whether in winter or in summer, while RIH is the least populated one. The Rural target area witnesses a significant rural exodus given the significant variances in population between summer (108,269 inhabitants) and winter (63,845 inhabitants).

In the targeted area, the ISWM practices suffer a gap with the technologies available in the market, due in part to limited finances, but even without additional costs there is margin to reduce the footprint of waste caused by the consumers. The involved Municipalities and Unions of Municipalities continued to assume responsibilities, with some of them handling collection on their own and then dumping the waste randomly, and with others outsourcing the collection and disposal services (to seven private contractors). Therefore, there is no coordinated innovative efforts at the strategic level to address SWM and reduce waste going to landfills/open dumps.

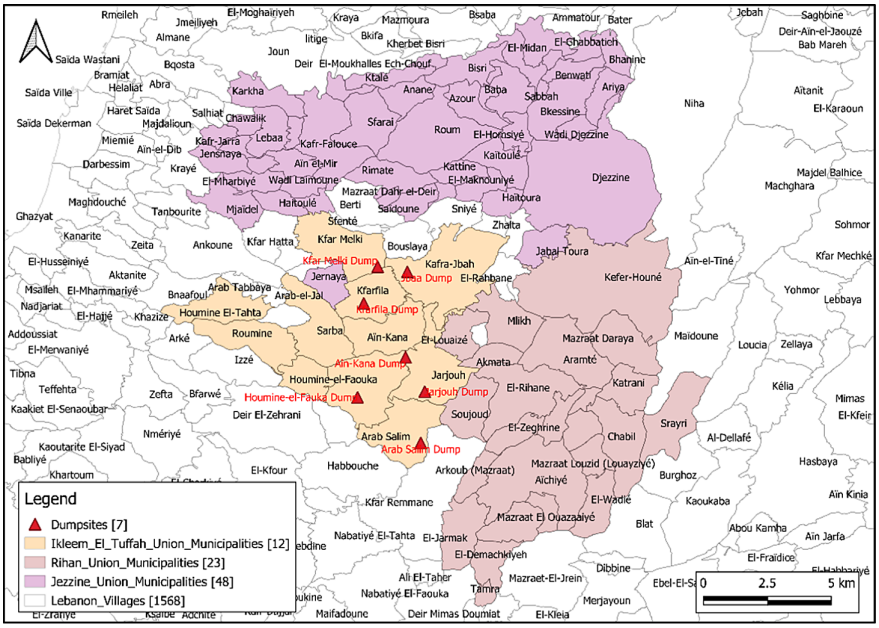


Fig. 1. Map of the project's covered region, the concerned villages, and the dumpsites

Many open dumps are spread throughout the target area (Fig. 1). Such dumps have immediate impact on residents' health and environment. Continuous burning of waste at open dump sites is also presumed to be a major cause of diseases/disorders. Several of these dumps are located directly onto the Sainiq riverbanks (Fig. 2). Leachates from these dumps directly pollute aquifers, the Sainiq River, and eventually the Mediterranean Sea. This is the central environmental concern that the project aims to address.

The region is therefore in deep need for an ISWM plan that provides a coherent approach to waste management while mitigating the negative environmental and social impacts. In order to mitigate the threats and effects and to meet the main objective of the solution, we aspire to build a 'Circular Economy' model by redesigning resource flows in the target area to maximize prevention and recycling of waste while preventing waste disposal from occurring in harmful ways, in addition to remediating existing open dumps.

It is estimated that by 2050, 66% of the global population will be residing in cities, compared to ~54% residing now [10]. This implies that 2.4 billion people will be potentially added to the global urban population. Consequently, this will inevitably result in a significant expansion of existing urban environments and lead to the need to create new ones. Cities use <2% of the earth's surface yet consume more than 75% of the natural resources available globally. The United Nations Environment Programme [10] estimates that the material consumption related to cities will augment to ~90 billion tons by 2050 compared to 40 billion tons in 2010. Some of these resources are primary energy, raw materials, fossil fuel, water, and food [11].

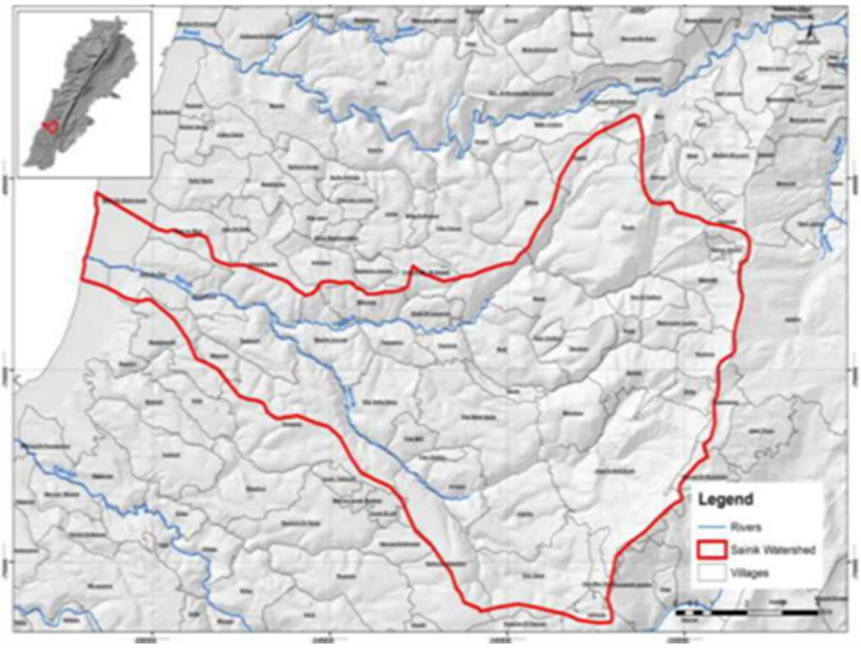


Fig. 2. Sainiq river Basin

As a result, cities are expected to experience challenges related to growth, performance, competitiveness and residents' livelihood [12]. Deterioration of liveability challenges related to waste management, scarce resources, air pollution and traffic congestion that cause human health concerns, as well as aging public infrastructure, are

some of the problems generated by rapid urbanization [13]. In order to address these issues, the smart city concept has emerged as one of the possible solutions.

ISWM (Integrated Sustainable Waste Management) [14] concept is a technique that facilitates comprehensive study of dynamic and multi-dimensional processes. The concept was established by waste urban environment and planning consultants and associates or organizations operating in developing countries and further developed by the Collaborative Working Group (CWG) on solid waste management [15]. The model recognizes the importance of three dimensions when the waste management system is analysed, developed, or changed. The dimensions are: stakeholders interested in the management of solid waste, the elements or stages of movement or flow of materials from generation points to treatment and final disposal, and the aspects or 'lenses' through which the system is analysed [16]. Reliable data should be generated, and proper information networks should be established within and between municipalities. Decision makers, responsible for planning and policy making, need to be well educated about the city's situation to make positive changes, designing innovative waste management solutions geared to residents' desires, considering their ability to pay for the facilities.

Solid waste facilities, like any other programs, have an expense, but the investment is not necessarily recovered. Services are needed to have skilled staff, sufficient facilities, proper infrastructure, proper maintenance, and service. Central government financial support, local leaders' engagement in waste management problems, utility customer interaction, and proper management of funds are crucial to a modernized sustainable system.

3 Current Situation of Target Area

In this section the baseline of the target area is described which include sanitary establishments, and commercial and industrial entities. Only one hospital of 28 beds exists in JEZ region. Few dispensaries and clinics exist in IET, JEZ and RIH. JEZ has the largest number of commercial and industrial entities, while RIH lacks the existence of multiple commercial entities (slaughterhouses, patisseries, industries, etc.). The total number of commercial entities in IET are 285 while 442 in JEZ and 39 in RIH.

A considerable part of the three unions is covered with vegetation, with forests mostly abundant in JEZ and RIH unions (cover more than 50% of the surface area). All 3 unions engage in agricultural activities, however agricultural land use is the highest in IET - 34% as compared to 13% and 18% for JEZ and RIH, respectively. The "Artificial Territory" are areas of urbanization and populated areas, the cover of these areas is low in our project's area since they are mostly rural areas.

3.1 Climate Conditions

The study area is mainly influenced by the Mediterranean climate. It is an eclectic climate between the moderate cold temperate zones, and desert sub-tropical regions [17, 18]. The study area is exposed to several types of wind because of its rugged topography, and the south western winds prevail most of the year [19, 20]. The annual average is between 12 °C and 20 °C. The relative humidity in the study area ranges from 50% to 85% most

of the days of the year [19]. Wind speed reaches up to nearly 14 m/s in the study area, and the annual average is 6 m/s. Moreover, the study area receives precipitation in several forms (water, hail, snow). The snow covers the mountains for around three months (Komat Jezzin). The average yearly mean precipitation ranges between 700 mm/year and 1500 mm/year.

IET is mostly dominated by red soil (Terra Rossa). JEZ is mostly dominated by red soil (Terra Rossa), white greyish soil and sandy soil. As to RIH, there is also a large part of it covered by red soil (Terra Rossa discontinued), but there is a wider mix of various soil types in the region [21].

In general, the region benefits from an ecological diversity which has relatively been maintained over the years. The pine and oaks forests are still widespread, and the flora is relatively stable. However, some of the springs have been exposed to pollution, which is affecting the diversity of living organisms [22]. There are currently five types of problems faced by the municipalities in land use and ecosystem managements, which are, random construction, ploughing the land which destroys large areas of pine trees especially in RIH, mismanagement of forest leading to a decreased forest surface area, forests fires during Israeli occupation and wars have also been a critical factor to the ecology and the negative effects of open waste dumps which has a major effect on both fauna and flora.

3.2 Human Capital

The unemployment rate in IET is 13.9% while 11.1% in JEZ and RIH. The percentage of families under the poverty line is about 40%, 44% of employees are paid monthly and same percentage of employees working in the production sectors. The health insurance coverage goes to 40% in IET and 49% in JEZ & RIH according to study conducted in 2014.

The level of education among the people of the target area is 66.7% and 70% up to elementary and middle school level, 9.4% and 13.1% up to secondary school level, 11.5% and 6.4% university and higher education while 12.4% and 10.5% vocational sector in IET and JEZ-RIH respectively.

3.3 Waste Sources, Amounts of Waste and Waste Composition

Municipal authorities do not possess any records concerning the composition of the general waste stream or the number of special wastes being generated within their respective towns. Therefore, the study team had to rely solely on the data provided by the waste characterization studies. Three sampling and sorting campaigns were conducted throughout year 2020, one during the season of winter (March 16th–26th), one during the season of summer (July 9th–16th), and one during the month of Ramadan (May 17th–21st).

The data recorded across the sorted samples was compiled to calculate the mean percentage estimates for each waste category. The sectors investigated during the winter and summer studies were the residential and the mixed residential and commercial (R&C) waste streams, with samples being collected from the unions of JEZ, RIH, and IET. The residential waste stream was broken down into four different sub-classifications based on housing density and income. The data derived from the summer and winter studies

were compared with one another to determine if any notable alterations in the composition of the disposed stream had occurred as a result of temporal changes. Meanwhile, the characterization study conducted during the season of Ramadan was constricted to exploring the residential waste stream within the union of IET and the village of Kfar Melki. The objective of that exercise was directed towards determining if the season of Ramadan would bring about any pronounced alterations in the consumption and waste generation patterns of the residents.

The total production of mixed solid waste from the target area is 65 tons/day, distributed as follows: 35 tons/day in IET, 20 tons/day in JEZ & 10 tons/day in RIH. mixed SW production is higher in summer in all municipalities. Bodies providing mixed SWM services are the municipality or the union itself or private contractors. SWM operations are limited to collection, transfer, and disposal, unless for JEZ where SW treatment is applied. Frequency of collection depends on the produced quantity of waste and the population in each village and varies between winter and summer.

In IET, each municipality undertakes the SWM operations (collection and disposal) within its borders and disposes the waste in the seven open dumps located within its borders (Fig. 1). Only 4 municipalities, "Roumine, Azza, Houmine Tahta and Sarba", assigned private contractors for the SWM operations (collection and transfer) within their borders. In JEZ, the union undertakes the SWM operations for all the municipalities within its borders, by assigning private companies for the collection, transfer, and treatment of waste. In RIH, each municipality assigns a private company for the SWM operations (collection and disposal) within its borders. Only the municipality of Aychieh is responsible of the SWM operations within its borders. Currently, this municipality is disposing waste in an open dump located within its borders, but it is going in the nearest to subcontract a private company for the collection and treatment of produced waste.

Quantities of excavation, construction and demolition waste are not determined. Bodies providing construction waste management services are the municipalities or construction contractors when no specific municipal management is applied. SWM applied by some municipalities in IET, and JEZ are collecting and disposing construction waste in small holes dedicated for that and reusing construction waste in special construction works. In RIH, only reusing construction waste in special construction works or to cover ground cracks.

Bodies providing farms waste management are the owners of farms themselves or the farms workers with no specific municipal management. Waste produced from farms are compost, manure, or dried residues and all of them are being sold to the farmers in the bigger farms in IET, JEZ and RIH.

Quantities of waste produced from the slaughterhouse in JEZ are equal to 10 tons/month. Bodies providing slaughterhouses waste management are the slaughterhouses themselves while no specific municipal management is applied. The slaughterhouses in IET collect and landfill in rented land or dispose in the dumpsites while in JEZ, collect and landfill in a hole near to the slaughterhouse whereas there is no slaughterhouse in RIH.

Small amounts of clinical waste are produced in the target area. Bodies providing clinical waste management are the clinics themselves in cooperation with private companies, Arc en Ciel [23] and Mirage company, with no specific municipal management. SWM applied to one dispensary in IET by a private company which collects the clinical waste only from the bigger clinic, Islamic Health Society, Jbaa located in IET (quantity: 3 kg/month and payments: 55–60 cent/kg). All clinics send their waste to Jezzine Governmental Hospital, and then the hospital treats it with an incinerator existing in the hospital (quantity: 2.5 kg/day). The small clinics in IET, JEZ & RIH dispose their hazards waste with the mixed municipal waste.

Only JEZ union applies a specific management for the carton/cardboard. The quantity of cartons produced and managed in JEZ goes to 62 tons/year. The municipalities collect the cartons and sends them to a Factory Located in Beqaa (Sicomo SAL) with payments $ 50/ton.

Currently, the capital expenditure (CAPEX) of the target area for performing SWM is $ 256,950 in total out of which 80.4% ($ 206,500) is shared by IET while JEZ and RIH share 11.7% ($ 30,000) and 7.9% ($ 20,450). But the operational expenditure (OPEX) of the target area for performing SWM is $ 3,054,173 in total out of which 31.1% ($ 1,780,000) is shared by IET while JEZ and RIH share 58.3% ($ 288,000) and 10.1% ($ 325,343).

4 Proposed Waste Management System

Projects are most often series of processes where various levels of participation play a role in achieving a satisfactory outcome.

This project focuses on the four distinct target groups (TG) that are segments of the general public (Fig. 3): waste generators (TG1): individual citizens who generate MSW; organizations that generate MSW (food related entities, hotels, shops, markets and schools), and special waste (health units, industries and slaughterhouses); waste managers (TG2): technical staff operating at the municipalities (technical committee), dealing with MSW, NGOs and SMEs working in the collection sector, environmental health professionals and specialists, at the local, national and international level; policy makers (TG3): local (heads of municipalities and/or representatives responsible for waste management), national (Ministries of Environment, Industry, Municipalities, Public Health, Social Affairs, Agriculture, Administrative Reforms, Supreme Planning Council) and international (EU network working on similar issues), public authorities dealing with SWM strategies; and other influencers (TG4): journalist and news media agencies covering especially those covering environmental issues, civil society organizations (scouts, women's groups, activist groups, cultural and service associations) and local public figures (religious leaders, educational and social actors).

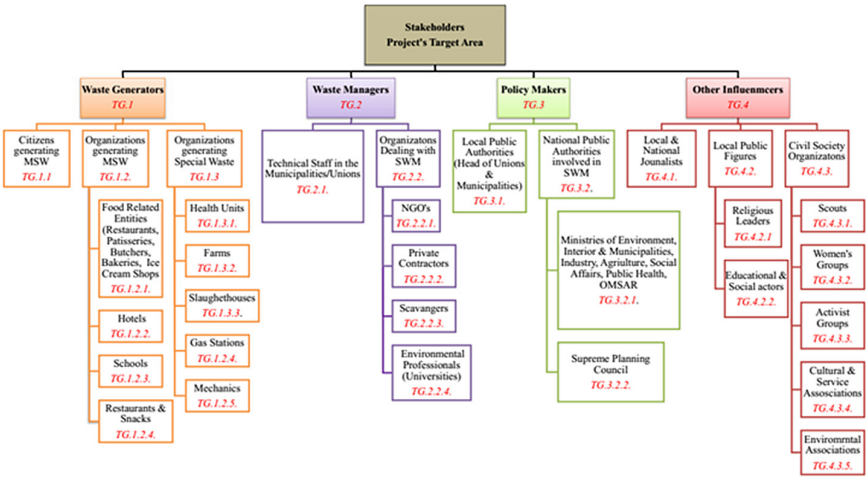


Fig. 3. Key stakeholders

4.1 ICT Platform

The concept of using information and communication technology (ICT) has influenced every sector of conventional workplace and solid waste management (SWM) is no different. Advanced technologies, such as big cloud, computing data, internet of things, cyber-physical systems, virtual and augmented reality, can play an essential part in the implementation of sustainable smart cities and green circular economy ideologies and the even out such initiatives by governments, organizations, and society all together [24]. The solution provided here has two dimensions, one is the introduction of technology like communication, computing, data analysis and another is the implementation of green economy such as reduce, reuse, recycle and restore. Both solutions help each other to resolve the issue of SWM [25].

Many researchers have presented the concept of green economy with different "R" models which include 3R, 4R, 6R, or even 9R [26]. The first three R's are related to "reduce", "reuse", and "recycle" of the model which are interlocked to achieve green economy [27]. Spatial technologies have been dominating the areas of environmental modelling and to manage complex spatial information for ICT platforms to integrate a variety of models, sub-systems and interfaces. These technologies can be categorized as geographic information systems (GIS), global positioning system (GPS) and remote sensing (RS). The main purpose of the technology is to capture, store, analyse and map spatial data. Most of such datasets may consist of attribute data, raster, features, spatial topology and networks of highways, roads, streets, and lanes [28].

GIS is one of the advanced computer-based spatial technology which has ability to collect, store, manage, integrate, manipulate, analyse and display of spatial data known as geospatial or geographically referenced data. Such data is present in the form of layers and GIS can separate theses layers for further manipulation [29].

In recent decades, organizations involved in ISWM have implemented different kinds of technologies to improve the effectiveness of waste management and automate the

collection of bins [30]. To solve the problems in manual data collection, many researchers have studied the possibility of implementing advanced ISWM systems that are based on identification technologies. The proliferation of identification technologies, such as barcode and RFID technologies, brought a new strength to ISWM systems.

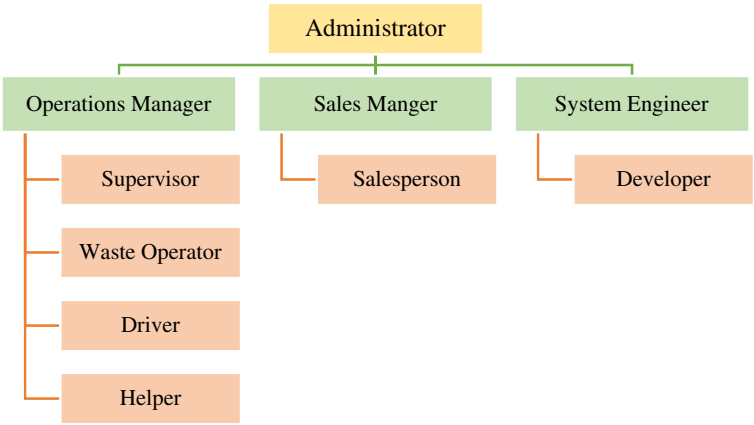


Fig. 4. Hierarchy of users with privileges

The platform discussed in this paper consists of user creation portal which is controlled by the administrator of the platform (Fig. 4). The administrator decides the role of the user and as with the role, the user can exercise the privileges of that role. For any specific user, administrator of the platform has right to award any particular privilege for a certain period of time. The administrator has also right to edit or delete any user. Currently, the platform holds the roles of administrator (ADM), operation manager (OM), sales manager (SM), system engineer (SE), supervisor (SU), waste operator (WO), driver (DR), helper (HLP), salesperson (SP) and developer (DLP) but not limited to these only and further roles can also be created upon requirement.

The OM has privileges to create tasks and user accounts for supervisors, drivers, and helpers, as well as OM creates, edits or removes scheduled tasks or daily tasks. He assigns tasks to the DRs and monitors the status of those tasks. He also manages the database of the tracks fleet. The SM has privilege to make quotations for the commercial customers and creating their task reports with his team which include SPs. The SE along with DLPs has responsibility of smooth functioning of the platform and troubleshoot any error that could hinder the operation of the platform. The SE is responsible for creation database of sources (bins/collection points) and destination (deposit locations: recycle plants, composting sites, and dumpsites). This data is generated with Google Maps location fetching tool (geolocation) and maintained/stored in the database. Similarly, the list type of waste and addition or removal of any specific type of waste is also performed by the SE/DLPs. The DRs input the data of point of collection, type, and quantity of waste as the job is completed. SUs assigns the WOs to crosscheck segregation and registering of the type of waste and the quantity against each completed task when DRs reaches the destination.

4.2 Implementation of ICT

The platform is organised into different groups and each group has its own tasks (Fig. 5). The first group is the roles which creates, edits, delete and manages the types of roles available in the platform and their privileges. The second group is users which include user creation, amending, deletion, assigning roles and user privileges. The third group is geolocation where data of source (waste collection point) and destination (recycle plant, compost site or export area) is created, edited and stored. The fourth group is waste which keeps the record of types of waste. The fifth group is fleet management which manages, creates, edits, and delete data pertaining to vehicles and trucks used to transport waste. The sixth group is allocation of vehicles to users for identification and keeping track of task and the last group is task which creates, schedules, edits, deletes the task of collection to dispose-off as well as keeping the record of users to whom task assigned to, quantity and type of waste. The platform is coded in PHP programming language, the database is kept in MySQL and Apache HTTP server is used.

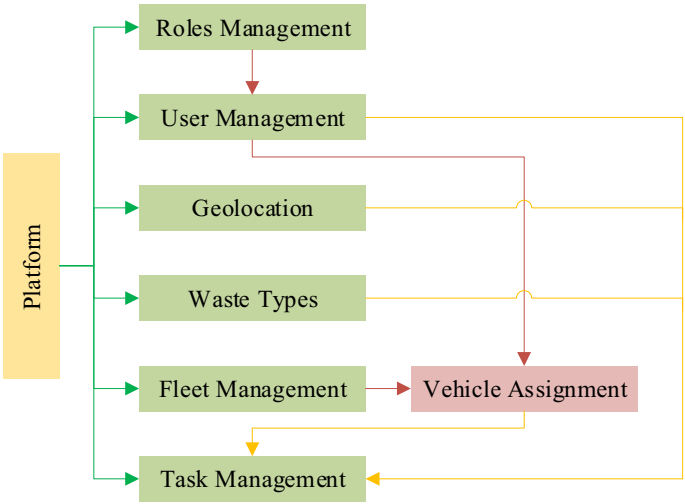


Fig. 5. Structure of platform

The bins are installed with IR sensors which senses how much the bin is filled. As soon as the bins are reached at 90% capacity, it sends a notification to the platform through the GSM module for the pickup of the bin. Each bin has an identification RFID on it, when the waste is collected, the quantity and type of waste is entered through the App which can be verified with the previously automatically sent data.

The routes of collection vehicles are optimized according to the real time traffic flow. Similarly, the placement of bins at the locations are also scheduled and optimized according to the daily/weekly waste collection of each type. This data is uploaded in the cloud and further used to perform statistical analysis to achieve breakeven and to maximize the benefit in terms of environment. This will not only increase the productivity,

efficiency and effectiveness of the platform as well as reduce the OPEX of the whole process.

4.3 Waste Collecting System

The most crucial aspect of any ICT platform is the data flow and the technologies used. Figure 6 shows how the traffic and data flows among the data centre, waste bins and deposit sites. The waste collection follows two-way procedure, one with the scheduling and another upon notification that can be generated by any passer-by near the open waste. As of scheduling, all the types of waste are scheduled on the days of the week. This scheduling process is automated and is optimized by analysing the amount of specific type of waste collected from certain bin location (Fig. 7). The scheduled tasks are notified to the SRs and HLPs through a mobile application, SMS, and email. The other way of identification of waste can be notified by the any citizen through sending a picture along with the geographical coordinates and/or bar code present on the waste bin. This notification alerts the OM who analyses the state of the operation and in case of failure, he creates an appropriate remediation task.

Once the tasks are created, whether through scheduling or by OM and notifications are sent to the relevant operators (DRs and HLPs), they start the job and notify it back through the mobile application. The OM monitors the location of each truck in real time as well as the status of the task. As soon as the task is finished, the DRs feed the data through the mobile application against the completed task. The collected waste is sent to three main locations (Fig. 6), (1) recycle plants, in case of segregated inorganic waste like glass, plastic, aluminium, paper etc., (2) composting sites, in case of segregated organic waste like vegetables or meat and (3) export, in case of undifferentiated and such waste which is uneconomical to segregate. The type and quantity of each type of waste in entered in the database as it is collected from its source by the WOs.

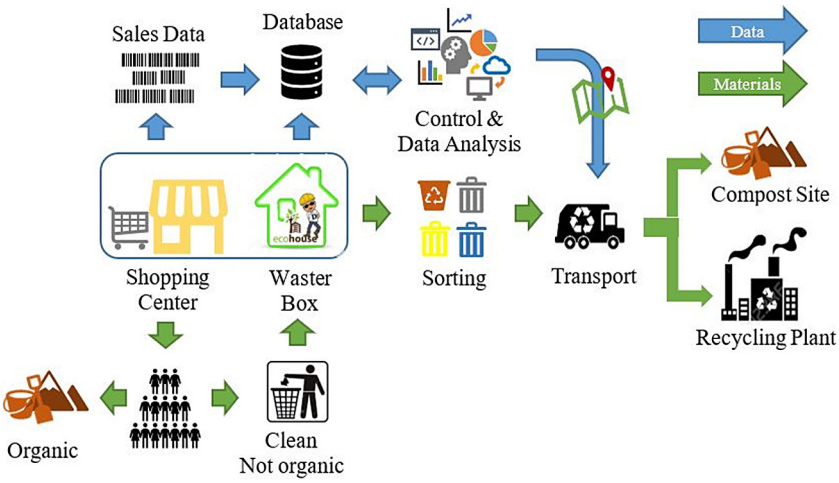


Fig. 6. Flowchart of data and materials

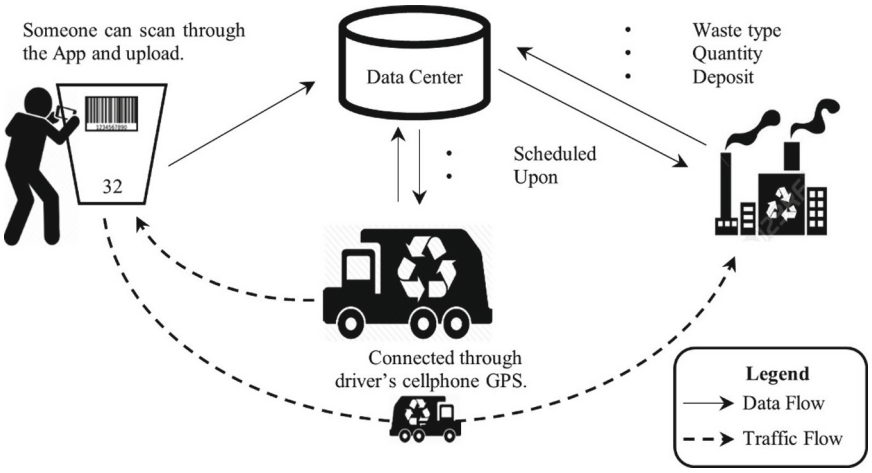


Fig. 7. Schematic of data and traffic flow among data centre, waste bins and deposit locations

5 Discussion and Conclusions

The intent of this paper was not only to summarize the existing problems and lack of organized management in Lebanon and the administrative, and public health challenges faced by the dwellers due to this scenario, but also to provide a smart solution to address these issues. The model presented in this paper provides a self-sustainable, economical, and data-driven solution. The concept of "how to implement circular economy and smart cities in developing countries" is discussed and feasible solution is provided in the form of a platform.

The problem of SW can be managed and resolved very efficiently and effectively if the modern tools like IoT, GIS, and cloud computing are implemented in a sensible way. As shown in the paper, this challenge in southern Lebanon is tackled with a newly implemented platform which uses sensors, algorithms, and artificial intelligence to not only perform the task but also doing them optimistically to reduce manpower as well as OPEX.

The platform is based on advanced technologies like sensors-installed bins, optimization algorithms for scheduling the task and managing the fleet for collection and disposing off waste from source (waste collection locations) to destination (recycle plants or composting site).

The platform has the ability to add more functions if needed to match a specific requirement in future. Furthermore, it can be implemented to other areas and municipalities of Lebanon to bring the complete network of ISWM under a single grid. For this, the platform can be expanded with a minimal cost and effort to make one national solution for SWM.

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