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A GIS-BASED FRAMEWORK FOR MANAGING CONSTRUCTION AND DEMOLITION WASTE: THE CASE OF SYRIA

by
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AN ABSTRACT OF THE THESIS OF

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The substantial amount of concrete waste generated from regular (non-emergency) construction and demolition works as well as emergency states such as wars and natural disasters poses a great threat to the environment in terms of increase in quarrying demand and diminishing landfilling space. Proper management and recycling of construction and demolition waste (CDW) helps alleviate those problems. GIS allows policy makers to spatially locate sources of waste as well as to analyze suitable lands for the construction of recycling facilities (RFs) using a multi-criteria evaluation process (MCE). The proposed framework in this study involves estimating CDW quantities, building a GIS model for RF siting, and carrying out an economic assessment. The framework is applied on the case of Syria to account for the concrete waste generated on a regular basis and the waste as a result of the ongoing war. The GIS model considers environmental and transportation objectives including slope, a vegetation index, a snow index, buffer distances to water bodies, green areas, urban areas, proximity to restricted roads and proximity to allowable roads. The results show that the percent of highly suitable land varies from 19 to 73 percent depending on the level of importance allocated for each of these factors. The economic assessment considers both capital and operational costs per RF module as well as different combinations for the revenues attainable from the recycled product price and the set gate fee.

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CHAPTER I

INTRODUCTION

The aim of this research study is to present a framework for recycling construction and demolition waste (CDW) in post-war scenarios or post natural disasters by using spatial locations of generated demolition waste (DW) and proposing final disposal sites using Geographical Information System (GIS). Users of GIS range from research institutions, environmental scientists, health organizations, land use planners and governmental agencies on all levels. Some common examples include historical mapping, hydrology, remote sensing applications, public transportation and waste management. As such, GIS allows policy makers to conduct comprehensive analyses in data collection, storage, integration and processing. The presentation is a spatial form of suitable locations for recycling facility siting, demolition quantities, and land cover which are processed using the software ArcGIS 10.2 (ArcGIS for Desktop).

According to waste statistics in the EU-28 for 2012, construction activities contribute up to 33% of the total waste generation, which is equivalent to 821 million tons per year. Of the total waste generated, 63% are mineral waste. Member states that have higher shares of mineral waste are characterized by their large quarrying, construction, and demolition activities. In fact, CDW accounted for 93.5% of the total mineral waste generated across the EU-28 in that year (Waste Statistics - Statistics Explained , 2015). Another stream of waste is generated from man-made or natural disasters. For example, several countries in the Middle East have experienced or are currently in war, resulting in huge amounts of DW which usually is disposed of at designated landfills or open dumps. For example, in the case of Lebanon, the war with Israel in 2006 resulted in 6 million m3 of DW, the vast majority of which ended up in temporary disposal sites throughout the country. Subsequently, in 2007, 0.6 million m3 of DW was generated from the heavy fighting in the Nahr El Bared Camp. Some of this waste was recycled into base material for nearby projects (expansion of the port of Tripoli and construction of roads around the camp) with the remaining material disposed of in the nearby valleys (Srour, Chehab, El-Fadel, & Tamraz, 2013). In the case of Palestine, more than 400,000 tons of concrete rubble was collected from former settlements and more than 600,000 tons of rubble was generated in the wars between December 2008 and January 2009 in Gaza according to the United Nations Development Programme (UNDP). As in any war zone, the targeted structures included private houses, public buildings and various infrastructure facilities. The fact that the Gaza Strip was sieged and closed off should have encouraged the involved parties to recycle and reuse the concrete rubble, due to the shortage of construction materials imported from outside Gaza. However, only about 10% of concrete rubble was recycled and reused, with the remaining quantities disposed in temporary UNDP crushing sites. This was primarily due to the lack of official direction regarding rubble storage locations, and hence the effort resulted in random relocation of rubble from the damaged sites to vacant lots and roadsides (Disaster Waste Recovery , 2009).

There are several reasons that impede recycling and reuse, and encourage illegal haphazard dumping of CDW. The lack of policies for proper CDW management foster a negligent community lacking awareness. Moreover, some public and private companies may be unaware of the economic benefits for recycling their CDW. Another reason behind haphazard dumping is due to the absence of necessary infrastructure such as dedicated facilities and operating requirements. That being said, to reach the goal of establishing a sustainable and successful DW management plan, the following elements must be addressed (Srour, Chehab, El-Fadel, & Tamraz, 2013).

- Estimate the amount of DW generated and the amount of construction waste (CW) generated over a period of time. This is further elaborated in Chapter 2, Section A.
- Locate potential markets for the resulting recycled material (cementitious and non-cementitious)
- Locate potential land for the construction of recycling facilities taking into consideration several constraints; urban areas, hydrographic features and green areas. Refer to Chapter 2, Section B for a detailed description of the methodology
- Determine the number and size of facilities that will handle the CDW to have a long-term production of construction materials
- Establish an economic/political system that proves to encourage recycling CDW

The methodology adopted in this paper consists of estimating the quantities of CDW in order to design for the required recycling facilities (RFs), in addition to identifying the important economic and environmental factors for RF site selection using

GIS. The results are presented as different scenarios depending on the evaluation of the decision makers handling the post disaster situation. The analysis includes an economic assessment of the net present value (NPV) conducted to estimate the costs and revenues of implementing the recycling strategy. The framework is applied to the case of Syria which covers a total area of 185,180 km2 and has a population density of 118.3 per square kilometer. The uprising political opposition to the Syrian government in 2011 developed into a fully-fledged civil war by 2012, and transformed parts of major cities to rubble resulting in large amounts of debris. In a recent conference by the Engineers Syndicate held in Damascus, the Minister of Public Works Hussien Arnous highlighted the importance of preparing the technical, legal and financial conditions for recycling the demolition debris. The planned efforts target debris from both public and private buildings in the ongoing war which is to be used in the reconstruction phase (Al-Frieh & Said, 2015). Prior to the war in the year 2010, Syria had planned an initiative to join the United Nations Framework Convention on Climate Change (UNFCCC) and implement the National Master Plan for solid waste management. The plan included the closure of random dumpsites, and replacing them with sanitary landfills, sorting plants, recycling plants, composting plants, transfer stations, medical waste treatment units and hazardous waste treatment plants (National Report of the Syrian Arab Republic to the United Nations Conference on Sustainable Development (Rio+20), 2012). The following section elaborates on estimation methods for CDW, evaluation of landfilling versus recycling strategies, using GIS for landfill site selection, and setting standards and policies for recycled concrete aggregate (RCA).

A. Literature Review

The three sources of CDW arise from new construction, demolition activities and emergency states. Several methods are used to quantify the amount of waste generated, depending on the country and ease of access to national statistical data.

1. *Estimation Strategies for CDW*

Table 1 presents the different methods depending on the source of CDW.

Table 1 Estimation methods for CDW

CDW	Method	Reference	Explanation
New Construction	Constructed area (survey and Quantity Take Offs)	(Bakshan, Srour, Chehab, & Fadel, 2015)	WGR (waste generation rates) based on collected data about waste generations during various phases of the construction process CW=WGR*TCA CW=Total quantity of construction waste, WGR=total construction waste generation rate, TCA=total constructed area New construction projects; based on 28 ongoing construction sites of different types, sizes and stages of construction
	Software tools	(BRE SMARTWaste, 2008)	SMARTwaste^{TM} developed in the UK by the British Research Establishment (BRE) Online tool to estimate the amount of CDW generated in new construction projects Based on site data input, monitoring and controlling waste, energy, water, materials, transport and timber
Demolition	Constructed area (survey and QTOs)	(Srour, Chehab, El-Fadel, & Tamraz, 2013)	DW=ND x ABA x W DW=demolition waste generated, ND=number of demolished buildings, ABA=average built-up area per building, W= average mass per m^2 of built-up area Based on data collected from interviews tackling demolition practices and 12 case studies; five recently demolished buildings, two existing buildings and five new constructed buildings
onsr ction &	Databases & Literature	(Mália, de Brito, Duarte Pinheiro, &	CDW global indicators: exhaustive surveys of previous international studies

CDW	Method	Reference	Explanation
		Bravo, 2013)	Considers residential, non-residential and refurbishment (new construction and demolition). Types of building structures; timber reinforced concrete and masonry Individual indicators are also put forward to each waste according to the European Waste Catalogue (EWC)
mergency	Debris Estimating Field Guide	(Federal Emergency Management Agency, 2010)	FEMA: Federal Emergency Management Agency and PDA: preliminary damage assessment Ground measurements of debris can be taken to develop estimates, using visual observation and detailed data collection with equipment such as measuring tapes and GPS units Aerial and satellite photographs of areas taken before and after the disaster event may be used to estimate debris quantities and types (for areas that are difficult to access) Computer models based on debris quantities generated by similar disaster events and/or GIS data on topography, land use and level of development
	Damage Assessments	(HDX, 2016)	The project was initially funded by Britain’s Department for International Development, the Swedish aid ministry and the Humanitarian Innovation Fund with additional funding from the Rockefeller Foundation. An open platform for sharing data among U.N. agencies, non-governmental organizations (NGOs) and governments Available maps based on satellite detected damage and destruction to identify number of affected buildings and extent of damage

Referring to the method of ‘constructed area’ in Table 1, the two studies are used to compare the amount of CDW from new construction versus demolition activities. The first study targets waste generation rates in $kg.m^{-2}$ for new construction projects. The estimated waste generation index WGI_c for concrete is 8.7 kg/m^2 (Bakshan, Srour, Chehab, & Fadel, 2015). Using the average permitted built-up area in Beirut over 2009-2010 (provided by the Order of Engineers and Architects OEA) which is 1,112,356 m^2, the total quantity of concrete waste due to new construction is calculated to be 9,677.5 tons. According to the second study, officials at the municipality of Beirut reported that 229 buildings were demolished over these two years resulting in around 0.91 million tons of waste of which 58% were reinforced concrete. This study estimated the quantity of concrete waste over the two years to be 580,000 tons (Srour, Chehab, El-Fadel, & Tamraz, 2013). Therefore, it is determined that in the specified region, demolition and new construction projects are responsible for 98% and 2% of the concrete waste generation respectively. The third source to CDW is emergency states such as wars or natural disasters. According to FEMA and US regulations, there are three main approaches to estimate debris; however, the level of accuracy is limited and depends on the assumptions and conversion rates adopted to quantify the debris (Federal Emergency Management Agency, 2010). The literature does not clearly present cases whereby the amount of demolition waste as a result of emergency states is quantified. Hence this facet will be tackled as one part of this paper, by proposing a framework for the estimation of CDW quantities as a result of new construction, demolition and emergency states. However it is worth mentioning an important challenge to estimating the amount of emergency waste, which is the precursor of clearing the demolition of unexploded ordnances (UXOs). Several countries have developed a strategy to safely clear the disaster sites from UXOs and military munition, such as the examples of Lebanon and Gaza. For the case of Lebanon and particularly Nahr El Bared, two entities cooperated through different frameworks; explosive ordnance disposal (EOD) organization and rubble removal contractors. UNDP signed a fixed price contract for the safe removal and treatment of approximately 500,000 m^3 of rubble waste material in an environmentally sound manner during an 18-month period. The integrated rubble removal and EOD process consisted of the following overall steps (Lauritzen, 2015).

- EOD teams visually surveyed the work area before entering

- UXO was removed and/or marked for destruction on site
- The rubble-removal team used machines to gradually clear the area to the natural ground level, stopping for UXO removal or destruction as needed
- At the natural ground level, the EOD team performed a survey of the newly exposed surface
- Any additional UXO found was removed or destroyed, and remaining rubble at the natural ground level was removed
- Cleared rubble was loaded onto trucks and transported from the work site to the lay down area for final inspection and additional UXO survey
- Rubble declared free of explosives was transported to the final disposal area

For the case of Gaza, UNDP was assigned to remove and crush more than 700,000 tons of mixed concrete rubble from Gaza ex-settlements. Nearly 400,000 tons of this rubble were removed in very good and clean conditions. Detailed tests in two laboratories[1] were carried out each on a sample of 30,000 tons for hazardous materials, asbestos, and heavy metals according to the international standards. The results showed that the concrete rubble was cleared safely and could be reused in road sub-base construction (Kharouby, 2011). The mentioned cases demonstrate that UXO clearance is a critical step in any rubble recovery strategy which can be achieved by an integrated framework for the management of rubble removal work and EOD work. The next section presents the advantages and financial benefits of recycling CDW when compared to the typical landfilling strategy.

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[1] The two labs are Materials and Soil Testing Laboratory at the Islamic University of Gaza. (IUL) and the Association of Engineers Laboratory (AEL)

2. Landfilling Versus Recycling Strategies

The concrete industry exploits 50% of raw materials, 40% of total energy and generates 50% of total waste (Behera, Bhattacharyya, Minocha, Deoliya, & Maiti, 2014). Many environmental problems are encountered due to the disposal of CDW and concrete waste from batch plants. These environmental problems include: diminishing landfilling space due to large quantities of CDW dumping, depletion of natural aggregate for building materials, negative health effects due to the increase in contamination from landfills, damage to the environment and the increase in energy consumption for transportation and manufacturing new materials. The availability of disposal sites is declining in urbanized environments. Hence, waste is being disposed of in an illegal manner that harms the environment. Recycling of DW takes care of illegal and haphazard dumping of materials. In particular, it alleviates the pressure exerted on quarries to supply natural aggregates, and extends the lifetime of landfills by reducing the amount of waste disposed. Utilizing recycled concrete diminishes quarrying and transporting of virgin materials and most importantly reduces the disposal of waste (ACI Committee 555, 2001).

There are several advantages to concrete recycling, of which cost reduction and environmental savings are most important. The primary advantages are: conservation of natural resources, reduction in energy consumption since the extraction and crushing of virgin aggregates use a substantial amount of energy and cause more emission of CO_2, addressing the waste disposal crisis and preservation of the environment (Behera, Bhattacharyya, Minocha, Deoliya, & Maiti, 2014). Recycling is considered as a sustainable alternative to traditional demolition and landfilling strategies. Savings as a result of recycling concrete are due to the elimination of transportation of demolition to remote landfills as well as a reduction in extraction of natural aggregates by quarrying. However, there are newly incurred costs to this alternative, such as transportation between demolition site and recycling plant, breaking the large concrete chunks into smaller pieces that can be fed into crushers, screening, removal of non-cementitious elements and reinforcing bars and multiple crushing stages. A study titled “Estimating the Costs, Energy Use and Carbon Emissions of Concrete Recycling Using Building Information Modelling” compares the cost of landfilling versus recycling concrete. The economic analysis is presented in Figure 1, which shows the costs for various stages of recycling and landfilling strategies as well as the earnings through the sale of recycled aggregate in 1000 USD. Such earnings were calculated by estimating the yield of the recycling process and multiplying the estimated volume of each size fraction of RCA by its estimated market price. The model also considers that steel rebars are sold at the market price for steel scraps (Akbarnezhad & Nadoushani, 2014).

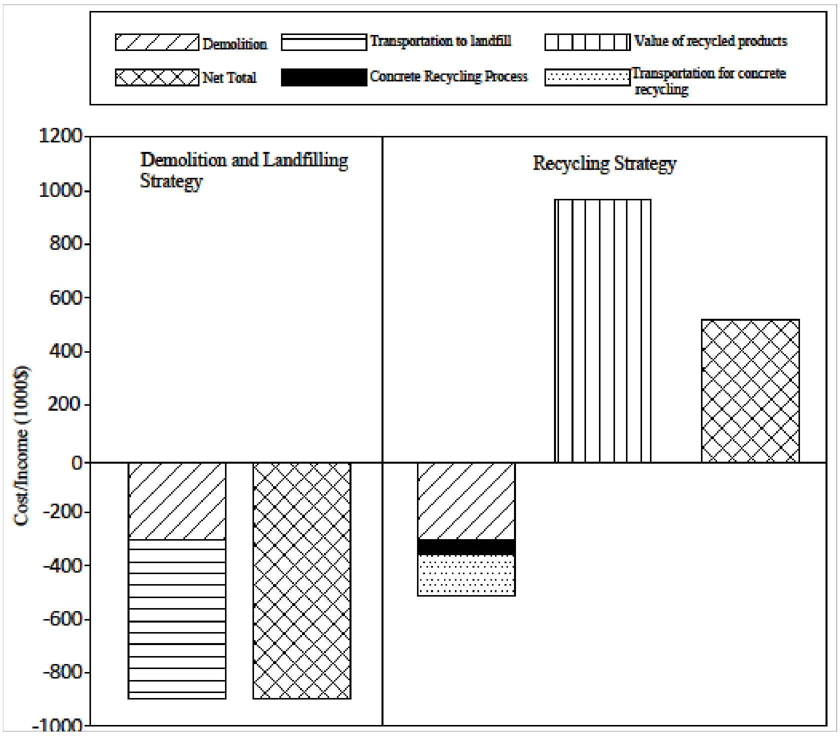

Figure 1 Costs incurred by concrete recycling and landfilling strategies (Akbarnezhad & Nadoushani, 2014)

As shown in Figure 1, as part of the recycling strategy, the study concluded that the lowest cost at 12.5% of the total cost is due to the concrete recycling process, whereas the demolition and transportation processes account for about 59% and 28% of the total recycling cost respectively (Akbarnezhad & Nadoushani, 2014). This proves that the actual recycling process including breaking, crushing, sieving and conveying is not the main cost factor, therefore the production of high quality RCA using costlier/more advanced recycling operations should be considered. In the mentioned study, the assumed distances to the landfills and recycling plants where considered to be 50 km and 10 km respectively. This assumption is valid given the locations of landfills which are situated in areas far “from everyone’s backyard”, and thus the transportation costs are about 70% of the total costs in the landfilling strategy. The overall cost of the recycling strategy is about 50% lower than the demolition and landfilling strategy. Another valuable aspect is the considerably high revenues attainable from the sale of recycled and recyclable products; RCA and steel scraps. Graphically it is notable that the revenues of recycled products (~1 million USD) can easily exceed the costs of concrete recycling (62,500 USD equivalent to 12.5% of total cost) and can serve as a source of income to the project, therefore the result is a positive total net economic impact for the concrete recycling strategy. Other comparisons regarding the energy use and carbon emissions incurred also result in a positive total net environmental impact for the recycling strategy as opposed to the landfilling strategy (Akbarnezhad & Nadoushani, 2014). Even though the mentioned Building Information Modelling (BIM) assessment was conducted on a small scale construction site, the economic and environmental benefits are prominent. In general considering the comprehensive cost, the price of recycled concrete made of a mixture of recycled and natural aggregates was reduced by 15% - 20% compared with ordinary concrete (Chaojie, Xiaodong, & Hanbing, 2013).

Once amounts of waste are estimated and policies are in-place to recycle CDW, the next step is to setup a network of recycling facilities. Selecting the most suitable locations for setting up facilities requires consideration of a critical number of mutually conflicting criteria. Most importantly the decision maker must consider development and operation cost, existence of all necessary basic infrastructure (road network and available workforce), distance from natural elements and human settlements and lastly social acceptance (Banias, Achillas, Vlachokostas, Moussiopoulos, & Tarsenis, 2010). The following section presents two studies used to locate landfills using a GIS application and a similar set of criteria.

3. Using GIS for Landfill Site Selection

GIS approaches are popular for planning and management because of their interdisciplinary nature. Several cases of using GIS for landfill siting are reported in the literature. These include the cases of Macedonia and Iran which are discussed in this section. This application is based on a multi-criterion evaluation (MCE) such as Boolean overlay and weighted linear combination (WLC). The Boolean overlay approach uses non-compensatory aggregation operators such as the intersection (AND) where every criterion is met and the union (OR) where a single criterion is met. The WLC approach uses compensatory aggregation rules where the decision set includes the overall value of the alternatives and where favorable criteria can outweigh unfavorable criteria. Compensatory aggregation involves making rational decisions through collecting and comparing all of the necessary data, which is too labor intensive in some cases. The WLC procedure allows a full tradeoff among criteria; high criteria weights can compensate for low criteria scores, and offers much more flexibility than the Boolean overlay approach. Fuzzy set theory is often used for criteria standardization before it is coupled with the WLC methods. Standardization is a process that transforms and rescales the original criteria into comparable units (Gorsevski, Donevska, Mitrovski, & Frizado, 2011). For the case of the Polog Region in Macedonia (which occupies 2,471 km^2), the method for landfill siting is an integrated GIS-MCE theoretical modeling approach with different applied fuzzy standardization membership functions. The site selection process requires consideration of extensive criteria to eliminate subsequent nuisances such as dust, noise and visual intrusion as well as long-term effects, mainly pollution of local environment and groundwater. The decision process consists of four levels in decreasing hierarchy: goals, constraints, objectives and criteria. The MCE is represented in the third level with two objectives: environmental and economical. Each objective entails a number of factors which are represented as criteria in the last level. Figure 2 illustrates the hierarchical structure involved in decision making input into GIS (Gorsevski, Donevska, Mitrovski, & Frizado, 2011).

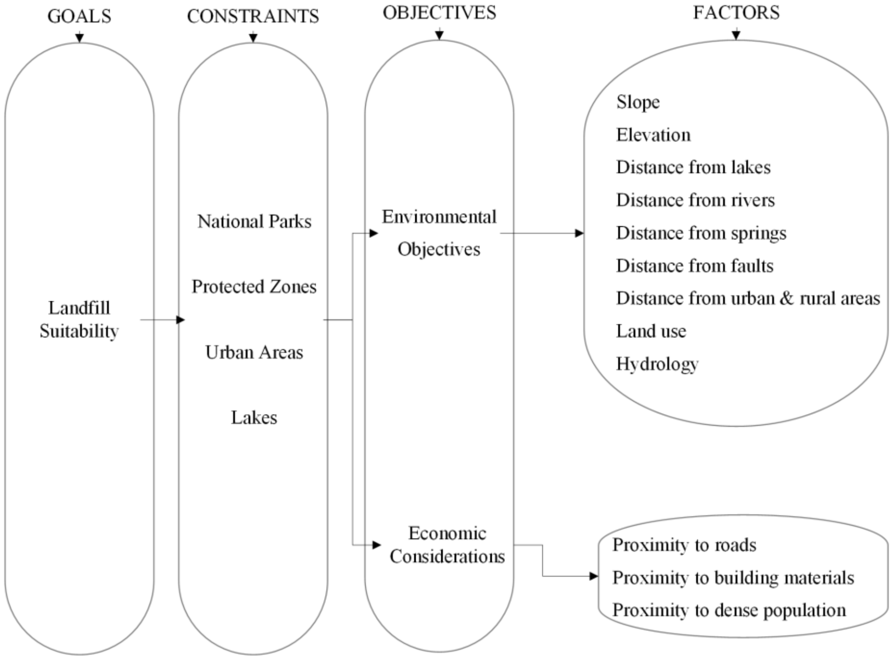

Figure 2 Hierarchical organization for landfill suitability in Macedonia (Gorsevski, Donevska, Mitrovski, & Frizado, 2011)

The results of the study present a total of three different scenarios for landfill suitability associated with the different weights obtained by the MCE method which are assigned to environmental and economic factors, where suitability is expressed on a scale range between 0 and 1, 1 being highest suitability. The most suitable areas for landfill siting are mapped out spatially in forested and barren areas away from agricultural and urban areas (Gorsevski, Donevska, Mitrovski, & Frizado, 2011).

Another paper applies MCE for the landfill site selection of the Birjand plain in Iran (which occupies 3,425 km^2), after facing a rapid municipal solid waste growth in 2015 (Motlagh & Sayadi, 2015). Similar parameters such as environmental and socio-economic factors are input into GIS using MCE and analytical network process (ANP). ANP is used to measure the alternatives comparative suitability of urban solid waste disposal by employing super matrix and value judgements of individual decision makers approaches. The criteria and attributes were identified and structured into 4 levels according to the ANP model. Figure 3 below shows the hierarchical structure adopted, the last level indicates the considered factors which are assigned weights using the super matrix. The super matrix is populated by the different combinations of weight possibilities for each factor, considering seven scenarios. The result is the presentation of regions according to a suitability scale of 0 to 5, 0 representing incapability and 5 representing extremely strong suitability (Motlagh & Sayadi, 2015).

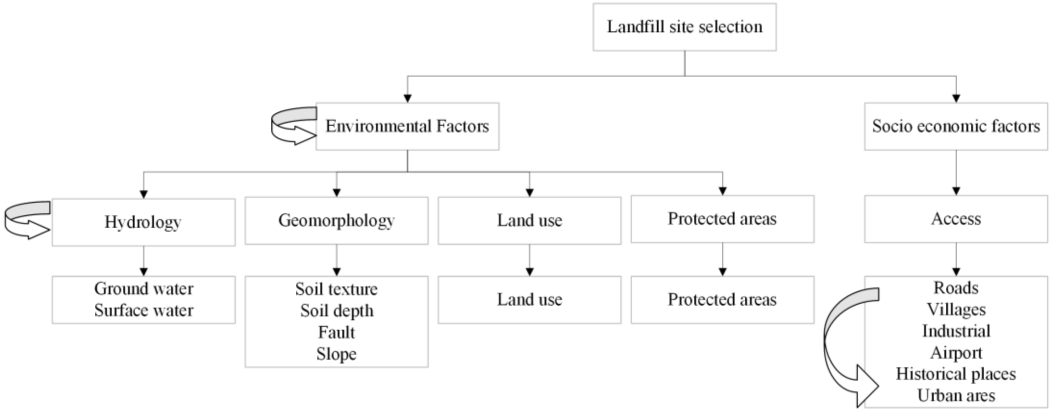

Figure 3 Hierarchical organization for landfill suitability in Iran (Motlagh & Sayadi, 2015)

From the aforementioned studies done in Macedonia and Iran, a similar methodology will be adopted for the purpose of this research; siting of suitable locations for recycling facilities. Fuzzy set theory is used for factor standardization then coupled with the WLC methods in order to select suitable sites. The applicable factors will be extracted and used in the hierarchical organization elaborated on in Chapter 2, Section B-1. To ensure that there is a market for the materials generated from recycling facilities, policies need to be in place to enforce or at least encourage recycling of CDW. The following section presents the political and economic framework for recycling CDW in various countries.

4. International Policies and Economics for Recycling CDW

a. International Policies and Economics for Recycling CDW

The recycling of construction and demolition waste has been tested and approved in the use of both structural and non-structural concrete elements and pavements, and has become an integral component of green building rating systems. For example, the LEED[2] rating system encourages the use of recycled content in concrete, cementitious and steel elements. This initiative was launched in an effort to develop a "consensus-based, market-driver rating system to accelerate the development and implementation of green building practices". If such an incentive is not enough for construction companies to consider recycling CDW, then the building code of most

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[2] LEED; Leadership in Energy and Environmental Design, was developed to address all buildings everywhere, regardless of where they are in their life cycle. It applies to building design and construction, interior design and construction, building operations and maintenance, neighborhood development and homes. LEED-certified buildings are resource efficient, the four rating levels are: Certified, Silver, Gold and Platinum, based on the number of points achieved

developed countries will oblige them to comply. Listed below are the required percentages of replacement of natural aggregate (NA) by RCA in different countries (Garber, et al., 2011).

- In the UK, for concrete cylinder strength of 20 to 40 MPa, a maximum of 20% replacement of coarse aggregate applies.
- In the USA, for structural elements ASTM C94/C94M-11b allows for up to 10% replacement by total weight of aggregates (equivalent to 20 to 25% by weight of coarse aggregate) generally, and 100% coarse aggregates replacement by recycled concrete aggregates for concrete strength up to 20 MPa.
- In Finland, RCA is required in 10% of new concrete elements and in 90% of concrete paving mixtures such as road surfaces, road base, landfilling and backfilling.
- In Austria, RCA is used as aggregate in concrete mixtures designed for the lower layer in two-lift construction. It is reported that virgin coarse aggregate can be replaced with up to 20% RCA.
- In Australia, RCA is allowed as a coarse aggregate in new concrete mixtures for curbs and sidewalks. Up to 30% of virgin coarse aggregate can be replaced by RCA, but only in new concrete mixtures for curbs and sidewalks.
- In Japan, RCA is recognized as an alternative to virgin aggregate in new concrete mixtures; however, a methodology to assess quality has been an issue for the implementation of this application. Research in Japan

concludes that up to 20% coarse aggregate can be replaced with RCA without affecting concrete properties

The listed studies below show ongoing research in different countries (Cement & Concrete Association of New Zealand (Cement & Concrete Association of New Zealand (CCANZ), 2011).

- Research in New Zealand, Spain, and the UK has also concluded that there is potential for RCA as an alternative to virgin aggregates for use in new concrete mixture designs
- A study in Belgium reports that RCA can be used successfully in roller-compacted concrete

The mentioned standards and codes are needed to control the amount of CDW waste reused and disposed of. The similar growth in population and economy as a result of the increase in the rate of industrialization and urbanization has made the use of concrete as the most non-sustainable material, as it is consuming the maximum amount of natural resources. The next section tackles different parameters needed to assess the economic feasibility for a recycling strategy.

b. Economic assessment for recycling strategy

It is necessary to consider technical, legal and economic factors while developing a framework for recycling CDW generated in post-disaster circumstances. The technical aspects involve the type and composition of CDW material, and the desired output of recycled aggregate materials. The legal aspects include the available space in the considered geography and the local standards and regulations as previously mentioned. Economic factors include the costs of CDW processing - fixed cost, operation cost and maintenance cost - as well as the revenues which include the charge for accepting CDW and price of recyclable products achievable in the market (Hiete, 2013). Table 2 shows the common parameters used in different regions and countries; the European Union (EU), Lebanon, the United States and Gaza, Palestine.

Table 2 Economic assessment parameters from literature

Parameter	Unit	EU (Hiete, 2013)	LEB (Srour, Chehab, El-Fadel, & Tamraz, 2013)	US (Wilburn & Goonan, 1998)	Gaza (Kharouby, 2011)
RCP: price of recycled product	\$/T	-	2 - 7	5.23	7.5[3]
P_m: price of natural aggregate	\$/T	5.5-11	11	-	15.38
C_r: recycling gate fee	\$/T	-	0-3	1.1	-
Capital investment	\$/T	-	-	7.65	-
C_{tf}: Transportation cost fixed	\$/T	1.38-1.49	0.5-3	-	1.5
C_{tv}: Transportation cost variable	\$/T.km	0.083-0.1	-	0.13	-
Plant capacity	T/year	100,000	364,000	110,000	-
Capacity utilization	%	80	80	88	-
O&M cost	%	-	7	24	-
Increase in operating cost[4]	%	-	3	-	-
ROR: rate of return	%	-	12	12	-

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[3] The processing cost includes sorting of non-concrete materials, demolition and crushing at the crushing

[4] Expected increase in variable costs such as materials, payroll and cost of electricity and other utilities

Parameter	Unit	EU (Hiete, 2013)	LEB (Srour, Chehab, El-Fadel, & Tamraz, 2013)	US (Wilburn & Goonan, 1998)	Gaza (Kharouby, 2011)
Site area	m^2	-	10,000	20,000	-
Designed operation life[5]	years	-	20	11	-

It can be concluded that the values for each parameter varies depending on the region considered and its local economy, technological advancement and availability of resources. A detailed economic assessment is developed as part of the framework in Chapter 2, Section C, based on the aforementioned parameters. That being said, there is no evidence of a specific study to locate suitable lands for recycling facilities in post natural or man-made disasters using GIS. In a post-disaster scenario, what is predominantly left in a city or a country is demolition waste that must be first safely

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[5] The designed operation life of a facility is the period of time during which the facility is expected by its operators to work within its specified parameters

cleared of UXOs and then strategically relocated to suitable sites where it is recycled; the goal of this proposed GIS model.

B. Proposed Scope of Work

Numerous studies have used GIS applications in landfill site selection, new road construction and assessment of the impact of external factors on ecosystems. However, none of these studies offer a GIS based methodology for sustainably managing large quantities of CDW generated as a result of wars or natural disasters. The GIS methodology proposed in this paper involves two main additional parameters other than the site selection process. The additional parameters are accurately locating and quantifying the sources of war rubble and their constituents as well as conducting a comprehensive economical assessment to quantify the different costs and revue variables. Therefore, this study presents a unique application using GIS to locate the optimal locations for recycling facilities while minimizing environmental and economic costs on the long run.

The proposed scope of work involves two dimensions of analysis. The first dimension is to compute the total quantity of CDW present after a man-made (war) or natural disaster. The second dimension is mapping via GIS the data of CDW spatially taking into consideration the land cover: public areas, private/residential areas, green/vegetative areas, water/hydrographic areas and road network of the study area. For the purpose of this paper, it is considered that all CDW is transferred to a recycling facility as proposed by the GIS model; however this may not be the case for some destroyed buildings that can be restored. At the recycling facility, several steps are taken to transform the incoming cementitious DW to RCA. Upon entering the recycling facility, trucks are weighed and the DW is inspected and sorted manually to remove any contaminated material. The sorted material is then transferred to a secondary separation line where it is cleaned to ensure that it is free of wood, plastic, metal and other organic material. The cementitious material (concrete, masonry and mortar) is then crushed, sorted and stockpiled. The equipment needed for such an operation scheme include a crusher, screener, magnetic separator and a loader (Srour, Chehab, El-Fadel, & Tamraz, 2013). The following steps are listed as general guidelines (Construction Waste Recycling and Processing Equipment)

- Pre-sorting and manual separation to remove impurities: preliminarily pre-sort the raw materials of construction wastes to select and sort other wastes and large material blocks
- Automatic magnetic separation: remove the residual iron metal from concrete blocks and construction waste mixed materials
- Crushing process: impact crushers handle large bulks to produce different sized aggregates
- Storage: The manual collecting platform consists of belts to separate wood blocks, aluminum alloys, cables and other impurities in different compartments. The centralized storage system collects the crushed aggregate separated into their different sizes.

As such, the high-level flow chart of CDW materials is established. The next chapter describes the proposed framework of this study.

CHAPTER II

PROPOSED FRAMEWORK

This section elaborates on the proposed framework presented in Figure 4 which includes a quantitative approach to estimate the amount of CDW in post-disaster environments, an economic assessment of the feasibility of recycling CDW, and a software application to determine the optimal location for recycling facilities. The framework is applied to the case of Syria under different economic and environmental scenarios.

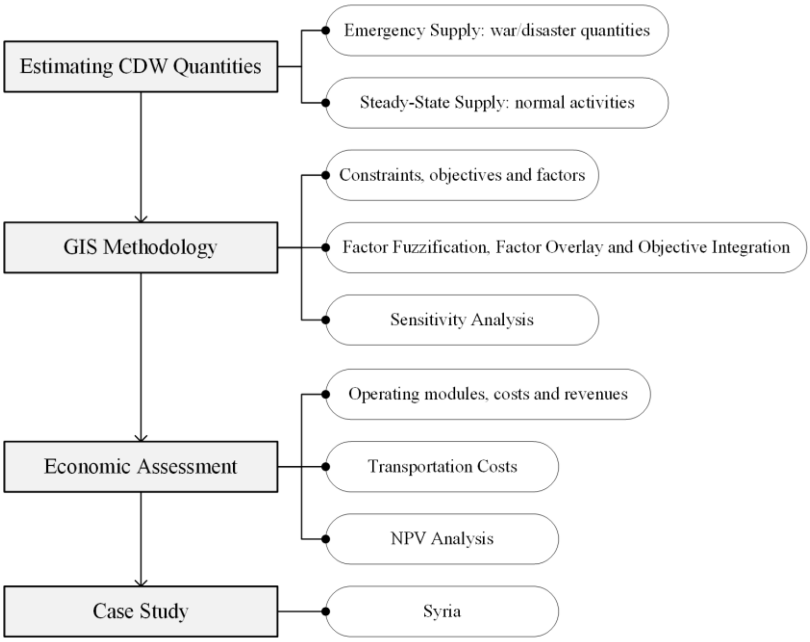


Figure 4 Proposed framework of study

A. Estimating the Quantities of CDW

Several steps are needed to address the problem of CDW management in post-disaster environments, and in countries with no policies and infrastructure for proper management of CDW. The first one of these steps is a methodology to estimate the amounts of CDW generated as a result of the disaster, in addition to the amount of CDW that is usually generated as a result of steady state construction and demolition activities. In this paper, the former is referred to as “emergency CDW” whereas the latter is referred to as a “steady state CDW”. In other words, steady state supply is the quantity of CDW resulting from country wide activities such as new construction and demolition projects (in non-war conditions) on a yearly basis, while emergency supply is the quantity of rubble resulting from war destruction.

1. Calculating the Steady State Supply

Many studies have been conducted to estimate the CDW indicators for different facilities such as new construction, demolition and refurbishment projects as mentioned in Chapter 1, Section A-1. As part of this study, we will focus on the concrete waste resulting from both steady state construction activities and emergency demolition waste which can be recycled and reused in the reconstruction process. The following subsections present the steps to calculate the steady state (i.e. non-disaster related) supply.

a. Average total floor area in the major states

The first step is to calculate the total floor area using Equation 1. It includes all the floor areas permitted for both residential and non-residential buildings, for all the cities/governorates/zones/states. This data is obtained from national statistics for each country, and should ideally include data from at least 10 years for a non-biased analysis.

$$\overline{\mathrm{TFA}_i} = {\left(\sum_j \mathrm{FA}_{\mathrm{NR}} + \sum_j \mathrm{FA}_{\mathrm{R}}\right)_{ij}} \Big/ \mathrm{j} \tag{1}$$

i refers to a state or zone (country sensitive, select major states)

j is an index of year (depending on available data)

$\overline{\mathrm{TFA}_i}$ = Average total floor area in a zone i (m^2)

FA=average floor area (m^2) for non-residential buildings (NR) or residential buildings (R)

b. Average built-up area

The second parameter is the average built-up area, which is given in Equation 2.

$$\overline{\mathrm{TBA}_i} = \overline{\mathrm{TFA}_i} \times n_i \tag{2}$$

$\overline{\mathrm{TBA}_i}$= Average built-up area in state/zone i (m^2)

n_i= average number of floors in state i

c. Total demolished building area

The third parameter is the total demolished building area. This figure is ideally obtained from city, state, or national statistics. Municipalities are often obligated to issue a demolition permit for each building that is to be demolished, either for exceeding its service life or to create space for new construction. Therefore, for each state the total demolished building area can be calculated using Equation 3.

$$\mathrm{TDA_{ij}} = \mathrm{NDB_{ij}} \times \mathrm{BUA_{ij}} \qquad (3)$$

TDA_{ij} = Total demolished building areas (m^2) per state per year

NDB_{ij} = Number of demolished buildings in state i in year j

BUA_{ij} = Total built-up area of demolished buildings in state i (m^2) in year j

d. Calculating the steady state supply

To calculate the annual concrete waste due to steady state activities in a region, the last parameter needed is the concrete production rate (CPR) arising from both new construction and demolition activities. CPR is the amount of concrete waste in kg per m^2 of built-up area resulting from construction or demolition activities. CPR is affected by building design and construction technologies. This figure is often reported at the federal or state level for developed countries, which may be available on online statistical platforms. In developing countries where the legislative bodies do not invest in obtaining such data for record keeping, the CPR value must be adopted from literature. In this paper, CPR is reported as a range with lower (l) and upper (u) limits rather than a single figure. The total steady state CDW quantity in kg for each state is calculated by multiplying the TBA from Equation 2, and the TDA from Equation 3 by the corresponding CPR, as shown in Equations 4 and 5.

$$\mathrm{SCW}_{i-l} = \sum_j \overline{\mathrm{TBA}_{ij}} \times \mathrm{CPR}_{nc-l} + \sum_j \mathrm{TDA}_{ij} \times \mathrm{CPR}_{d-l} \qquad (4)$$

$$\mathrm{SCW}_{i-u} = \sum_j \overline{\mathrm{TBA}_{ij}} \times \mathrm{CPR}_{nc-u} + \sum_j \mathrm{TDA}_{ij} \times \mathrm{CPR}_{d-u} \qquad (5)$$

$\mathrm{SCW}_{i\text{-}l}$ = lower limit of steady state concrete waste quantity in state i (kg)

$\mathrm{SCW}_{i\text{-}u}$ =upper limit of steady state concrete waste quantity in state i (kg)

$\sum_j \overline{\mathrm{TBA}_{ij}}$= sum of average built-up areas in state i over years j= 1,2…J (m^2)

$\mathrm{CPR}_{nc\text{-}l}$ = lower rate of concrete production per square meter of built-up area for new construction ($kg.m^{-2}$)

$\mathrm{CPR}_{nc\text{-}u}$ = upper rate of concrete production per square meter of built-up area for new construction ($kg.m^{-2}$)

$\sum_j \mathrm{TDA}_{ij}$= sum of demolished building areas in state i over years j (m^2)

$\mathrm{CPR}_{d\text{-}l}$ = lower rate of concrete production per square meter of demolition ($kg.m^{-2}$)

$\mathrm{CPR}_{d\text{-}u}$ = upper rate of concrete production per square meter of demolition ($kg.m^{-2}$)

It is worth mentioning that in case the concrete production rate data is available then the equations are simplified into one;

$$\mathrm{SCW}_{i} = \sum_j \overline{\mathrm{TBA}_{ij}} \times \mathrm{CPR}_{nc} + \sum_j \mathrm{TDA}_{ij} \times \mathrm{CPR}_{d} \qquad (6)$$

2. Calculating the Supply of Emergency CDW

As previously mentioned, the emergency supply is the quantity of CDW as a result of war or natural disaster. In situations where it is not safe or practical to conduct site surveys of all demolition sites, the number of affected buildings can be extrapolated from online platforms for damage assessment and estimation of CDW.

a. Data from HDX on number of affected buildings

The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) recognized the importance of collecting and managing data, especially at the times of crisis where such data can be used for humanitarian relief. As such, OCHA has led the development of HDX, a new data sharing platform that encompasses the best standards in accurate data collection (Humanitarian Data: OCHA launches ground-breaking data exchange platform, 2014). The Humanitarian Data Exchange is an open platform for sharing data. The goal of HDX is to make humanitarian data easy to find and use for analysis. This data exchange platform combines the input of over 770 sources covering 244 locations worldwide with around 4000 datasheets. For the purpose of defining the emergency DW in this study, geodata of the damage assessment for the area under study will be used. The data includes the number of affected buildings for each state.

b. Total emergency concrete waste amount

The total concrete waste corresponding to the emergency supply is calculated using Equations 7 and 8. Using national statistics, one can obtain the average built-up area per building for each state, which will be part of the calculation. Lower and upper limit values are considered for CPR.

$$\mathrm{ECW}_{i-l} = \mathrm{NAB_i} \times \overline{\mathrm{BUA}_\iota} \times \mathrm{CPR}_{d-l} \tag{7}$$

$$\mathrm{ECW}_{i-u} = \mathrm{NAB_i} \times \overline{\mathrm{BUA}_\iota} \times \mathrm{CPR}_{d-u} \tag{8}$$

$\mathrm{ECW_l}$= Lower limit of emergency concrete waste quantity (kg)

$\mathrm{ECW_u}$= Upper limit of emergency concrete waste quantity (kg)

$\mathrm{NAB_i}$ = Number of affected buildings in state i from damage assessment reports

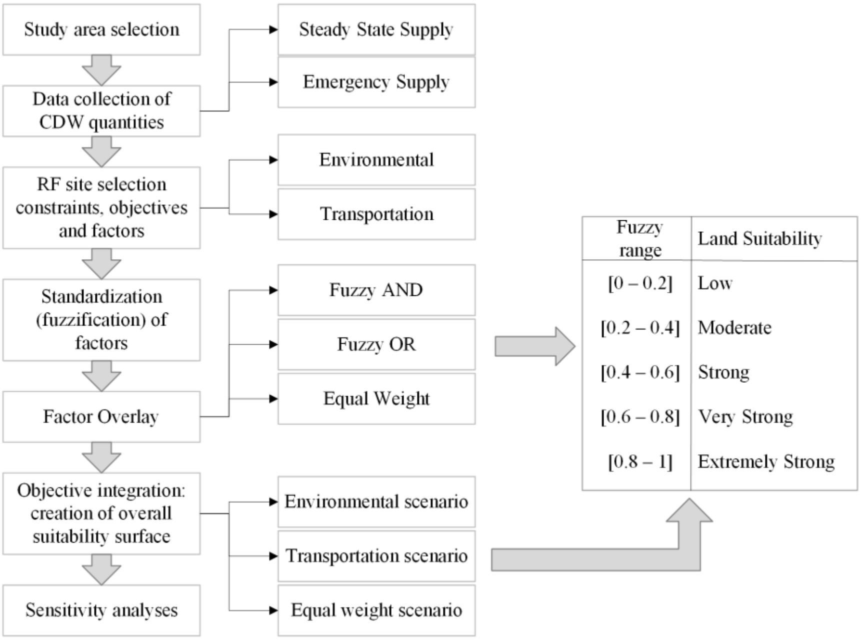
$\overline{\mathrm{BUA}_\iota}$= Average built-up area in state i (m^2)

Once the steady state and emergency quantities of CDW are estimated, the number and location of recycling facilities can be determined. The following section discusses the use of GIS for selecting suitable recycling facilities.

B. GIS Methodology

The site selection for recycling facilities is conducted using the MCE method paired with fuzzy set analysis. A methodology similar to the studies done by (Banias, Achillas, Vlachokostas, Moussiopoulos, & Tarsenis, 2010), (Motlagh & Sayadi, 2015) and (Gorsevski, Donevska, Mitrovski, & Frizado, 2011) is adopted to prepare the constraints and factors to fulfill the objectives, which are translated to map layers in

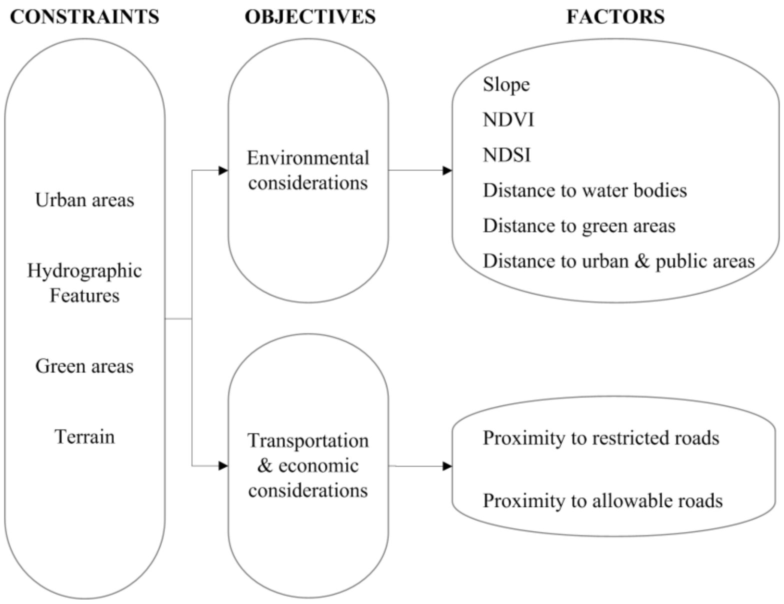
ArcMap. The factors are projected to a coordinate system depending on study region using projected coordinate system tables (ArcGIS 10.1 Projected Coordinate System Tables, 2012). Factors considered are in raster format; raster datasets represent geographic features by dividing the world into discrete square or rectangular cells laid out in a grid. Each cell has a value that is used to represent some characteristic of that location, such as elevation or a spectral value. Rasters are the universal data type for holding imagery in GIS, and they have a rich set of analytic geoprocessing operators. Figure 5 shows the general methodology including the GIS application which is elaborated on in the next sections.



igure 5 Schematic representation of methodology

1. *Objectives and factors*

The process to select the most suitable site for the construction of recycling facilities involves many criteria. There are several social and spatial constraints that have to be accounted for in order to reach the optimal solution from both an environmental and an economic perspective. The common public stance of ‘Not in My Back Yard’ highly affects the economic aspect of site selection, since the largest contributor to operational cost is the transportation cost. Hence, densely populated areas may not be feasible. Other constraints such as the spatial locations of hydrographic features, green areas and land terrain must be considered to protect the environment from the resulting pollution of RFs. While the aim is to maximize the objectives of environmental and economic savings, the zones of suitable land get reduced (limited), to account for the set constraints. Six important factors are selected as part of the MCE and represented as map layers based on common criteria selected in previous studies (Gorsevski, Donevska, Mitrovski, & Frizado, 2011) (Motlagh & Sayadi, 2015). Figure 6 shows the expanded points to consider regarding the third step in the methodology ‘recycling facility site selection constraints, objectives and factors. The six mentioned environmental factors: slope, normalized different vegetation index (NDVI), normalized difference snow index (NDSI), distance to water bodies, distance to green areas, distance to urban and public areas, and the two economic factors (proximity to restricted roads and proximity to allowable roads) are elaborated on in the following sub-sections.



igure 6 Factors affecting the process of selecting locations for recycling facilities

a. Slope

Elevation data is important since terrain data such as slope, aspect and contour can be extracted. The Digital Elevation Model (DEM) from the U.S. Geological Survey website can be used in this case to obtain the slope map for the region under study (Earth Explorer). For each region, it is necessary to merge several DEM files which overlap at their extremities to cover the area under study. This can be done using the 'Mosaic to New Raster' Tool under Data Management Tools, while taking the following assumptions:

- Setting the number of bands to 1
- Setting the pixel type to 16 bit signed
- Selecting mean mosaic operator type (the output cell value of the overlapping areas will be the average value of the overlapping cells) and match as the mosaic color map mode which takes all the color

maps into consideration and attempts to match the value with the closest color available.

The DEM data is then projected to change its coordinates from degrees to kilometers. It is worth mentioning that the raster spatial resolution is set to 90 m, which is equivalent to 3 arc seconds - each cell in the DEM is resampled to a 90 by 90 grid. The slope is obtained using the ‘Slope’ tool under the Spatial Analyst Tools; it represents the rate of change of elevation for each DEM cell and is calculated as percent rise. It is important to consider since it affects land stability and constructability of facilities and their access routes. Areas with slopes greater than 5% are of lower suitability for facility siting since there is a danger of producing downfall in the case of rainfall and water penetration (Motlagh & Sayadi, 2015). Thus, the value of 5% will be used as the midpoint during the standardization process in Chapter II, Section B-2-a-i. Another assumption taken is eliminating cells with a slope value greater than 20% corresponding to non-feasible locations for RF siting. This is done by applying a conditional statement ‘Set Null’ under Spatial Analyst Tools with an expression= "value">20. Such cells are represented as ‘No Data’ cells.

b. Normalized Difference Vegetation Index (NDVI)

The NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and to assess whether the target being observed contains live green vegetation or not. The NDVI raster is obtained from the U.S. Geological Survey website and is used to eliminate all vegetated areas (Earth Explorer). The same assumptions taken from DEM for merging the several files are used on NDVI data for the month of June to show agricultural areas pre-harvesting; densest land vegetation. NDVI values range from [-1, 1], the threshold classification is presented in Table 3 below (Nazneen). Cells with a NDVI value less than 0.1 correspond to barren rock, sand or snow and are considered as suitable land. As such an NDVI value equal to 0.1 will be considered as the midpoint in the standardization process as explained in Chapter II, Section B-2-a-i. It is worth mentioning that cells that may correspond to snow are tackled and eliminated via the NDSI factor in the following sub-section.

Table 3 NDVI threshold classification

$-1 \leq NDVI \leq 0.1$	Barren rock, sand or snow
$0.2 \leq NDVI \leq 0.5$	Sparse vegetation (shrubs and grasslands or mature crops)
$0.6 \leq NDVI \leq 1$	Dense vegetation (forests or crops at their peak growth stage)

c.

d. Normalized Difference Snow Index (NDSI)

The Normalized Difference Snow Index (NDSI) is used to eliminate high elevations with likelihood of snow coverage which are also unsuitable for RF construction and activity. The NDSI map is obtained in a similar way to the DEM map, the difference is the source which in this case is the Landsat surface reflectance L8[6] from the U.S. Geological Survey website (Earth Explorer) Data for the region under study is obtained for the month of December[7] and merged using the same assumptions for the

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[6] Landsat Surface Reflectance Climate Data Records (CDRs) are high level Landsat data products that support land surface change studies. Landsat Surface Reflectance CDRs are generated using Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) software, which applies Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric correction routines to Landsat Level-1 scenes. All Level-1 scenes can be processed to Surface Reflectance; Landsat 8 was launched in 2014 (Landsat Surface Reflectance Climate Data Records, 2014)

[7] The month of December displays the highest snow coverage all year round

DEM and NDVI maps. The Landsat8 data consists of 11 band layers as presented in Table 4 (Band Combinations for Landsat 8|ArcGIS Blog, 2013).

Table 4 Landsat8 band properties

Band Name	Bandwidth (µm)	Resolution (m)
Blue 1 Coastal	0.43 – 0.45	30
Band 2 Blue	0.45 – 0.51	30
Band 3 Green	0.53 – 0.59	30
Band 4 Red	0.64 – 0.67	30
Band 5 NIR	0.85 – 0.88	30
Band 6 SWIR 1	1.57 – 1.65	30
Band 7 SWIR 2	2.11 – 2.29	30
Band 8 Pan	0.50 – 0.68	15
Band 9 Cirrus	1.36 – 1.38	30
Band 10 TIRS 1	10.6 – 11.19	100
Band 11 TIRS 2	11.5 – 12.51	100

The NDSI is calculated according to Equation 9, where L8 band 3 equates to spectral wavelengths of 0.53 to 0.59 µm (the green band) and L8 band 6 equates to spectral wavelengths of 1.57 to 1.65 µm (the short wavelength infrared band, SWIR1) (Johnson, Black, Fretwell, & Gilbert, 2016).

$$\mathrm{NDSI} = \frac{\text{Landsat8 band3} - \text{Landsat8 band 6}}{\text{Landsat8 band3} + \text{Landsat8 band 6}} \qquad (9)$$

Applying Equation 9 in ArcMap produces the NDSI map layer with values ranging between 0 and 1 inclusive. The NDSI threshold classification is shown in Table 5 (Enhancing the Landsat 8 Quality Assessment band – Detecting snow/ice using NDSI, 2014). Values of NDSI greater than 0.4 indicate the presence of snow and thence unsuitable areas. Therefore, the value of 0.4 will be taken as the midpoint in the standardization process explained in Chapter II, Section B-2-a-i.

Table 5 NDSI threshold classification

$0 \leq NDSI \leq 0.4$	No snow
$0.4 < NDSI \leq 0.5$	Medium confidence
$0.5 < NDSI \leq 1$	High confidence

The next section continues the presentation of environmental factors relating to land use features in addition to the two transportation factors relating to the road network. The following five factors are input as polygon features and are considered the ‘source’ in the Euclidean distance analysis. The Euclidean distance tool under ‘Spatial Analyst Tools’ generates an output raster containing the measured distance from every cell to the nearest specified source. The distances are measured in the projection units of the raster (meters) and are computed from cell center to cell center. The Euclidean distance tool is used to spatially provide a buffer distance from each feature, in reference to standards and practices used in different countries. Table 6 shows commonly used buffer distances from different features.

Table 6 Buffer distances of different standards and practices from literature

Study Location and Objective	Buffer distance (m)[8]				
	Water bodies	Urban Areas	Green Areas	Allowable Roads	Restricted Roads
Iran – landfill site selection (Motlagh & Sayadi, 2015)	250	3000	500	<300	>300
Macedonia –landfill site selection (Gorsevski, Donevska, Mitrovski, & Frizado, 2011)	300	500	-	<2000	>2000
Ethiopia – Solid waste dump (Ebistu & Minale, 2013)	1000	2500	1000	<500	>500
US States[9] - Regulations (Bilkovic, Hershner, & Olney, 2002)	100	305	-	-	-

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[8] Buffer distances are taken from the polygon boundaries

The range of common buffer distances according to Table 6 is: 100 -1000m for water bodies, 305–3000m for urban areas, 500-1000m for green areas and 300-2000m for roads. In theory, there is an optimal distance to each factor, but there is no fixed proximity to consider and each case study will have to abide by certain regulations. Hence, applying fuzzy set analysis, as presented Chapter II, Section B-2-a, removes uncertainties in classifying the buffer distances. In this study, we have adopted a lenient approach to the environmental factors and a conservative approach to the transportation factors. These buffer distances may be adjusted depending on hydrological conditions and legislation regulations in the region under study. The distance from water bodies, urban and public areas, green areas and the road network is elaborated on in the following sub-sections. The road map can be simplified and divided into two categories,

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[9] A buffer distance of 100 m is selected based on an assessment of fish habitat in rivers in Virginia - The Ohio state requirement for buffer distances from dwellings to landfills is 305m – For surface mining activities in Matewan, KY and Noble, KY require 300ft buffer distance from towns and 100 ft buffer distance from major rivers (Carter & Gardner)

allowable roads consisting of primary and secondary roads, and restricted roads consisting of internal roads and intersections, inner-city and pedestrian roads.

e. Distance to Water Bodies

Water bodies include rivers, streams, lakes, reservoirs and dams. Applying the Euclidian distance tool on the mentioned polygon features is necessary to ensure an environmentally safe site selection process. Recycling facilities receive an incoming amount of mixed waste from the damage sites and supply the market with recycled and recyclable products. The materials involved are both cementitious and non-cementitious and could present a long-term threat to hydrologically connected surface or groundwater sources as in the mentioned case of Macedonia. For this study, the adopted buffer distance to water bodies is considered as 100m.

f. Distance to Urban and Public Areas

The map layer of private and public points including residential, commercial, public, historical, cultural, archeological and governmental points is obtained from satellite imagery data. Potential sites for recycling facility should impose no effect to residential, educational, health-care facilities and environmentally sensitive areas, this is ensured by creating buffer zones via the Euclidian distance tool. A buffer distance of 300m will be adopted around these points in this study.

g. Distance to Green Areas

Data from satellite imagery regarding land use is obtained showing farms, grass fields, brownfields, vineyards and forests. These lands may be either privately owned or held by the government, both of which have high value for their property. Applying a buffer distance from these areas will avoid any public or private opposition or resistance to siting a facility nearby. For the purpose of selecting an acceptable buffer distance to green areas, a conservative value of 300m is used.

h. Distance to Restricted Roads

The rubble recovery process entails the transport of CDW from damage sites to the proposed RF locations. Restricted roads are not assessable as part of the route of hauling trucks. Sites near restricted roads must be eliminated for RF siting since those areas will face public opposition, violate safety standards and hinder achieving the environmental objective. In reference to common practices listed in Table 6, the upper range of buffer distances to roads is typically 2km, which will also be adopted in this paper.

i. Distance to Allowable Roads

As previously mentioned, allowable roads consist of primary and secondary roads which are the only roads that the hauling trucks are allowed to access. Recycling facility sites that are placed far away from allowable roads increase the costs associated with transportation and construction of new access roads. This point is further elaborated on in the economic assessment section. Similar to the buffer around restricted roads, a buffer of 2 km is considered for the distance from allowable roads.

2. *Factor Classification*

After defining the factors, it is necessary to analyze their influence on the site selection process. This is done by considering the range of values for each factor and assigning higher influence to the preferred range. As previously mentioned, there is no definite method to classify the values for each factor; some examples of deterministic classification methods are by natural breaks (jenks), equal interval, quantile and standard deviation. These methods imply that the values before and after the cut-off values strictly belong to different classes for each factor. The limitations for using a deterministic classification method are the resulting inaccuracies in the definition of classes, the assigned suitability to each, and the fact that the different factors have different value ranges. This study applies a heuristic classification method, i.e. fuzzy logic. The selected buffer distances previously mentioned serve as the midpoint for each factor in the fuzzy logic standardization process.

a. Fuzzy Logic

Fuzzy logic specifically addresses situations when the boundaries between classes are not clear. Unlike crisp sets in deterministic methods, fuzzy logic is not a matter of in or out of the class; it defines how likely it is that the phenomenon is a member of a set (or class). Fuzzy logic is based on set theory; therefore, possibilities and not probabilities are defined. The two main steps in fuzzy logic analysis are standardization by fuzzy membership (fuzzyfication) and fuzzy overlay analysis. The Fuzzy Overlay tools help the decision maker address these imprecisions.

i. Standardization: Fuzzy membership process

In the fuzzyfication process, the ideal definition for membership function to the set is defined according to the following criteria:

- Each value of the factor more central to the core of the definition of the set is assigned to 1.
- Values that are definitely not part of the set are set to 0.
- Values that fall between the two extremes fall in the transitional zone of the set, i.e. the boundary. As the values move away from the ideal or the center of the set, they are assigned a decreasing value on a continuous scale from 1 to 0. As the assigned values decrease, the original factor value has less possibility of being a member of that set.
- Given that a fuzzyfication value of 0.5 is the crossover point, any fuzzy value greater than 0.5 implies that the original factor value may be a member of the set.
- As the fuzzyfication values go below 0.5, it is less likely that the original factors' value is a member of the set; i.e. the values may not be part of the set.

The adopted fuzzyfication membership function for each factor is presented in Table 7 along with the two selected function diagrams in Figures 7 and 8 which show the transition of fuzzy values over [0,1]. The fuzzy membership function is a function of the two parameters; the midpoint (m) and the spread (s).

Table 7 Factor fuzzy membership functions properties

Factor	Fuzzy membership function shape and type	Description	Parameters (m=midpoint s=spread)
Slope	FuzzySmall Decreasing – S-shape	Small input values are more likely to be a member of the set; the flatter the land the more suitable	m=5 s=5
NDVI	FuzzySmall Decreasing – S-shape	Small input values are more likely to be a member of the set; values less than 0.1 are more suitable	m=0.1 s=0.5
NDSI	FuzzySmall Decreasing – S-shape	Small input values are more likely to be a member of the set; values less than 0.4 are more suitable	m=0.4 S=0.5
Distance from water bodies	FuzzyLarge Increasing – S-shape	Large values are more likely to be a member of the set; distances greater than 100 from water bodies are more suitable	m=100 s=5
Distance from urban areas	FuzzyLarge Increasing – S-shape	Large values are more likely to be a member of the set; distances greater than 300 from urban areas are more suitable	m=300 s=5
Distance from green areas	FuzzyLarge Increasing – S-shape	Large values are more likely to be a member of the set; distances greater than 300 from green areas are more suitable	m=300 s=5
Distance to allowable roads	FuzzySmall Decreasing – S-shape	Small input values are more likely to be a member of the set; cells within 5km are more suitable	m=2000 s=5
Distance to restricted roads	FuzzyLarge Increasing – S-shape	Large values are more likely to be a member of the set; the farther away from restricted roads the better	m=2000 s=5

The midpoint is a user-defined value with a fuzzy membership of 0.5. The default value is the midpoint of the range of values of the input raster. The selection of midpoint values is based on the property of each factor as previously mentioned in ChapterII, Section B-1. The spread defines the spread of the membership function. The spread generally ranges from 1 to 10, with the larger values resulting in a steeper distribution from the midpoint. The default spread value is adopted and is equal to 5. It is worth explaining the selection of the spread for the NDVI and NDSI factors which values are less than 1. The data for each factor is highly dense within a small range, therefore the most representative value for the spread was s=0.5 as it best represented the small variation with the least noise. A sensitivity analysis is done on the Spread in Chapter II-Section B-2-c.

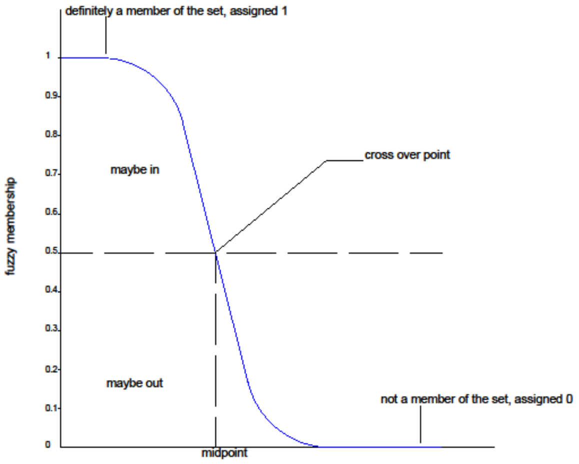

Figure 7 Fuzzy Small membership diagram

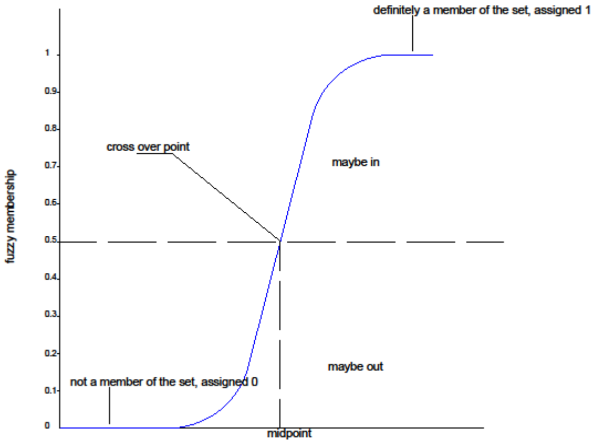

Figure 8 Fuzzy Large membership diagram

ii. Fuzzy overlay analysis

For the second step, the fuzzy overlay tool explores the likelihood of the cell being a member of each set defined by the multiple factors selected for each objective (environmental and economic). The available fuzzy set overlay techniques are fuzzy And, fuzzy Or, fuzzy Product, fuzzy Sum, and fuzzy Gamma. Each of these techniques describes the cell's membership relationship to the objectives (see Table 8).

Table 8 Factor overlay methods used

Overlay method	Property
AND	Identifies the lowest possibility of the cell belonging to one of the suitable sets within the multiple criteria. Used in land suitability models when each of the multiple criteria has been fuzzyfied relative to its membership
OR	Returns the maximum value of the intersection of the sets. That is, in the suitability model, the highest potential membership (the highest suitability value) for each cell is evaluated for the multiple criteria
Equal Weight	Overlays several fuzzy membership functions using equal weights such that each cell value is the linear average of the input rasters. This scenario is similar to the weighted linear combination method with equal influence set to the rasters

The result of each fuzzy overlay method is also a fuzzy raster with values ranging between 0 and 1, which are classified into five equal interval classes as presented in Table 9. Each class corresponds to a land suitability for RF siting, whereby the higher the fuzzy value range, the higher the suitability assigned.

Table 9 Fuzzy overlay value reclassification into suitability

Range of data	Suitability
[0 – 0.2]	Low
[0.2 – 0.4]	Moderate
[0.4-0.6]	Strong
[0.6 – 0.8]	Very Strong
[0.8 – 1]	Extremely Strong

b. Objective Integration: Overall site selection suitability maps

The final step is to integrate the two objectives. Using the weighted overlay tool under ‘Spatial Analyst Tools’, different weights are assigned to the objectives which are then added to obtain three scenarios as shown in Table 10. The weight distribution for each scenario is given by 25%, 50% and 75% for the two objectives.

Table 10 Objective integration by different scenarios

Objectives	Environmental scenario	Equal Weight Scenario	Economic scenario
Environmental	0.75	0.5	0.25
Economical	0.25	0.5	0.75

As such, land suitability is classified on a scale of 0 to 1 and presented in three scenarios for RF siting. The lands having an extremely strong suitability with a corresponding fuzzy overlay value between 0.8 and 1 will be the concern of the decision maker to locate the proposed RFs for the selected scenario. The number of needed RFs will be tackled in the economic section.

c. Sensitivity Analysis: Fuzzyfication parameter spread

To assess how the design parameter of spread affects the land classification among environmental and transportation objectives, a sensitivity analysis is done by focusing on the percent allocation of ‘very strong suitability’ when changing the spread and the method of fuzzy overlay. The midpoint is fixed for each factor while the spread value is varied by taking the lower and upper extremes and the default middle value. The lower value of s =1 corresponds to the least steep curve in the fuzzyfication process hence will produce the most relaxed outcome. On the other hand, the highest value of s= 10 corresponds to the steepest curve which produces the most conservative outcome. Table 11 presents the considered values for the sensitivity analysis on the spread parameter.

Table 11 Parameters for sensitivity analysis on spread (s)

Factor	Control	Conservative	Relaxed
Slope	s=5	s=10	s=1
Distance from water bodies	s=5	s=10	s=1
Distance from green areas	s=5	s=10	s=1
Distance from urban areas	s=5	s=10	s=1
NDVI	s=0.5	s=0.99	s=0.1
NDSI	s=0.5	s=0.99	s=0.1
Distance to allowable roads	s=5	s=10	s=1
Distance to restricted roads	s=5	s=10	s=1

Consequently, the GIS methodology is concluded and the next section tackled is in regards to the economic assessment.

C. Economic Assessment

The proposed sites and sizes of RFs need to be determined to conduct an economic assessment of the feasibility of recycling CDW. The aforementioned GIS methodology locates lands which have a high suitability for RF siting, but disregards the political factors such as zoning, permitting requirements and land value. This is where the decision makers, with the help of experts, integrate their knowledge to select the most suitable land. The total incoming waste is calculated after estimating the waste production from steady-state activities and emergency demolition. The next step is to calculate and set the facilities operating capacity and revenue parameters. The total steady state waste quantity and emergency waste quantity is given by Equations 10 and 11, such that their addition gives the total waste quantity range presented in Equation 12.

$$\mathrm{TSW} = [\textstyle\sum_i \mathrm{SCW}_l\,; \sum_i \mathrm{SCW}_u] \times 10^{-3} \tag{10}$$

TSW= Total steady state waste range (Tons)

$$\mathrm{TEW} = [\textstyle\sum_i \mathrm{ECW}_l\,; \sum_i \mathrm{ECW}_u] \times 10^{-3} \tag{11}$$

TEW= Total emergency waste range (Tons)

$$\mathrm{TWQ} = [\mathrm{TWQ_l}\,;\ \mathrm{TWQ_u}\,] \times 10^{-3} \tag{12}$$

TWQ = Total waste quantity range (Tons)

$\mathrm{TWQ_l} = \sum_i \mathrm{SCW_{i-l}} + \sum_i \mathrm{ECW_{i-l}}$

$\mathrm{TWQ_u} = \sum_i \mathrm{SCW_{i-u}} + \sum_i \mathrm{ECW_{i-u}}$

The operating capacity (OC) for the recycling facilities is a function of the total waste quantity from Equation 12, years to process all the emergency waste (Y) and number of facilities as shown in Equation 13. The facility capacity is assumed to be greater than the amount of incoming waste to be recycled. As mentioned in Table 2, the OC found in the literature range from 100,000 T/year to 364,000 T/year depending on the plant size and the designed operation life to process the waste.

$$\mathrm{OC} = \frac{\mathrm{TWQ}}{\mathrm{Y \times NRF}} \tag{13}$$

OC=Operating capacity (Ton/year/RF)

NRF=Number of recycling facilities

Y= years needed to process all the emergency concrete waste quantity

The revenue parameters are the price of recycled products (RC_p) and the recycling gate fee (GF_r), whereby the price of recycled products must exceed the difference between the cost of recycling the CDW (R_c) and the recycling gate fee in order for it to be a viable strategy. The cost of recycling, R_c, includes both the capital and operational costs. The capital and operational costs depend on the technology used in terms of size and type. Stationary recycled facilities are selected and therefore the cost of land is included in the capital cost. This condition is shown in Equation 14. Another condition that affects the ability to sell recycled product is that the price of recycled product must be less than or equal to the price of NA as shown in Equation 15 (Srour, Chehab, El-Fadel, & Tamraz, 2013). This condition is important since international construction specifications limit the extent of replacing recycled products with natural aggregate, therefore settings a competitive price will ensure a steady demand for the recycled materials.

$$\mathrm{RC_p} \geq \mathrm{R_c} - \mathrm{GF_r} \tag{14}$$

RC_p= Price of recycled product ($/T)

R_c = Recycling Cost ($/T)

GF_r =Recycling gate fee ($/T)

$$RC_p \leq \alpha \mathrm{NA_p} \tag{15}$$

NA_p = Price of natural aggregate

α=multiplier varying between 0 and 1

The economic assessment is done using a cost-benefit analysis across various waste management strategies. The net present value for investing in a recycling facility is calculated under different scenarios. The Equation to quantify the positive and negative cash flows is presented below and is obtained from earlier work by the research team (Srour, Chehab, El-Fadel, & Tamraz, 2013).

$$\mathrm{NPV} = \left(\mathrm{PV}_{\mathrm{gate}} + \mathrm{PV}_{\mathrm{sell}} + \mathrm{PV}_{\mathrm{env}}\right) - \left(\mathrm{PV}_{\mathrm{cap}} + \mathrm{PV}_{\mathrm{op}} + \mathrm{PV}_{\mathrm{land}}\right) \quad (16)$$

PV_{gate} = present value of gate fee

PV_{sell} = present value of price of recycled product

PV_{env} = present value of environmental savings

PV_{cap} = present value of capital cost

PV_{op} = present value of operation cost

PV_{land} = present value of land cost

Conducting the NPV shows when the recycling facility will break even, which depends on the revenue parameters previously mentioned.

CHAPTER III

THE CASE OF SYRIA

This section applies the proposed framework to the case of Syria which has large quantities of CDW generated as a result of the ongoing war as well as the steady-state (non-war) conditions. The goal of applying the proposed framework is to locate suitable sites for the construction of recycling facilities in Syria and conducting an economic assessment based on national figures and statistics. After assessing the spatial locations of major states also known as governorates in Syria, damaged buildings due to war destruction, the proposed framework is applied on eight spatial zones in Syria rather than on a national level, by either grouping several governorates together or keeping a governorate as a zone itself. As such, each zone is allocated a recycling facility with an operating capacity depending on the respective estimated quantities of CDW. Figure 9 shows the division of Syria into zones according to governorates, the dots represent the damaged buildings as a result of the war (available data up until 2015).

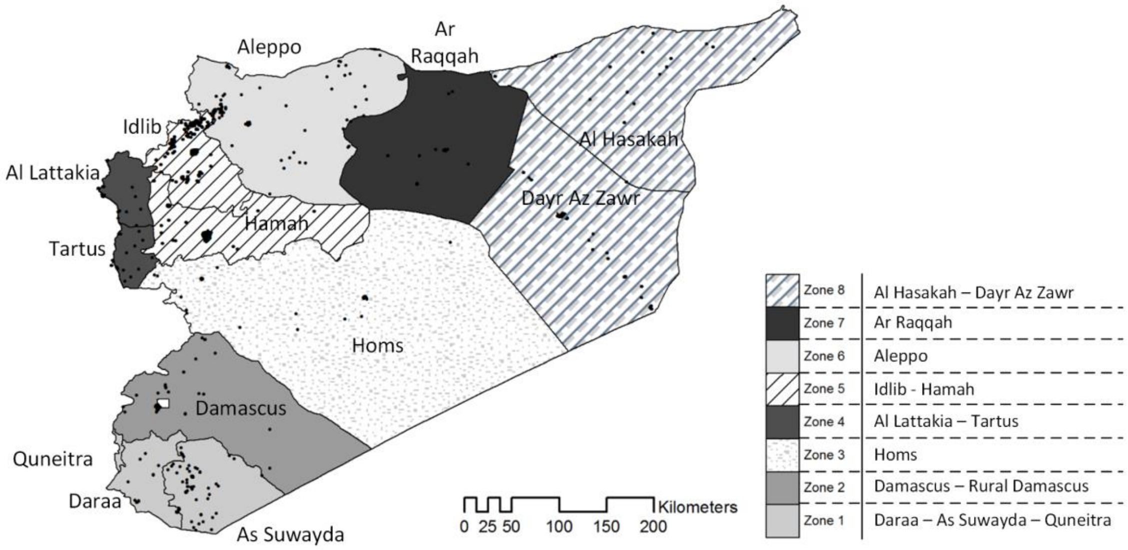

Figure 9 Division of Syria into zones

A. Estimating the Quantities of CDW

In order to estimate the quantities of CDW resulting from emergency and non-emergency demolition in Syria, two sources of information are used. The quantities of non-emergency waste are based on national construction figures which are surveyed annually and presented on an online platform of the Central Bureau of Statistics by the Office of Prime Minister. For the case of emergency waste, damage assessment data of the majorly destructed Syrian cities were obtained from the HDX website for humanitarian relief efforts. Satellite images along with maps and news reports indicate that 1.2 million houses, or one third of all houses in Syria, have been damaged or destroyed by December 2013, generating millions of tons of rubble (Zwijnenburg & te Pas, 2015). Given that the ultimate goal of this study is to propose a strategy for recycling CDW, quantities of non-emergency waste are referred to as “steady state supply” whereas quantities of emergency waste are referred to as “emergency supply”. These supplies will be served by a set of recycling facilities located in each of the major zones or governorates in Syria.

1. *Steady state supply*

The total floor area in Syria is obtained from data covering the years 2004 to 2010, i.e. before the war began (Statistical Indicators and National Accounts Statistics). The statistics showed that in 2007, there was a general increase in construction as confirmed by the experts. The experts interviewed as part of this study are Mr. Omar Abdelaziz Hallaj and Eng. Philip Chite (Hallaj, 2016) (Eng. Chite, 2016). Mr. Hallaj is an architect and development consultant with over 20 years of experience and was part of a consortium for urban development and urban heritage planning in Aleppo. Engineer Chite is a consultant with over 25 years of experience who was a member of the Syrian order of Engineers and the Syrian Enterprise and Business Centre (SEBC). The experts explained that in year 2007 a new lenient governor was appointed and he allowed flexibility in building permitting especially in Rural Damascus. This phenomenon occurred in parallel with a high migration of young adults to Rural Damascus since it is considered the outskirt of the city. Hence, the average yearly floor area was obtained by dividing the sum of total floor areas in those six years, over six years. Table 12 shows the total floor area for each zone i over the considered years and the average TFA_{ij}. The presented total floor area includes both residential and non-residential buildings in the following Governorates: Daraa, Al-Sweida and Quneitra as Zone 1, Damascus and Rural Damascus as Zone 2, Homs as Zone 3, Tartous and Al Lattakia as Zone 4, Idlib and

Hamah as Zone 5, Aleppo as Zone 6, Ar Raqqah as Zone 7 and Deir Ez Zor and Al Hasakah as Zone 8.

Table 12 Average total floor areas TFA_i ($1000m^2$) (Statistical Indicators and National Accounts Statistics)

Year j	2010	2009	2008	2007	2006	2004	Total	Av.TFA_i
ZONE 1	2,343	1,531	1,591	3,488	860	810	10,624	1,771
ZONE 2	1,520	3,489	4,358	14,928	3,128	2,387	29,808	4,968
ZONE 3	1,665	977	976	3,004	1,231	519	8,371	1,395
ZONE 4	1,954	2,355	3,527	6,395	2,223	1,104	17,557	2,926
ZONE 5	1,572	1,681	1,884	6,588	1,633	1,565	14,923	2,487
ZONE 6	3,643	1,728	983	4,023	1,074	934	12,384	2,064
ZONE 7	1,969	547	266	1,084	647	289	4,802	800
ZONE 8	1,276	572	468	2,687	960	359	6,322	1,054

The highest average total floor area corresponds to Zone 2, while the lowest corresponds to Zone 7. This variability across zones will result in different required capacities for the recycling facilities, as discussed in Chapter III, Section C-3. The next step is to calculate the built-up area. To quantify the total volume of concrete built over the considered years, the missing parameter is the number of floors built. To estimate this parameter, an expert in the field of planning and construction in Syria was consulted. Mr. Sinan Hassan, who is an architect with over 20 years of experience, has founded and led the architectural department at the International University of Science and Technology in Syria (2005-2010) (Hassan, 2016).The average numbers of floors used in the calculation are shown in Table 13.

Table 13 Average number of floors (n_i) taken from survey

Governorate i	n_i used
Damascus	6
Rural Damascus	5
Aleppo	4
Homs	3
Hama	4
Lattakia	5
Deir-ez-Zor	4
Idleb	4
Al-Hasakeh	4
Al-Rakka	4
Al-Sweida	3
Dar'a	4
Tartous	4
Quneitra	4

The average built-up area is computed by multiplying the values of average floor area per zone by the average number of floors, shown in Table 14. The average value is used in the concrete waste production calculation.

Table 14 Average Built-up area by zone (1000m²)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8
Av.TBA_{ij}	7,083	24,840	4,186	11,705	9,949	8,256	3,201	4,215

The third step is to calculate the total demolished building area (TDA) for each governorate. For this case study, no official formal statistics for the number of demolition permits was found. The interviewed experts explained that for a period of about 20 years, the government had put a moratorium on such permits to save on subsidizing construction materials. The situation eventually changed and a slow stream of demolition permits was officially allowed. In order to reach a comparative figure for the TDA, a study done in the nearby city of Beirut, Lebanon, over the two years of 2009 and 2010 previously mentioned in the literature review is referred to. This study estimated the quantity of concrete waste over the two years to be 527,800 tons (Srour, Chehab, El-Fadel, & Tamraz, 2013). Moreover, referring to statistics provided by the Order of Engineers and Architects (OEA), the average of permitted built-up area in the Greater Beirut Area (GBA) over 2009-2010 is 1,484,308 m^2. The next step is to estimate the amount of demolition in the whole of Lebanon - it is assumed that the quantity of demolition in GBA is half that of Lebanon. Although the stated assumption involves a certain level of inaccuracy, it is considered a good scale up due to the highly dense urban structure in the capital, whereby the availability of empty lots is nearly zero and most new construction projects require the demolition of an existing structure. In the other cities of Lebanon, which are less densely populated and more spacious, there are plentiful of unconstructed lands relatively. Hence, the amount of demolition waste generated every year in Lebanon is considered as 527,800 T. As such, we can calculate the quantity of demolition (TDQ) in Tons by assuming a linear relationship with a factor of five[10], between the TBA of Syria to the TBA of Lebanon. Hence, the quantity of demolition resultant per year is obtained as;

$$\mathrm{TDQ}_{\mathrm{Syria}} = \mathrm{TDQ}_{\mathrm{Lebanon}} \times \frac{\overline{\mathrm{TBA}}_{\mathrm{Syria}}}{\overline{\mathrm{TBA}}_{\mathrm{Lebanon}}} = 527{,}800 \times \frac{73{,}433{,}958}{15{,}993{,}156} = 2{,}424{,}439\ \mathrm{T}$$

Now that the total demolition quantity in Syria is known, the TDQ in each zone i can be calculated as a percent based on its total built-up area. The sum of TBA for all zones (as shown in Table 14) is 73,433,958 m^2, then the percent of TBA in each zone is multiplied by the total demolition quantity in Syria. Table 15 summarizes the total demolition quantity as part of the steady state supply. These values will be used instead

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[10] Assuming a linear relationship between the TBA and TDQ; TBA of Lebanon in 2009 is 15,993,156, which is 4.6 times the TBA of Syria (73,433,958). We consider a factor integer of five.

of the terms derived in Equations 3 and 4 ($\sum_j \mathrm{TDA_{ij}} \times \mathrm{CPR}_d$) due to the previously mentioned reasons. Hence, the adjusted equations for the case of Syria for the steady state supply become:

$$\mathrm{SCW}_{i-l} = \sum_j \overline{\mathrm{TBA_{ij}}} \times \mathrm{CPR}_{nc-l} + \mathrm{TDQ}_i \qquad (4')$$

$$\mathrm{SCW}_{i-u} = \sum_j \overline{\mathrm{TBA_{ij}}} \times \mathrm{CPR}_{nc-u} + \mathrm{TDQ}_i \qquad (5')$$

Table 15 Total demolition quantity part of steady state supply

ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8
6%	16%	13%	11%	4%	6%
13,810,035	386,300,276	32,830,018	272,500,469	10,560,046	139,100,093

	ZONE 1	ZONE 2
% TBA	10%	34%
TDQi (T)	23,370,036	819,800,767

The remaining unknown parameter is the concrete production rate for new construction in Syria. Similar to the case of demolition permits in Syria, there has been no effort to evaluate the CPR in Syria. Therefore, due to the lack of data, we will resort to values adopted in the literature. A report titled “Construction and Demolition Waste Indicators” mentioned under the ‘database and literature’ method in Table 1 is referred to. According to this report, the concrete production rate from new construction ranges from 17.8 to 40.1 kg.m^{-2} (Mália, de Brito, Duarte Pinheiro, & Bravo, 2013). This range is adopted in our SCW calculations.

Using the Equations 4’ and 5’, the total steady state concrete waste production is calculated and summarized in Table 16. To illustrate the values obtained for the steady state concrete production, Equations 4’ and 5’ will be applied on Zone 2.

$\mathrm{SCW}_{2\text{-l}} = \sum_5 \overline{\mathrm{TBA}_{2\;5}} \times \mathrm{CPR}_{nc-l} + \mathrm{TDQ}_2$

$= (24{,}840 \times 1000)\ \mathrm{m}^2 \times 0.0178\ \mathrm{T.m}^{-2} + 819{,}767\ \mathrm{T} = 442{,}156 + 819{,}767 = 1{,}261{,}923\ \mathrm{T}$

$\mathrm{SCW}_{2\text{-u}} = \sum_5 \overline{\mathrm{TBA}_{2\;5}} \times \mathrm{CPR}_{nc-u} + \mathrm{TDQ}_2$

$= (24{,}840 \times 1000)\ \mathrm{m}^2 \times 0.0401\ \mathrm{T.m}^{-2} + 819{,}767\ \mathrm{T} = 996{,}092 + 819{,}767 = 1{,}815{,}859\ \mathrm{T}$

Following the calculations above, the average concrete waste from new construction is equal to $\frac{(442{,}156 + 996{,}092)}{2} = 719{,}124$ T per year. The ratio of concrete waste quantities from demolition activities to new construction activities = 819,767 / 719,124 = 1.14 indicating a nearly equal contribution from each source.

Table 16 Total Steady State Concrete Waste Quantity (T)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8
SCW_{i-l} (T)	359,805	1,261,923	212,641	594,621	505,402	419,429	162,627	214,116
SCW_{i-u} (T)	517,746	1,815,859	305,983	855,637	727,254	603,543	234,015	308,105

The annual steady state concrete waste production ranges from 3.73 MT to 5.37 MT[11].

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[11] From Table 16: Sum of SCW_{i-l} in all zones = 3.73 MT and sum of SCW_{i-u} in all zones =5.37 MT.

2. Emergency supply

The summary of the data obtained from the HDX website is presented in Table 17.

Table 17 Summary of the number of affected buildings and the damage extent

Damage Extent	**NAB**
Destroyed	9,245
Impact Crater	1,104
Damaged	35,834
Total	46,183

It is assumed that 100% of the affected buildings are demolished and are to be transported to a proposed RF. As for the CPR for demolition, the same report (Mália, de Brito, Duarte Pinheiro, & Bravo, 2013) is used to depict the range which varies between 401 $kg.m^{-2}$ and 840 $kg.m^{-2}$. Analyzing the CPR of new construction and demolition, we consider the average of each indicator. As such, $Av(CPR_{nc})= 28.95\ kg.m^{-2}$ and $Av(CPR_d)= 620.5\ kg.m^{-2}$[12]. If we consider one square meter of mixed concrete, then the

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[12] The $CPR_{nc} = [17.8 – 40.1]\ kg.m^{-2}$. The average value $Av(CPR_{nc})=28.95\ kg.m^{-2}$

percent due to new construction is 4.5% while the percent due to demolition is 95.5%. These figures are comparable to the percentages derived for Beirut of 2 and 98% respectively and are in-line with literature. A report on construction and building materials titled “Recycled aggregate from C&D waste & its use in concrete” published in 2014 addresses the fast rate of modernization and industrialization which led to the generation of large amounts of debris from CDW. The report concludes that the major volume of these wastes emerges from demolition of old construction work. New construction works generate waste to a smaller volume, primarily attributed to the left over concrete of batch plants and tested samples in compliance to laboratory applications (Behera, Bhattacharyya, Minocha, Deoliya, & Maiti, 2014). Table 18 uses the results of the survey and expert consultation for the average floor area and number of floors, coupled with the derived Equations 7 and 8 to calculate the range in tons of concrete

The CPR_d = [401 – 840] $kg.m^{-2}$. The average value $Av(CPR_d)$=620.5 $kg.m^{-2}$

waste as a result of war demolition. The total war concrete waste amount ranges from 16.8 MT to 35.19 MT.

Table 18 Total emergency concrete waste amount in Tons

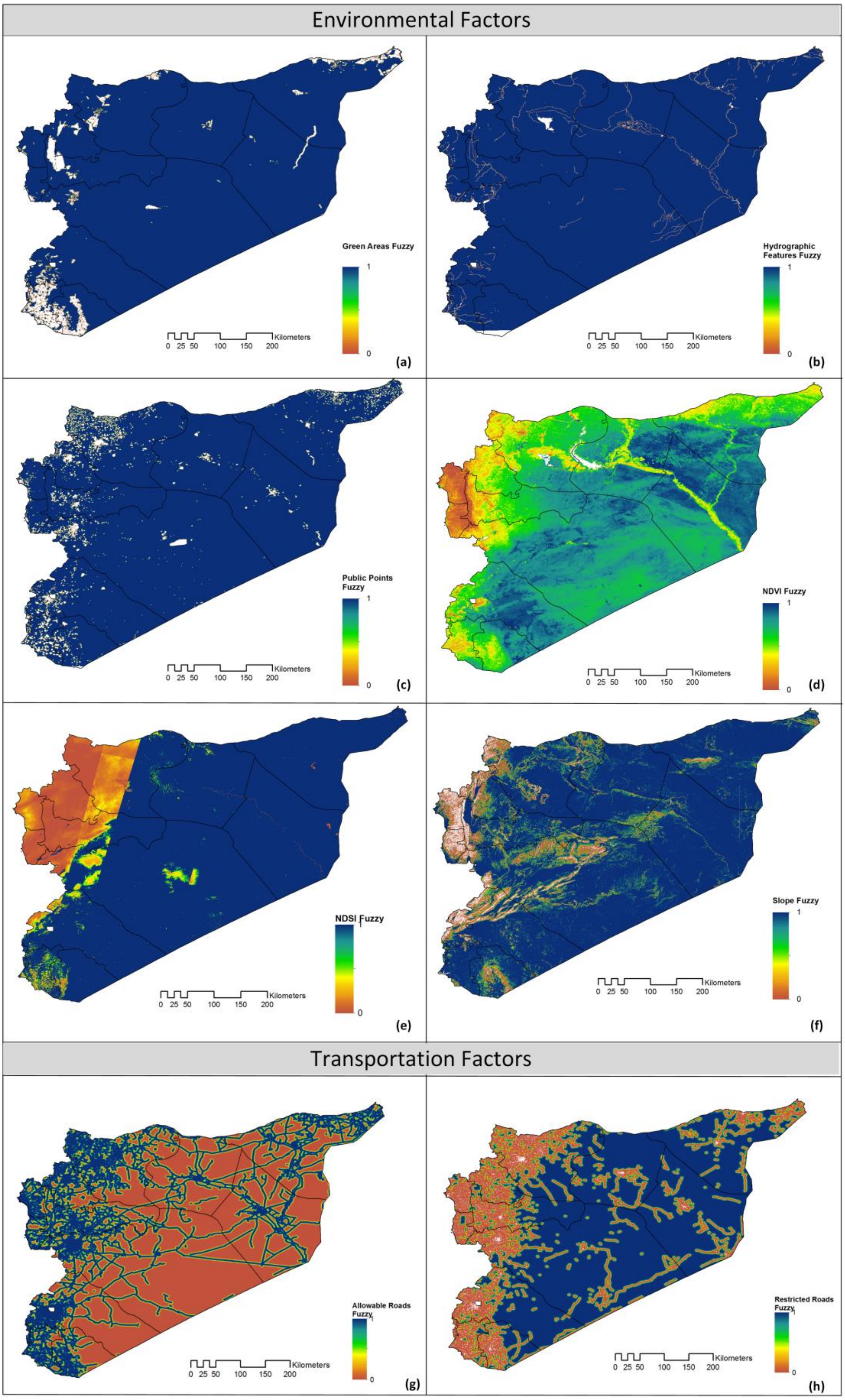
	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8
NAB	1086	264	14862	54	6040	18608	1725	3544
BUA (m^2)	940	1,568	840	1565	1019	1055	400	400
ECW_{i-l}	409,357	165,969	5,006,116	33,890	2,468,059	7,870,512	276,690	568,458
ECW_{i-u}	857,506	347,665	10,486,627	70,992	5,169,998	16,486,857	579,600	1,190,784

The next section presents the software application portion of this study. After quantifying the amount of CDW present in Syria due to war and annually produced, it is critical to strategize a management plan of clearing and recycling the large amount of concrete rubble. The next section applies the GIS methodology on a national level, whereby the resulting suitability maps cover all zones. The final objective is to locate a recycling facility in each zone according to the most suitable land.

B. Site Suitability- GIS implementation

1. Factor Fuzzyfication

The data for the slope, NDVI, NDSI, water bodies, urban points, green areas and road network is input into ArcMap. The factors are projected to WGS_1984_UTM_Zone_36N coordinate system (ArcGIS 10.1 Projected Coordinate System Tables, 2012). Each factor is standardized using its corresponding fuzzy membership function and presented in Figure 10. All white points present within the Syrian boundaries correspond to NODATA points, originally from the input polygon files of the factors. This ensures that all the polygons referring to green areas (Figure 10a) for example are eliminated from the suitability analysis. Similarly, the public points fuzzy map (Figure 10c) excludes all residential houses, industrial buildings, places of worship, restaurants, parking lots, schools, universities, pharmacies, hotels, hospitals, supermarkets, banks, police stations and governmental institutions.



igure 10 Factor Fuzzyfication for each factor

Looking into the environmental factors from Figure 10, it is apparent that for the three factors of green areas (Figure 10a), hydrographic features (Figure 10b) and public points (Figure 10c), the majority of the land is considered as highly suitable for RF siting. While the NDVI factor (Figure 10d) shows the largest range of fuzzy values, where the east and center lands are highly suitable (barren land) and the west lands are of low suitability. The NDSI (Figure 10e) and the slope factors (Figure 10f) relay similar results showing the east as highly suitable where the land is flat and not exposed to snow while the west has a low suitability knowing that that land is predominantly hills and mountain ranges which experience snow during the winter. As for the transportation factors, the resultant fuzzy maps are nearly complementary as expected. The range of suitability corresponding to the road network is somewhat strict; land is highly suitable if it relates to an allowable road (Figure 10g) otherwise it is of low suitability. Similarly in logic, land is highly suitable if it does not relate to a restricted road (Figure 10h). It is important to note that superimposing the war damage points and the allowable road map showed that most of the destruction is either on a primary or secondary road or falls within 2 km of their border. Hence the allowable road fuzzy map gives an incentive for RF sites to be closer to a road and sources of DW and limits map to areas near the main supply of DW. Analyzing the factors individually sheds light on the site selection process but is not sufficient for the final decision which is based on overlay and integration methods

2. *Factor overlay*

The next step is to integrate the factors using the three overlay methods: AND, OR, and Equal Weight. The results are maps where the factors are all integrated by applying a means similar to the intersection property, the union property and equal weights given to each factor respectively. A sensitivity analysis is conducted on the spread to analyze to effect of the spread on the land suitability. Land suitability is presented as low, moderate, strong, very strong and extremely strong according to the classification of Table 9. From the suitability maps in Figure 11, it is clear that the AND overlay type is the most conservative allocating the least areas with ‘extremely high suitability’ shown in red (Figure 11 a, b). The OR overlay type is the most lenient overlay type with most of the land falling in the most suitable category (Figure 11 e, f). The equal-weight scenario (Figure 11 c, d) presents a trade-off between the AND and OR overlay types. For the purpose of this study, the equal weight overlay method is selected since it gave moderate results. This is applied for the objective integration which is explained in the next section.

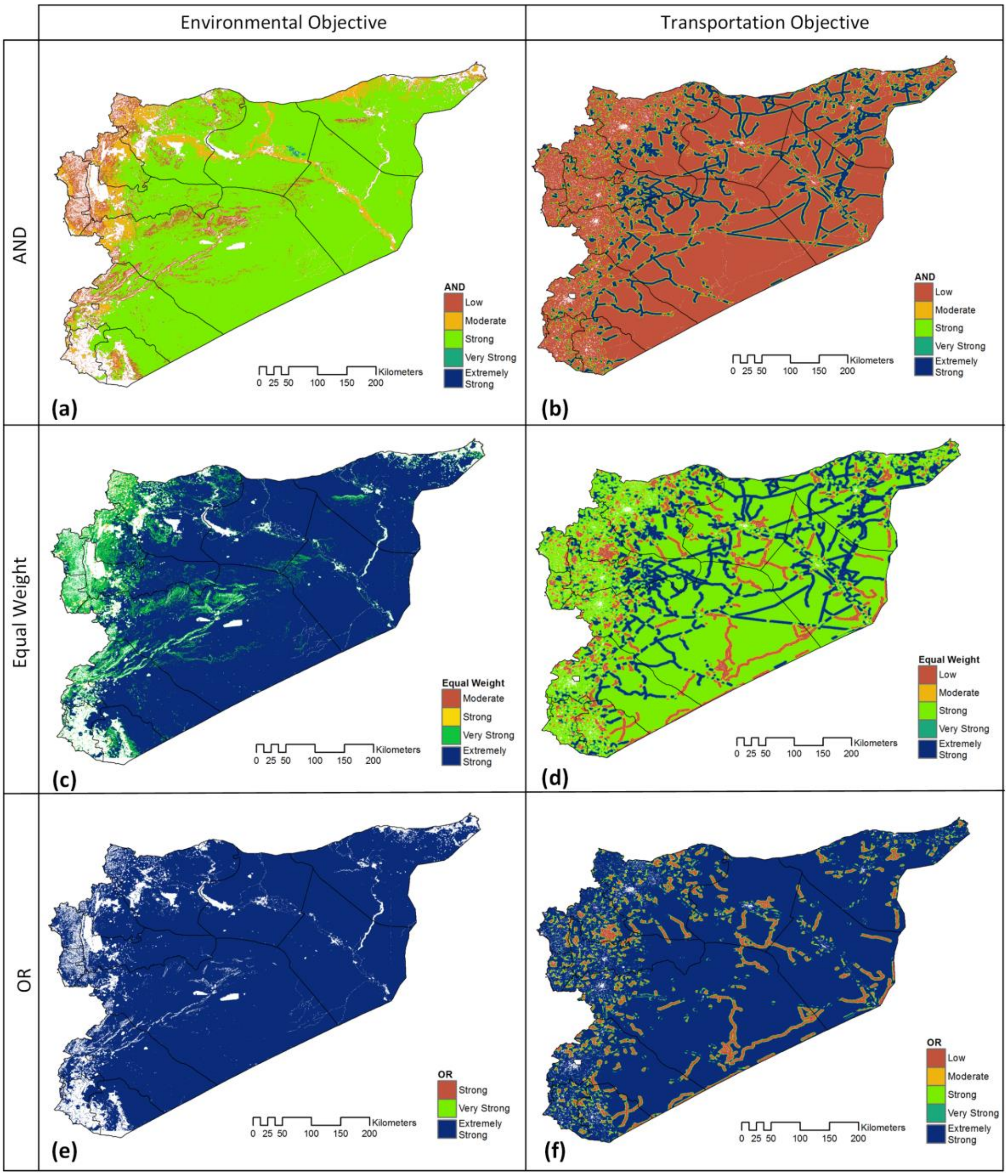


Figure 11 Weighted overlay suitability maps for each objective

3. *Objective integration*

Possible suitability maps are derived by integrating both objectives from the equal weight overlay method (Figure 11c and d). Using different weights for the environmental and transportation objectives according to Table 10, the overall suitability maps are presented in Figure 12. The results are also presented in pie chart format in Figure 13, which shows the percent of land in each suitability class for the three scenarios. The next step is to look at each of the zones to locate its RF in an extremely strong suitable land.

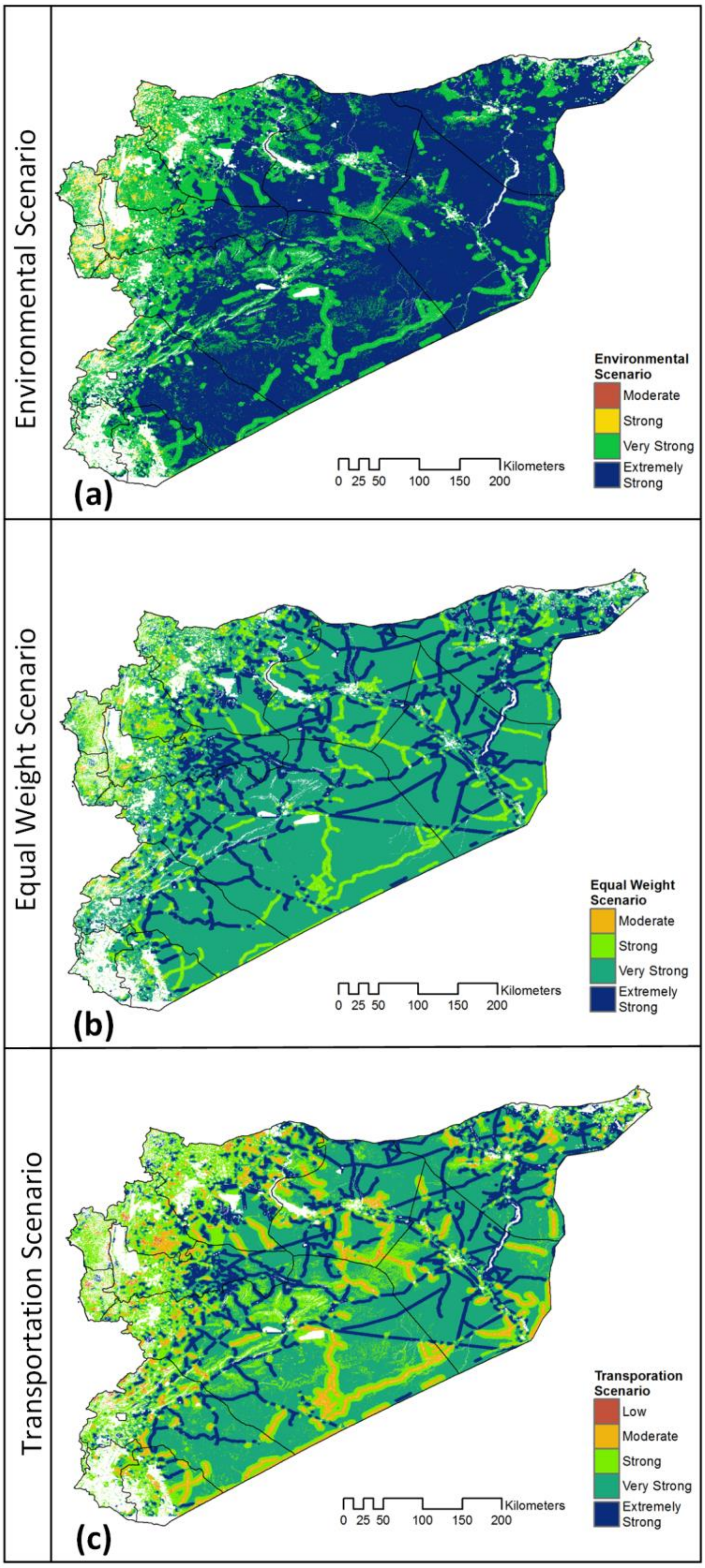


Figure 12 Overall suitability maps for different scenario

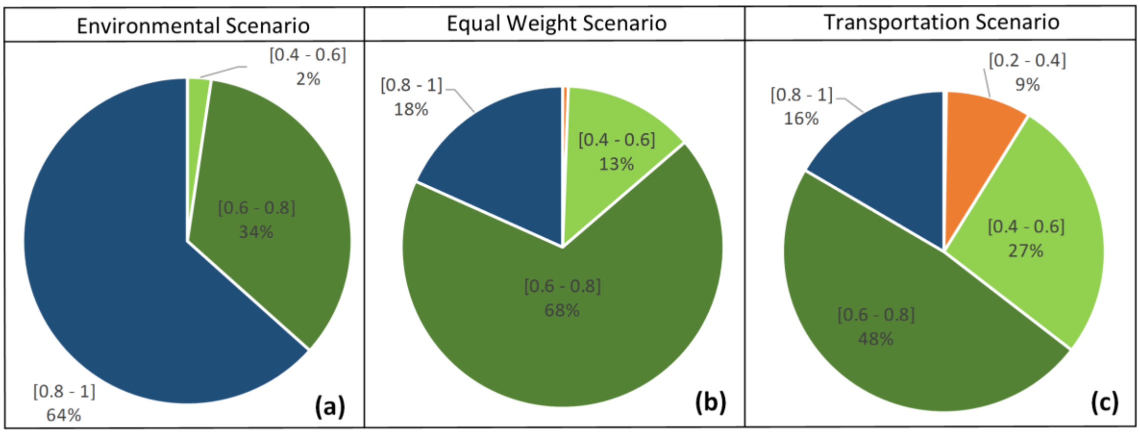


Figure 13 The three scenarios of overall suitability maps and their resultant class division

From the suitability maps above and Figure 13, it is concluded that for the equal weight overlay method, the transportation scenario is the most conservative allocating the least areas (16%) with 'extremely high suitability' (Figure 13c). The environmental scenario is the most lenient with 64% of the land falling in the most suitable category (Figure 13a). The equal-weight scenario presents a trade-off with skewed results towards the transportation objective, 18% of land corresponds to very high suitability (Figure 13 b). The results are consistent with the individual fuzzy factor maps, where the environmental factors corresponded to highly suitable land predominantly, and the transportation factors showed a strict distinction between high suitability and low suitability lands. Assigning a higher weight in the objective integration, in this case 75%, to either objective will skew the results in its favor. Hence, the transportation scenario, which is led by the road network, will present a lower percentage of land with high suitability as compared to the environmental scenario.

4. Sensitivity analysis

Focusing on the very strong suitable lands, and fixing the midpoint parameter of the factors according to Table 11, the following conclusions can be made from the graphs of Figures 14 and 15 of the sensitivity analysis.

- Generally, the percent of 'very strongly suitable' land increases as the spread increases
- It is concluded that the OR overlay type is the most flexible and the AND overlay type is the most conservative. The Equal-weight overlay type presents the moderate case which may reflect the most realistic case.
- There is a higher variability between the overlay methods of OR and Equal Weight for the transportation objective than the environmental objective

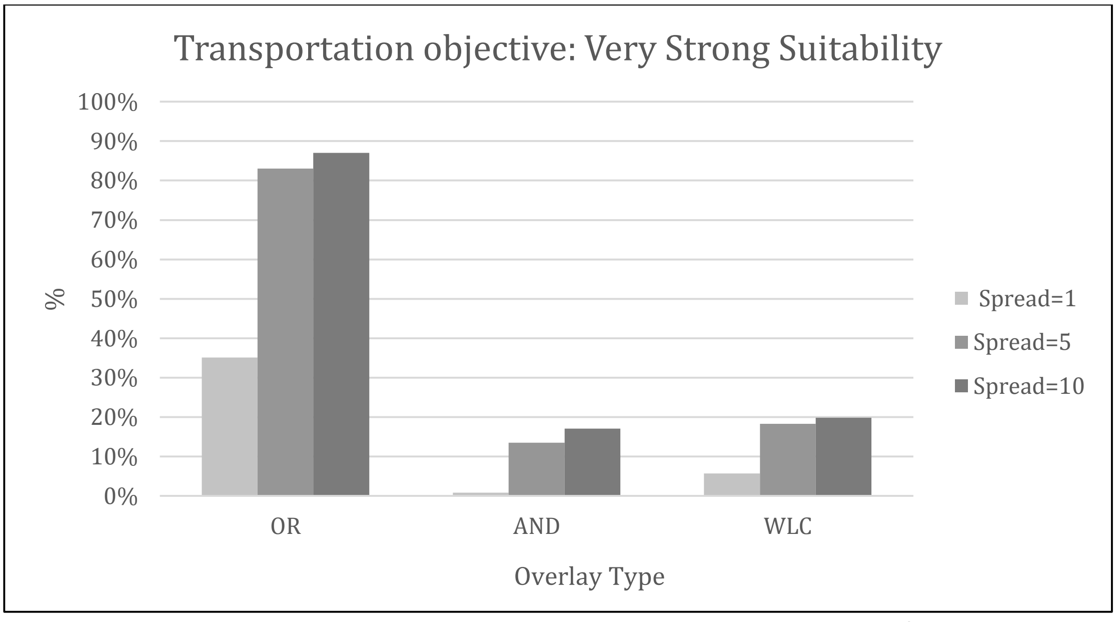


Figure 14 Sensitivity analysis on spread and percent land suitability for transportation objectives

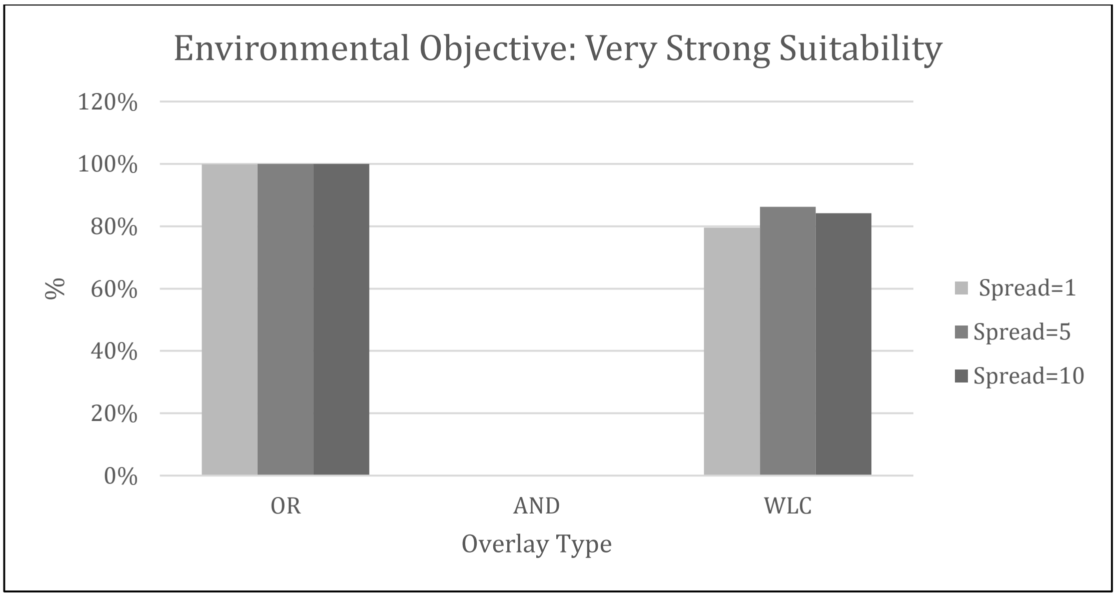


Figure 15 Sensitivity analysis on spread and percent land suitability for environmental objectives

C. Economic assessment

1. *Design parameters selected based on literature*

Looking into the literature and as mentioned earlier, a recent study conducted in Lebanon recommended the construction of a CDW recycling facility with an OC of 175T/hr to cover the waste generated from Beirut (Srour, Chehab, El-Fadel, & Tamraz, 2013). A facility of this size is considered as one operating module for the case of Syrian governorates. In other words, some of the Syrian governorates may require one module – in case the quantities of CDW are of comparable to Beirut; while others may require more than one module. The parameters used for this module are shown in Table 19.

Table 19 Design parameters for NPV analysis

Parameter	Unit	Value
Area	m^2	10,000
Operating Capacity	T/year	364,000
Operation period	years	25
Acceptance rate	%	90
ROR	%	12
Discount rate	%	7
Increase in operation cost	%	3

2. Unit Costs of Module

The adopted module includes the unit costs of the major capital costs such as equipment, construction, freight and commissioning costs. For the case of Syria, the values of unit costs of land cost, raw material and permit/fees (Table 28 in the appendix) are the average values between the years 1975-2010 of the following data:

- Industrial floor area (Accomplished Residential & Non-residential Buildings 1963, 1970-2008 in Private & Cooperative Sectors, 2009)
- Land cost for industrial buildings
- Non-residential fees (Expenditure on Accomplished Residential & Non-Residential Buildings 1975-2008, 2009)

The values for overhead and labor costs are obtained from the 'Construction and Reconstruction Price Analysis Guide' adopted in the Syrian Ministry of Housing and Construction (دليل تحليل الأسعار لأعمال البناء و التشييد, 2009). Refer to Figure 21 and Table 29 in the appendix showing the translation and conversion rate. The revenues are attained from the gate fee (GF) and price of recycled product (RC_P) as presented in Table 20 (Srour, Chehab, El-Fadel, & Tamraz, 2013). Table 21 summarized the unit costs used in the economic assessment.

Table 20 Values assessed for the revenue

α	RC_p ($/T)	GF ($/T)
0.18	0.9	0
0.27	1.4	1
0.36	1.8	1.5
0.45	2.3	2
0.55	2.8	2.5
0.64	3.2	3

Table 21 Capital and operational costs

Item	Unit	Unit Cost $	#	Cost $ / year
Capital Cost				
Equipment cost (crushers, screener, conveyor, and metal separator)	Unit	927,400	1	927,400
Other equipment (loader)	Unit	300,000	1	300,000
Construction cost	Unit	135,000	1	135,000

Freight costs	Unit	41,000	1	41,000
Engineer to commission the equipment	Unit	10,000	1	10,000
Land cost	$\$/m^2$	114.54	10,000	1,145,396
Permits/fees	$\$/m^2$	6.64	10,000	66,428
Miscellaneous	%	1%	2,625,225	26,252
Total capital cost USD				2,651,477
Operational Cost				
Equipment Maintenance (6% of equipment investment)	%	6%	1,362,400	81,744
Equipment Insurance (1% of equipment investment)	%	1%	1,362,400	13,624
Overhead + Labor Wages[13]				
Unskilled Worker	labor	4479	15	67,180
Skilled Worker	labor	6166	8	49,325
Manager	labor	7722	1	7,722
Loader Operator	labor	7722	1	7,722
Total Operation cost USD				227,315

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[13] For unit costs of labor refer to appendix

After setting the design parameters and unit costs, the operating capacity needed to process all the supply and the number of modules per RF is calculated as part of the economic analysis.

3. Operating Capacity of RFs

For the purpose of this study, it is assumed that the number of years needed to process all the emergency supply (Y) is 10 years, after which the RFs will be receiving only the annual steady state supply. It is worth mentioning that a Y of 10 years is effective from the start of the RF operating phase, and was selected after conducting a sensitivity analysis on the value of Y to assess its affect on the OC. In order to illustrate the methodology, a detailed outline for Zone 1 is explained next. As shown in Tables 15 and 17, the steady state supply in Zone 1 ranges from 359,806 to 517,746 T/year, whereas the emergency supply ranges from 409,357 to 857,506 T respectively. Considering the set parameter of Y=10 years, the estimated yearly emergency supply to be processed in the RF is the lower or upper value divided by 10. Considering both limits, the resultant operating capacities are computed for Zone 1.

$$\frac{\mathrm{ECW_l}}{\mathrm{Y}} = \frac{409{,}357}{10} = 40{,}936 \text{ T/year}$$

$$\frac{\mathrm{ECW_u}}{\mathrm{Y}} = \frac{857{,}506}{10} = 85{,}751 \text{ T/year}$$

Hence, the required operating capacity lower limit for $\mathrm{RF_{zone1}}$ = 40,936 + 359,806 = 400,741 T/year. Knowing that the operating capacity of one module is 364,000 T/year, the number of modules needed for Zone 1 is two. Considering the upper values, the required OC for Zone 1 is 85,751 + 517,746 = 603,497 T/year and the number of modules required are two. Table 22 shows the steady state supply and emergency supply in Zone 1, Figure 16 shows graphically the lower limit status of the RF upon initiation throughout a designed operation life of 25 years. A similar graph can be produced for the upper limit waste generated. It is noticed that for this zone, the OC is driven by the steady state supply.

Table 22 Steady state and emergency supply in Zone 1

LOWER VALUES					UPPER VALUES			
No. of Modules:				2	No. of Modules:	2		
Y (years to clear emergency supply): 10								
Year	SCW_l	ECW_u	Total	Design OC	SCW_l	ECW_u	Total	Design OC
1	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
2	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
3	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
4	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
5	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
6	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
7	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
8	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
9	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
10	438,776	63,343	502,119	502,119	517,746	85,751	603,497	603,497
11	438,776	0	438,776	502,119	517,746	0	517,746	603,497
12	438,776	0	438,776	502,119	517,746	0	517,746	603,497
13	438,776	0	438,776	502,119	517,746	0	517,746	603,497
14	438,776	0	438,776	502,119	517,746	0	517,746	603,497

15	438,776	0	438,776	502,119	517,746	0	517,746	603,497
16	438,776	0	438,776	502,119	517,746	0	517,746	603,497
17	438,776	0	438,776	502,119	517,746	0	517,746	603,497
18	438,776	0	438,776	502,119	517,746	0	517,746	603,497
19	438,776	0	438,776	502,119	517,746	0	517,746	603,497
20	438,776	0	438,776	502,119	517,746	0	517,746	603,497
21	438,776	0	438,776	502,119	517,746	0	517,746	603,497
22	438,776	0	438,776	502,119	517,746	0	517,746	603,497
23	438,776	0	438,776	502,119	517,746	0	517,746	603,497
24	438,776	0	438,776	502,119	517,746	0	517,746	603,497
25	438,776	0	438,776	502,119	517,746	0	517,746	603,497

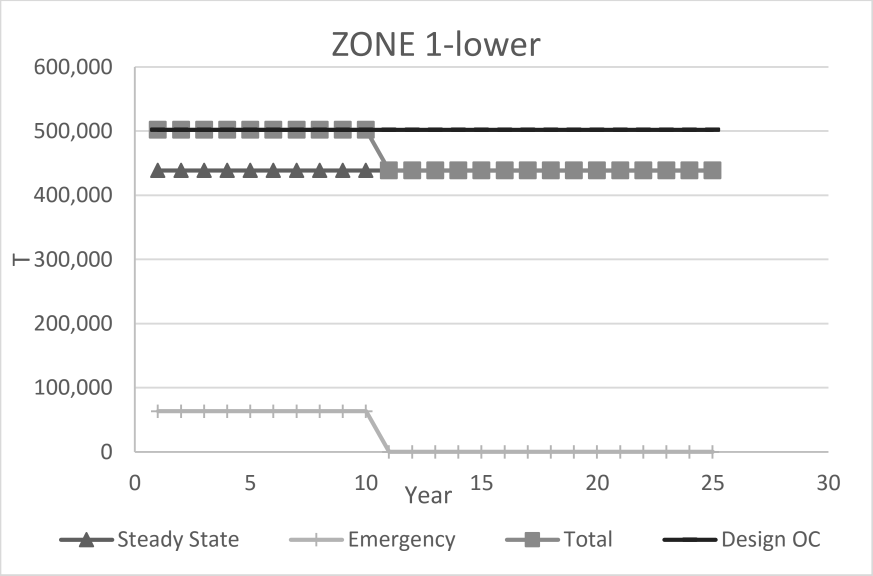

Figure 16 Graphical Interpretation of zone 1 RF lower limit status

Similarly the analysis is done on the other zones, the results area presented in Table 23, showing the operating capacity for each RF and their respective number of modules.

Table 23 Summary of RF operating capacity and number of modules

ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8
594,621	505,402	419,429	162,627	214,116
33,890	2,468,059	7,870,512	276,690	568,458
598,010	752,207	1,206,481	190,296	270,962
2	3	4	1	1
855,637	727,254	603,543	234,015	308,105
70,992	5,169,998	16,486,857	579,600	1,190,784
862,736	1,244,254	2,252,229	291,975	427,183
3	4	7	1	2

		ZONE 1	ZONE 2	ZONE 3
Lower	SCW (T/y)	359,805	1,261,923	212,641
	ECW (T)	409,357	165,969	5,006,116
	RF OC	400,741	1,278,520	713,253
	No. of Modules	2	4	2
Upper	SCW (T/y)	517,746	1,815,859	305,983
	ECW (T)	857,506	347,665	10,486,627
	RF OC	603,497	1,850,626	1,354,645
	No. of Modules	2	6	4

It is important to note that the governing supply differs for each zone. For the cases similar to Zone 6 where the ECW is significantly larger than the SCW, we can propose a way to address the overdesign in OC once the emergency quantity is all processed. To illustrate this, the strategy for zone 6 upper limit values will be outlined, since it demonstrates the largest OC. As shown in Table 24 and Figure 17, the number of needed modules up until year ten is seven, however after that year, the RF can remain operating on two modules only with a capacity of 728,000 T/year which is still higher than the total supply after that point. This will help in saving operating costs and indirect environmental damage.

Table 24 Steady state and emergency supply in Zone 6

ZONE 6 – Upper Values

No. of Modules:			7	
Y (years to clear emergency supply):			10	
Year	SCWu	ECWu	Total	Design OC
1	603,543	1,648,686	2,252,229	2,252,229
2	603,543	1,648,686	2,252,229	2,252,229
3	603,543	1,648,686	2,252,229	2,252,229
4	603,5432	1,648,686	2,252,229	2,252,229
5	603,543	1,648,686	2,252,229	2,252,229
6	603,543	1,648,686	2,252,229	2,252,229
7	603,543	1,648,686	2,252,229	2,252,229
8	603,543	1,648,686	2,252,229	2,252,229
9	603,543	1,648,686	2,252,229	2,252,229
10	603,543	1,648,686	2,252,229	2,252,229
No. of Modules: 2				
11	03,543	0	603,543	728,000
12	603,543	0	603,543	728,000
13	603,543	0	603,543	728,000
14	603,543	0	603,543	728,000
15	603,543	0	603,543	728,000
16	603,543	0	603,543	728,000
17	603,543	0	603,543	728,000
18	603,543	0	603,543	728,000
19	603,543	0	603,543	728,000
20	603,543	0	603,543	728,000

21	603,543	0	603,543	728,000
22	603,543	0	603,543	728,000
23	603,543	0	603,543	728,000
24	603,543	0	603,543	728,000
25	603,543	0	603,543	728,000

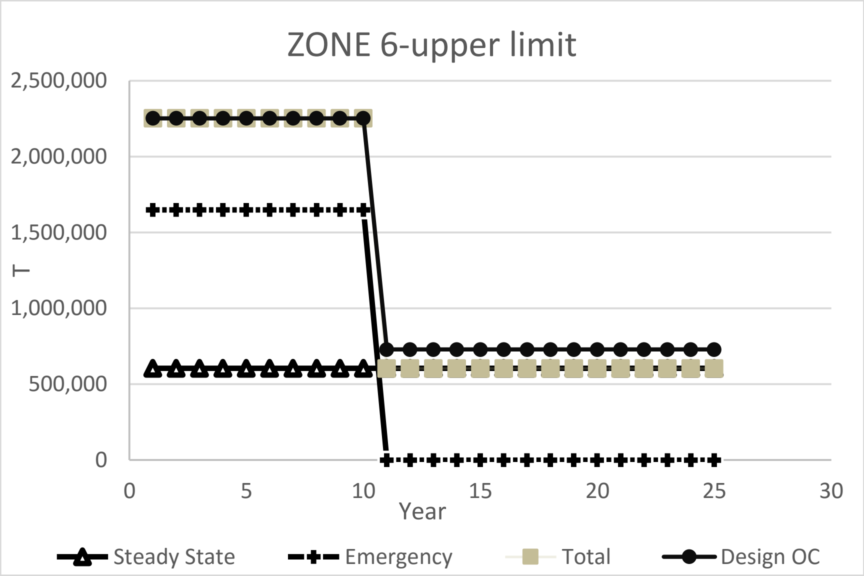

Figure 17 Graphical Interpretation of zone 6 RF status

An important factor which affects the environmental and transportation objectives is the distance which the CDW must be transported between the damage points to the RF in each zone. The next section elaborates on the fixed and variable transportation costs.

4. Transportation Costs

Transportation is a main driver of the economics cost, contributing to 13% of total cost (Hiete, 2013). Transportation costs are part of the dynamics that define the market for recycled material, but they most often do not directly affect the profitability of the recycling operation. The supplier of material from the “urban deposit” to the recycler is aware of transportation costs. The amount of material that the supplier will make available to the recycler is based on a calculation that compares delivering and paying a tipping fee to the recycler, to any competitor of the recycler, or to the landfill. Transportation distance and costs are very significant factors in determining the optimum location of a recycler when assessed alongside sources of material, competitors, and customers (Wilburn & Goonan, 1998). The fixed cost for demolishing and transporting concrete elements over 5 km is 11.64$/T. This value includes heavy machinery, equipment, tools, labor, trucks and 20% profit (دليل تحليل الأسعار لأعمال البناء و التشييد, 2009). The variable cost of transportation depends on the distance of hauling. For a truck transporting a 5 km distance which is the buffer distance set for roads in Chapter II, Section B-2-a-I, the total variable cost is 1.15$/T based on the distribution of several item costs (دليل تحليل الأسعار لأعمال البناء و التشييد, 2009) as per Table 25. An excerpt from the original document is found in the Appendix (Figures 22 and 23)

Table 25 Variable transportation unit cots

Item	Description	$/T
1	Excavator	0.42
2	Truck (5km)	0.54
Total		0.96
3	Profit 20%	0.19
Net total		1.15

The truck cost (item 2) varies according to the distance hauled as shown in Table 26. Clearly, the greater distance of transport the higher the variable cost incurred, with the difference to be added to the fixed cost. For example, transporting over a distance of 15 km (which is three times the assumed distance for this study), the variable cost increases by 0.63 $/T to get a total fixed cost of 12.28$/T.

Table 26 Variable truck haul unit cost per km distance

Cost $/T[14]	Distance (km)
0.54	5
0.89	10
1.07	15
1.49	20
1.91	30
2.35	40
2.77	50

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[14] The specified truck can fit 10-20 m^3 of concrete rubble

5. Net Present Value

In this section, the cost benefit analysis will be conducted on one module with its derived design parameters and unit costs. To quantify the revenues, six cases for the RCP are considered, along with six cases for the GF. The following graphs present the decision maker with the possible scenarios to select the appropriate gate fee and recycled product price depending on the financial and managerial constraints. It is worth mentioning that the NPV analysis does not consider the present value of environmental savings in this study. Figure 18 presents the different scenarios of setting the gate fee and recycled concrete price.

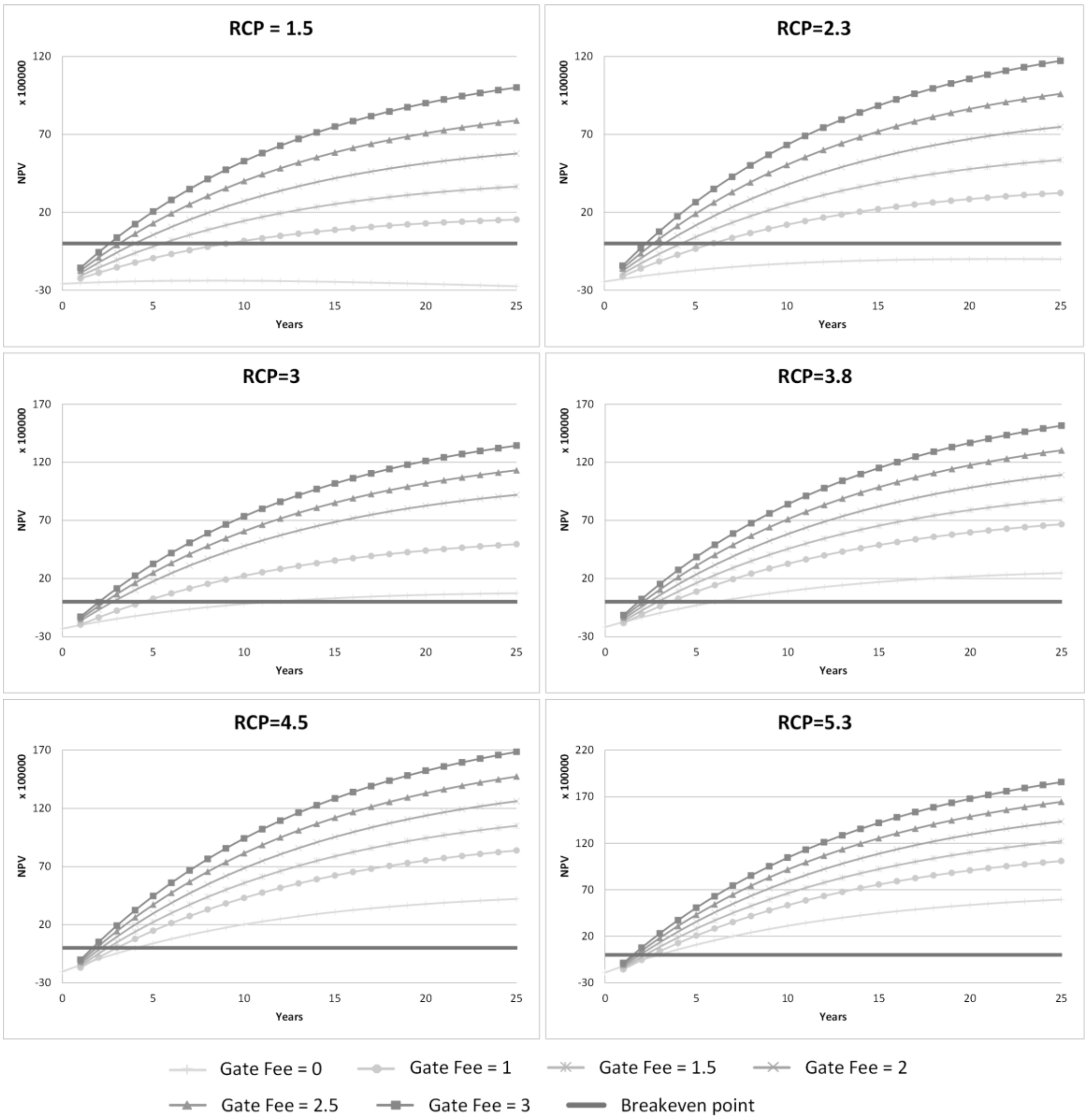


Figure 18 NPV with respect to RCP, GF and years for one module

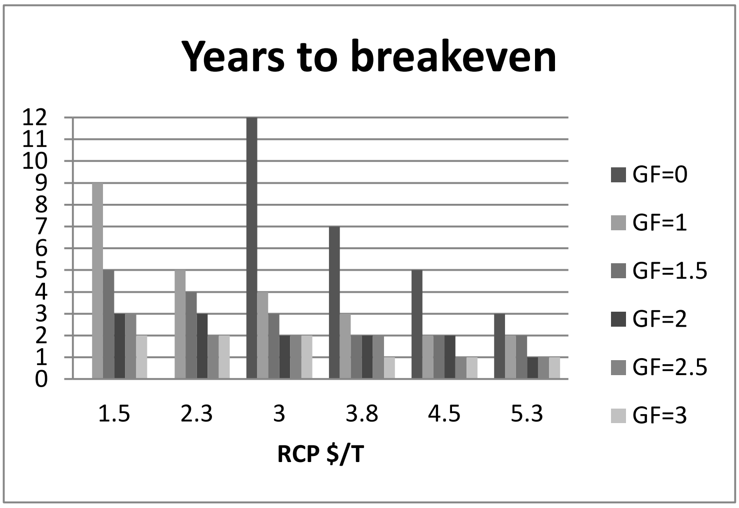
6. Years to breakeven

Table 27 and Figure 19 show the numbers of years to breakeven for one module in a facility as the values for the gate fee and price of recycled product vary. Considering the best scenario of GF=3 $/T and RCP=5.3 $/T, the breakeven point will be achieved at the first year. On the other hand, the worst case scenario breaks even at year 12 for a

GF=0 $/T and RCP=3 $/T. Figure 20 graphically shows the different combinations and the corresponding years to breakeven.

Table 27 Years to breakeven considering different RCP and GF for one module

	GATE FEE $/T					
RCP $/T	0	1	1.5	2	2.5	3
1.5	-	9	5	3	3	2
2.3	-	5	4	3	2	2
3	12	4	3	2	2	2
3.8	7	3	2	2	2	1
4.5	5	2	2	2	1	1
5.3	3	2	2	1	1	1



igure 19 Years to breakeven bar chart

From Figure 20 it is clear that the time to breakeven will decrease as either the RCP or the GF increases. Depending on the decision maker’s strategy, the appropriate revenue fees can be set.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The concurrent increasing urbanization and population growth rates have a high impact on the amount of waste from construction and demolition activities. Moreover, the ongoing wars and unforeseen natural disasters pose an environmental threat to natural habitats and ecosystems, as well as availabilities of landfill space. It is, thus, crucial to acknowledge the importance of recycling construction and demolition materials in an effort to minimize environmental damage and reduce costly and inefficient waste disposal strategies.

In the case of wars, any strategy must first safely address the likely l presence of UXO in the area. This can be achieved by integrating both explosive ordnance disposal organization as well as a rubble recovery contractor. It is recommended to adopt the following flow chart (Figure 20) for the process/cycle of screening the emergency DW after executing a UXO clearance strategy. If the building is totally destroyed or not salvageable, then the action is to demolish and transfer the volume to the facility proposed by the model. However, if the building is salvageable, then the logical decision is restore/refurbish it. The two main categories of resultant materials are cementitious (e.g., concrete, masonry units, tile) which is transferred to a recycling facility and steel which undergoes volume reduction and sent to export. Other materials such as glass, wood and aluminum can be collected and separated to be reused in refurbishments.

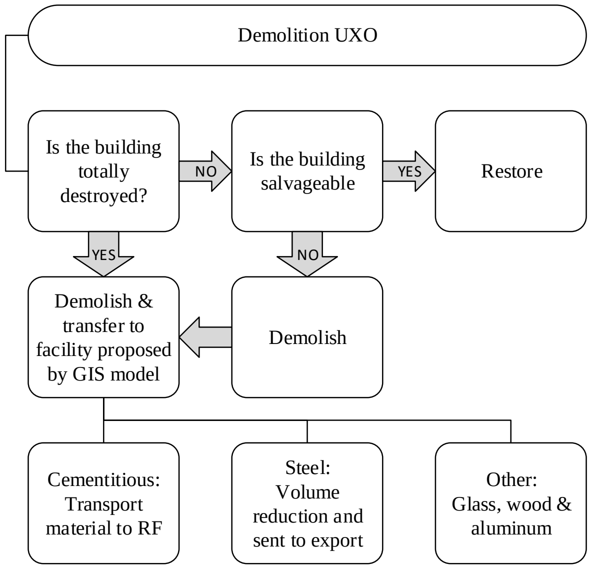


Figure 20 CDW Flow Chart

Quantifying the amount of rubble in order to understand the extent of the emergency is the second step after clearing the CDW from any safety hazard. This study develops the guidelines to quantify the amount of waste from different activities and can be applied to different scales. The distinction between CDW materials as a result of emergency and non-emergency construction and demolition activities is established and the means to quantify the concrete waste from each source is justifiably proposed. The proposed estimation method is sturdy in developed countries where waste indexes and construction logs are available and accurate. The methodology is particularly useful in less developed countries where governments are lacking the expertise and awareness in managing their waste.

The proposed GIS model introduces the necessary objectives and factors needed to optimize the recycling facility site selection process. The model is dynamic and can be expanded to include more parameters in the multi-criteria evaluation such as social and political factors with the help of experts. The outcome of the model is a spatial presentation of land according to a suitability scale and the objective in mind. Depending on the decision maker’s target objective, whether it is an economic, environmental or an equal-weight scenario, the highly suitable land for RF siting are presented in each zone or state. Some strategies for rubble clearance may focus on diverting the rubble from certain prioritized locations for example, from hospitals and governmental institutions at first. This can be achieved by assigning a higher weight to those input data whereby the overall objective integration will reflect the nearby suitable lands to receive the rubble. The GIS application is used to present the decision maker with the possibilities of action plans, depending on the regional priorities, budget and urgency. Uncertain design parameters such as the spread in the fuzzy set must be addressed with sensitivity analysis then taken into consideration.

The proposed methodology in this paper comes full circle by conducting an economic assessment. The siting of recycling facilities is developed to handle long-term incoming waste and to produce recycled materials to the market. Once the RF site is selected for a certain zone or state, it is followed by a cost-benefit analysis which highlights the capital and operational costs as well as revenues from the recyclable product. The methodology introduces the concept of a module which can be singularly operating or paired with more than one other module to account for the regional supply. This allows for a flexible operating capacity, whereby the RF operator may employ all its modules or limit the number of active modules. Conducting a NPV analysis proved to be financially profitable in the long run; after the breakeven point. Investors in post-disaster or war areas can benefit from recycling the bulky rubble and by that minimizing environmental damage.

The results of the case study applied to Syria present viable estimated CDW quantities as confirmed by the experts. Considering Syria’s current unstable conditions as well as the lack of proper waste generation documentation protocol, the estimated quantities can be assumed to be representative. The amount of concrete waste as a result of the ongoing war is around six times the amount of yearly steady state activities on a national level. Moreover, considering the large spatial land which Syria covers, whereby the emergency and steady state CDW is geographically spread out, the division of Syria into eight zones is necessary and practical. For instance, Zone 2 which represents Damascus and Rural Damascus showed that the steady state supply is six times the emergency supply, primarily due to its level of urbanization and high density. Whereas Zone 6 representing Aleppo, which despite being considered a World Heritage Site by the UNESCO in 2013, showed the emergency supply to be around 24 times the steady state supply. Furthermore, applying the GIS methodology showed that some factors are more important than others. The 22.85 million (2013) inhabitants of Syria are densely located in the urban cities and their outskirts, which leaves the larger portion of land uninhabited, deserted and barren land. In particular, considering the environmental objective, the land suitability was controlled by the vegetation index (NDVI) and the terrain slope. The remaining factors: green areas, hydrographic features, public points and NDSI, indicated little restriction to RF siting, and thus the corresponding scenario resulted in the highest percentage of suitable land (64%). In terms of the transportation objective, the road network majorly determined the land suitability considering both the allowable and restricted roads. Therefore, the corresponding scenario resulted in the lowest percentage of highly suitable land (16%). Furthermore to siting RFs in each of the eight zones, the operating capacity of each is determined by the respective estimated quantity of CDW. As mentioned, Zone 2 and 6 feature the highest variability in terms of steady state and emergency supply, nonetheless they correspond to the largest waste stream which require allocating five operating modules each to process all the emergency supply within 10 years. The remaining zones vary in the required number of modules from one to three. These results reveal the importance of considering Syria in terms of zones instead of a whole nation. Finally, the NPV analysis showed the financial profitability of constructing the proposed eight RFs. The worst case scenario under a gate fee of 0$/T and a recycled product price of 3$/T ensured a breakeven point at the twelfth year, which is less than half the RF designed operation life.

This study has several limitations, which could be addressed in future research. Firstly, the assumed concrete production rates reflecting the generated tons per square meter of built-up area for the steady state and emergency supplies applied to the case of Syria are taken from the literature. The estimation of CDW can be strengthened by conducting a large survey of the construction industry in Syria once the state of security is stable. Similarly, the total demolished building area is in reference to the surveyed quantities in Beirut, Lebanon. This is due to the lack of record keeping for demolition permits, and can be strengthened with a similar approach of collecting available demolition records and surveys. Other limitations are present in the software application, whereby the buffer distance applied to each factor was assumed and then used as the midpoint parameter in the fuzzy set analysis as part of the standardization process. As previously mentioned, in underdeveloped countries the necessary buffer distance from different features is not clearly known or enforced, however this can be set with the help of urban planning experts and engineers. Another limitation is the adopted unit prices for some of the capital cost items, particularly the equipment, loader, construction, freight and commissioning engineer cost. These values are taken from a study done in 2013 (Srour, Chehab, El-Fadel, & Tamraz, 2013).

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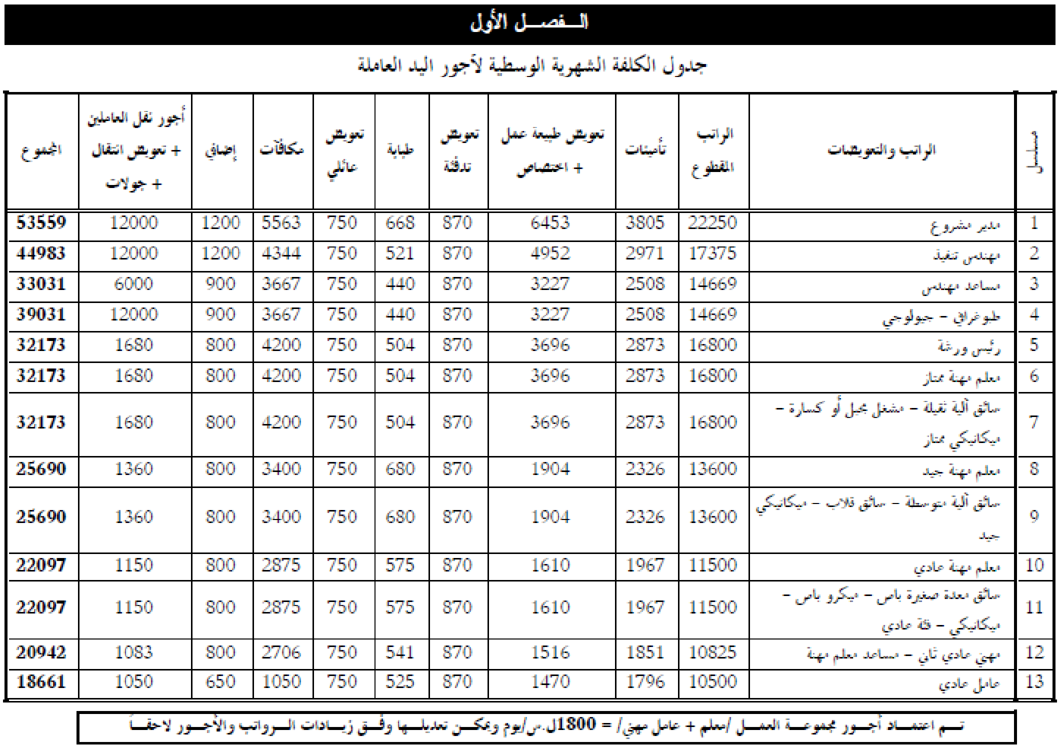
Appendix

Table 28 Average Land, fees and raw materials cost

Average industrial floor area [1975-2010] in m^2 =237,467			
	Land Cost	Fees	Raw Materials
Av. Cost $ [1975-2010]	27,199,333	1,577,455	41,623,695
Av. Cost $/m^2	114.54	6.64	175.28



الـفصـــل الأول

جدول الكلفة الشهرية الوسطية لأجور اليد العاملة

مسلسل	الراتب والتعويضات	الراتب المقطوع	تأمينات	تعويض طبيعة عمل + اختصاص	تعويض تدفئة	طبابة	تعويض عائلي	مكافآت	إضافي	أجور نقل العاملين + تعويض انتقال + جولات	المجموع
1	مدير مشروع	22250	3805	6453	870	668	750	5563	1200	12000	**53559**
2	مهندس تنفيذ	17375	2971	4952	870	521	750	4344	1200	12000	**44983**
3	مساعد مهندس	14669	2508	3227	870	440	750	3667	900	6000	**33031**
4	طبوغراف – جيولوجي	14669	2508	3227	870	440	750	3667	900	12000	**39031**
5	رئيس ورشة	16800	2873	3696	870	504	750	4200	800	1680	**32173**
6	معلم مهنة ممتاز	16800	2873	3696	870	504	750	4200	800	1680	**32173**
7	سائق آلية ثقيلة – مشغل مجبل أو كسارة – ميكانيكي ممتاز	16800	2873	3696	870	504	750	4200	800	1680	**32173**
8	معلم مهنة جيد	13600	2326	1904	870	680	750	3400	800	1360	**25690**
9	سائق آلية متوسطة – سائق قلاب – ميكانيكي جيد	13600	2326	1904	870	680	750	3400	800	1360	**25690**
10	معلم مهنة عادي	11500	1967	1610	870	575	750	2875	800	1150	**22097**
11	سائق معدة صغيرة باص – ميكرو باص – ميكانيكي – فئة عادي	11500	1967	1610	870	575	750	2875	800	1150	**22097**
12	مهني عادي ثاني – مساعد معلم مهنة	10825	1851	1516	870	541	750	2706	800	1083	**20942**
13	عامل عادي	10500	1796	1470	870	525	750	1050	650	1050	**18661**

تــم اعتمـــاد أجـــور مجموعـــة العمـــل /معلم + عامل مهني/ = **1800**ل.س/يوم ويمكـــن تعديلـــها وفـــق زيـــادات الـــرواتب والأجـــور لاحقـــا

Figure 21 Extract from the guide of monthly labor wages (**دليل تحليل الأسعار لأعمال البناء و التشـييد**, 2009)

Table 29 Annual unit overhead and labor fees

No.	label	Labor Position	Monthly Fees (Syrian	Annual Fees $

			Lira)[15]	
13	عامل عادي	Unskilled Worker	18,661	4479
8	معلم مهنه جيد	Skilled Worker	25,690	6166
5	رئيس ورشه	Manager	32,173	7722
7	سائق الية ثقيله	Loader Operator	32,173	7722

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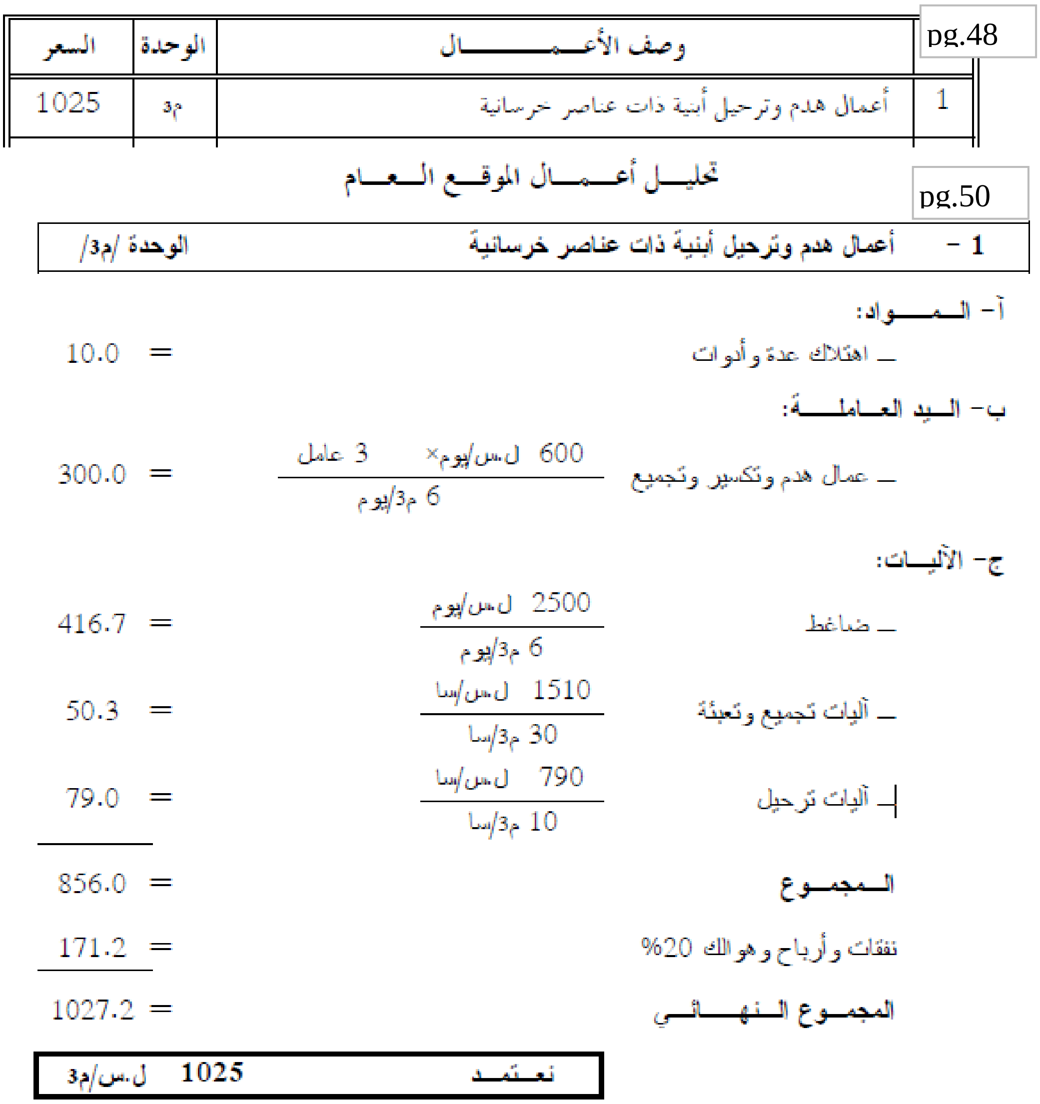
[15] The conversion rate adopted in 50 Syrian Liras = 1 USD which was valid in 2010 pre-war and the fees correspond to one laborer



pg.48

	وصف الأعمال	الوحدة	السعر
1	أعمال هدم وترحيل أبنية ذات عناصر خرسانية	م3	1025

pg.50

تحليل أعمال الموقع العام

1 - أعمال هدم وترحيل أبنية ذات عناصر خرسانية الوحدة /م3/

آ- المواد:

ـ اهتلاك عدة وأدوات = 10.0

ب- اليد العاملة:

ـ عمال هدم وتكسير وتجميع $\frac{600 \text{ ل.س/يوم} \times 3 \text{ عامل}}{6 \text{ م3/يوم}}$ = 300.0

ج- الآليات:

ـ ضاغط $\frac{2500 \text{ ل.س/يوم}}{6 \text{ م3/يوم}}$ = 416.7

ـ آليات تجميع وتعبئة $\frac{1510 \text{ ل.س/سا}}{30 \text{ م3/سا}}$ = 50.3

ـ آليات ترحيل $\frac{790 \text{ ل.س/سا}}{10 \text{ م3/سا}}$ = 79.0

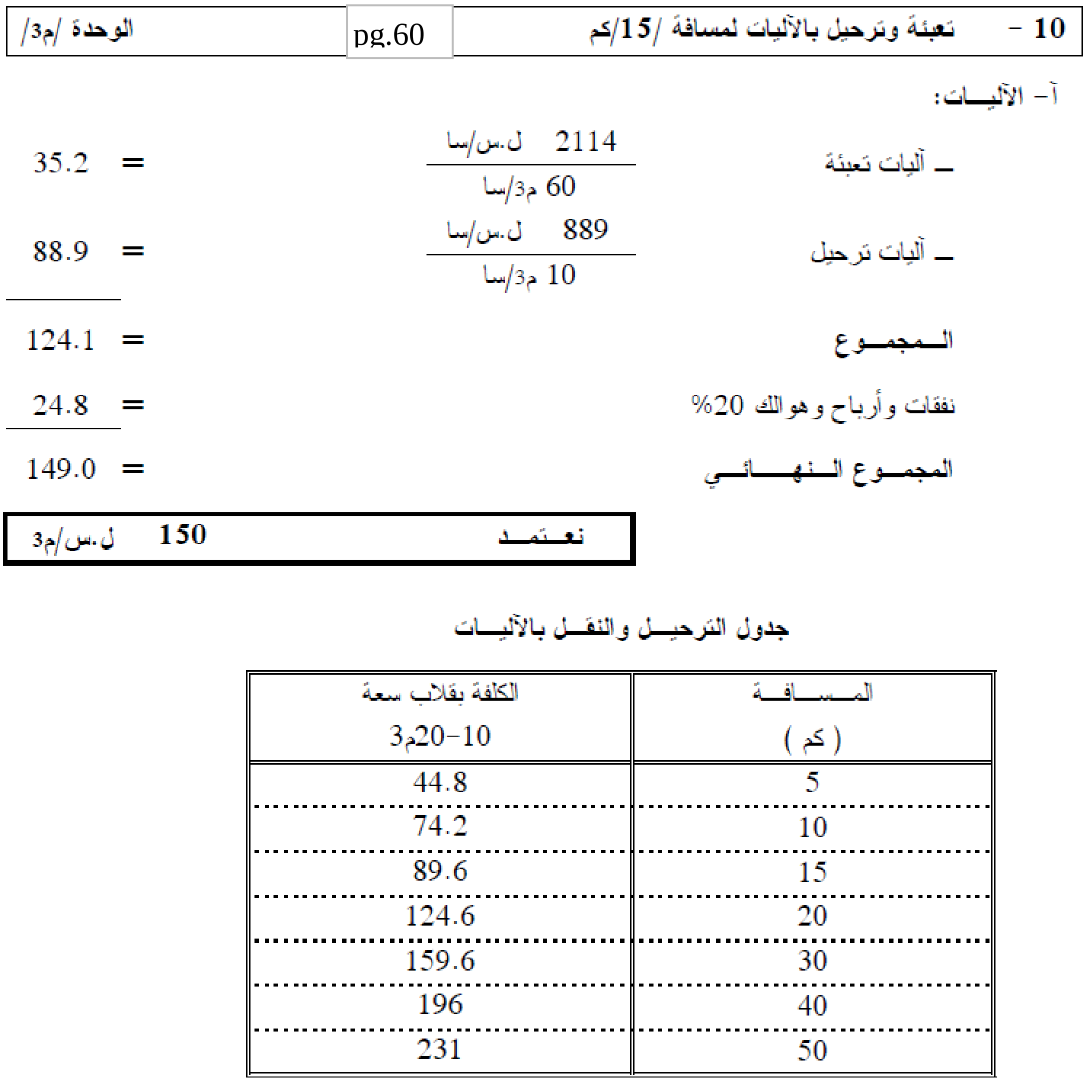
المجموع = 856.0

نفقات وأرباح و هوالك 20% = 171.2

المجموع النهائي = 1027.2

نعتمد 1025 ل.س/م3

Figure 22 Extract for fixed cost of demolition and transportation (تحليل دليل التشييد و البناء لأعمال الأسعار, 2009)



الوحدة /م3/	pg.60	10 - تعبئة وترحيل بالآليات لمسافة /15/كم

آ – الآليات:

ـ آليات تعبئة $\frac{2114\ \text{ل.س/سا}}{60\ \text{م}^3\text{/سا}}$ = 35.2

ـ آليات ترحيل $\frac{889\ \text{ل.س/سا}}{10\ \text{م}^3\text{/سا}}$ = 88.9

المجموع = 124.1

نفقات وأرباح و هوالك 20% = 24.8

المجموع النهائي = 149.0

نعتمد 150 ل.س/م3

جدول الترحيل والنقل بالآليات

المسافة (كم)	الكلفة بقلاب سعة 10-20م3
5	44.8
10	74.2
15	89.6
20	124.6
30	159.6
40	196
50	231

Figure 23Extract for variable cost for truck transportation per km distance