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Towards sustainable solid waste management in Jordan

Mohammad Aljaradin

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Towards sustainable solid waste management in Jordan

By

Mohammad Aljaradin

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Abstract: Jordan is a country with a rapidly growing economy, modernization and growing population. The rapid increase in volumes of solid wastes and a steady increase in the cost and logistical difficulties with the associated risk to human health is a source of concern. The increasing solid waste generated in Jordan has not been accompanied with adequate sanitation facilities and management programs. The detrimental financial status of municipalities constitutes an obstacle to modern solid waste collection, recycling and successful landfill management. Mixed waste is collected without source separation, open dumping and co-disposal of wastewater is practiced. Mismanagement of solid waste leads to more public health risks, adverse environmental impacts and other social and economic problems. This has put increasing pressures on the infrastructure and authorities responsible for the management of solid waste. The objective of the current work was to analyze and review the existing SWM system and to suggest different waste management options as a step for moving toward more sustainable waste management in the future considering the current local financial, social and environmental situations. Field and laboratory experiments, numerical simulation as well as and surveys were used to achieve these objectives. The field experiment was conducted to gather information about the Mafraq landfills sanitary status as well as assessing its leachate and groundwater quality in its surroundings. Lab experiment using typical Jordanian waste were used to investigate the effect of the landfill practices and the climate influence on emission potential from landfills in Jordan and similar regions and climates. Modeling and numerical simulation were used to compare different waste management options and its effect on climate change accounting th GHG production. Studying different daily landfill cover (Mafraq landfill) and intrducing a water balance equation for predicting the leachate generated from the co-disposal of wastewater due to disposal of liquid sewage mixed with municipal waste and its possible effect on the groundwater (Akaider landfill). Two surveys was counducted; The first was desigined to analyis the people perception and there awareness and willingness for recycling MSW and also to develop an understanding for the best SWM practices. The second was designed to describe the role of scavangers in waste management in term of waste reduction, minimization and material recovery. Field experment showed that Mafraq landfill clearly does not fulfill the requirements to be classified as sanitary. The leachate is free to interact with the groundwater aquifer. Furthermore, the leachate analysis showed that the soil under the landfill is contaminated. Groundwater from various wells is unsuitable for household purposes due to its high concentration of fluorine and mercury. This may cause severe health damages to humans if indigested. Labrtory experment results showed significant amount of leachate and landfill gas was produced during wet seasons. However, during the summer time the gas and leachate production rate was negligible. Significant amount of heavy metals traces was found in the leachate due to the mixed waste disposal. Thus, it was suggested that landfill design and operational modes for sustainable landfill operation might need to be adjusted. Modeling of different waste mangment options results showed that a vast reduction of GHG emission was observed especially if organic waste is recovered and either composted or treated with in anaerobic bioreactors. Numerical simulation for a suitable landfill daily cover its founded that clay loam cover is the suitable cover for Mafraq landfill and for specific sites having similar soil and climate conditions as it proofed to provide the lowest penetration depth at the end of the simulation period, beside it is available in sufficient quantities in the landfill and do not waste landfill space while effectively isolating the waste. The simulation result for the suggested water balance equation has shown that the co-disposed wastewater plays a major role in controlling the rate and magnitude of the contaminant that percolate from MSW leachate and increases the possible groundwater contamination. Finally, the survey results revealed that the residance had a very low level of knowledge about recycling. However, they had a positive attitude and were willing to learn more. Although the respondents were aware of the environmental and economic benefits of recycling. Satisfaction with the municipal waste collection services was very high.Thus, source separation at the point of generation will be difficult to achieve in the immediate future in Jordan. scavengers have an important role in the informal solid waste management especially in term of waste reduction, minimization and material recovery. Significant values from the scavenged material make the scavenging somewhat a profitable business for poor people and could track more in the future.

Key words: Solid Waste Management; Public Participation; Recycling; Landfilling; Jordan

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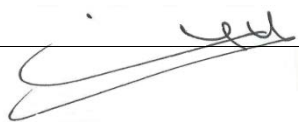

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Finally, this work is dedicated to my late father soul in his 3rd memorial.

Mohammad Aljaradin
محمد عبدالمجيد محمد الجرادين
Lund, Sweden, April 2013

Abstract

Jordan is a country with a growing population that is undergoing rapid modernisation. The increased volume of solid waste and associated logistical difficulties, the steady growth in the cost of waste management and the risk to human health are sources of concern. The increasing amount of solid waste generated in Jordan has not been accompanied by adequate sanitation facilities or management programmes. The poor financial situation of municipalities constitutes an obstacle to modern solid waste collection, recycling and successful landfill management. Mixed waste is collected without source separation, in addition to which open dumping and co-disposal of wastewater are practised. Solid waste mismanagement leads to public health risks, adverse environmental impacts and other social and economic problems that put increasing pressure on the infrastructure as well as the authorities responsible. The objectives of the present work were to; (1) investigate and evaluate the existing solid waste management (SWM) system as well as the current policy, institutional, legal and financial framework, (2) review regulations, compare options and identify needs, (3) determine the problems associated with current practices, especially landfilling and source separation, with focus on the environmental impact of municipal solid waste (MSW) landfills and describe the main obstacles to developing this sector to a sustainable level in the future, and (4) suggest design parameters and operational methods for sustainable landfill operations in the light of the current financial, social and environmental situation in Jordan. Field and laboratory experiments, numerical simulation as well as surveys were used to achieve these objectives. The field experiment was conducted to gather information about the sanitary status of Mafraq landfill by investigating the leachate and groundwater quality in its surroundings. Laboratory experiments on typical Jordanian waste were undertaken to explore the effects of landfill practices and climate on emission potential from landfills in Jordan and similar regions. Modelling and numerical simulation were used to compare different waste management options and their effects on climate change and greenhouse gas *(*GHG*)* production. The daily landfill cover of Mafraq landfill was studied, while in Akaider landfill a water balance equation was applied to predict the leachate generated by the co-disposal of wastewater (liquid sewage mixed with municipal waste) and its possible effect on groundwater. Two surveys were conducted; The first was designed to explore the public perception and awareness of as well as willingness to recycle MSW and to

determine best SWM practices. The aim of the second was to describe the role of scavengers in waste management in terms of waste reduction and material recovery. Field experiments clearly demonstrated that Mafraq landfill does not meet the standards of a sanitary landfill, as the leachate is free to interact with the groundwater aquifer. Furthermore, the leachate analysis revealed that the soil under the landfill is contaminated. Groundwater from wells in the vicinity is unsuitable for household use due to high concentrations of fluoride and mercury which, if ingested, can cause serious health problems in humans. Laboratory results provided evidence of the production of a significant quantity of leachate and landfill gas during wet seasons. However, the gas and leachate production rate was negligible in summer. Significant traces of heavy metals were found in the leachate due to mixed waste disposal, indicating that the landfill design and operation could be improved. Modelling of various waste management options revealed a vast reduction in GHG emissions when organic waste was separated and either composted or treated in anaerobic bio-reactors. The numerical simulation of landfill daily cover demonstrated that clay loam was suitable for Mafraq landfill cover as well as for sites with similar soil and climatic conditions, as it had the lowest penetration depth at the end of the simulation period, is available in sufficient quantities in the landfill, does not waste landfill space and effectively seals the waste. The simulation result for the suggested water balance equation illustrated that the co-disposed wastewater plays a major role in controlling the rate and magnitude of contaminants percolating from MSW leachate and increases groundwater contamination. Finally, the survey revealed that people in Jordan had a very low level of knowledge about recycling, albeit a positive attitude towards and willingness to learn more about it. Satisfaction with municipal waste collection services was very high. Thus, source separation at the point of generation will be difficult to achieve in the immediate future in Jordan. Scavengers play an important role in informal SWM, especially in terms of waste reduction and material recovery. The value of the scavenged material makes scavenging a relatively profitable business for poor people and could attract more in the future.

PAPERS

Appended papers

I. **Mohammad Aljaradin** and Kenneth M. Persson, 2012. Environmental impact of municipal solid waste landfills in semiarid climates - case study – Jordan. The Open Waste Management Journal 5, 28-39.

II. **Mohammad Aljaradin** and Kenneth M. Persson, 2012. Comparison of different waste management technologies and climate change effect-Jordan American Journal of Climate Change 1, 57-63.

III. **Mohammad Aljaradin**, Tarek Selim and Kenneth M. Persson, 2012. Numerical evaluation of different landfill daily cover in semiarid areas- Jordan. International Journal of Environment and Waste Management 0(2013) 00-00.

IV. **Mohammad Aljaradin** and Kenneth M. Persson, 2012. Proposed water balance equation for municipal solid waste landfills in Jordan. Waste Management & Research 0 (2013) 00-00.

V. **Mohammad Aljaradin** and Kenneth M. Persson, 2012. Design parameters and operational modes for sustainable landfill operation- Jordan (mansucript).

VI. **Mohammad Aljaradin**, Kenneth M. Persson and Hossam I. Alitawi, 2010. Public awareness and willingness for recycle in Jordan. International Journal of Academic Research 3(2) 507-510.

VII. **Mohammad Aljaradin** and Kenneth M. Persson, 2012. The role of informal sector in waste management, - case study – Jordan (submitted).

Author's contributions to the appended papers

Paper I. The author planned the work together with the co-authors author. The author wrote all sections of the paper. The co-author participated in discussions and technically revised the paper.

Paper II. The author planned the work together with the co-author. The author wrote all sections of the paper. The co-author participated in discussions and technically revised the paper.

Papers III. The author planned the work together with the co-authors. The author conducts the field work and wrote all sections of the manuscript. The simulation part of the study was carried out by the second co-author. The co-authors participated in discussions and technically revised the manuscript.

Papers IV. The author planned the work together with the co-author. The author wrote all sections of the paper and conducts the simulation part of the manuscript. The co-author participated in discussions and technically revised the manuscript.

Papers V. The author planned the work together with the co-author. The author performed the experimental work that was done in the laboratory of the water resources engineering department. The author wrote all sections of the manuscript. The co-authors participated in discussions and technically revised the manuscript.

Papers VI. The author planned the work together with the co-author. The author performs the survey with the third co-author. Analysis for the results, interpreted the results, carried with the second co-author. The author wrote all sections of the manuscript. The second and third co-authors participated in discussions and the technical and linguistics revision of the manuscript.

Papers VII. The author planned the work together with the co-author. The author performs the survey and wrote all sections of the manuscript. Analysis for the results, interpreted the results, and discussions and the technical and linguistics revision carried with the co-author.

Related publication not included in this thesis

Journal paper

I. **Mohammad Aljaradin** and Kenneth M. Persson, 2011. Municipal solid waste landfills in Jordan. Waste Management 31, 1897-1900.

II. Nicolas Schoeffler, **Mohammad Aljaradin** and Kenneth M Persson, 2012. Groundwater quality in the surroundings of Mafraq landfill, Jordan. The Journal of Water Management and Research (Vatten) 68, 97–101.

III. **Mohammad Aljaradin** and Kenneth M. Persson, 2010. Design of sanitary landfills in Jordan for sustainable solid waste management. Journal of Applied Sciences Research 6, 1880-1884.

Conference paper

I. **Mohammad Aljaradin** and Kenneth M. Persson, 2010. Municipal solid waste landfills in Jordan, current and prospective future. 1st International Conference on Final Sinks, Vienna.

II. **Mohammad Aljaradin**, Kenneth M. Persson and Hossam I. Al-Itawi, 2010. Public Awareness and Willingness for Recycle in Jordan. 1st International Conference on Environmental Management, Jordan.

III. **Mohammad Aljaradin** and Kenneth M. Persson. Threats to groundwater resources due to uncontrolled landfilling in Jordan, a review with recommendations. WOCMES 2010, Barcelona, Spain. And the International Conference on Water, Energy and Environment 2011, United Arab Emirates.

IV. **Mohammad Aljaradin**, Tarek Selim and Kenneth M. Persson, 2011. Evaluation of the cover effect in Mafraq landfill –Jordan using Hydrus-2D Hydrus- 2d/3d. 13th International Waste Management and Landfill Symposium, CISA, Cagliari, Italy.

V. **Mohammad Aljaradin**, Kenneth M Persson and Tarek Selim, 2012. Modeling of different landfill daily cover using Hydrus- 2d/3d . Proceeding of Environmental Science and Technology, American Science Press, Houston, USA, 2, 1-632.

Master thesis

I. **Elin Johnsson**, 2010. Correlation between methane concentration and emission from old landfills in Sweden, performed at the Department of Water Resources Engineering, Lund University, presented at Dec.7th 2010, ISSN: 1101-9824.

II. **Nicolas Schoeffler**, 2011. A study of the groundwater quality in the surroundings of the Mafraq landfill, Jordan groundwater contamination, performed at the Department of Water Resources Engineering, Lund University, presented at June 7th 2010, ISSN: 1101-9824.

III. **David Muddle**, 2012. Modeling of landfill cover in arid areas, University of Exeter, United Kingdom.

Abbreviations and Symbols

B_2-A_7	Amman (B_2) and Wadi Sir (A_7) basin
BOD	Biological oxygen demand
CDM	Clean development mechanism
CEA	Country environmental analysis
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical oxygen demand
COED	Cost of environment degradation
CSCs	Common service councils
DM	Dry matter
Dunam	1000 m^2
E.coli	Escherichia coli
EC	Electrical conductivity
GDP	Gross domestic product
$GgCO_{2\ eq}$	Total greenhouse gas emissions CO_2 equivalents
GHG	Greenhouse gas
GWP	Global warming potential
HELP	Hydrology Evaluation Leachate Performance
ISWM	Integrated solid waste management
K	Unsaturated hydraulic conductivity function
K_r	Relative hydraulic conductivity
K_s	Saturated hydraulic conductivity
LFG	Landfill gas
MC	Moisture content
MCM/a	Million cubic meter annually
Mg/l	Milligrams/Liter
MSW	Municipal solid waste
NGO_s	Non-governmental organizations
ppm	Part per million
SWM	Solid waste management
TCC	Total coliform counts
TOC	Total organic carbon
TS	Total solid
TSS	Total suspended solids
$TVOC_s$	Total volatile organic carbon
UN	United nation
VS	Volatile solids
W_f	Weight of sample and crucible after 550^oC
WHO	World health organization
W_o	Weight of sample and crucible after 105^oC

Contents

1. Introduction

1.1 Background

Waste production and management are among the issues that need to be urgently considered and dealt with. In many countries waste generation has increased as a result of population and economic growth in addition to unsustainable patterns of consumption and production. The World Bank estimates that it is common for municipalities in developing countries to spend 20-50% of their available budget on solid waste management (SWM) (WBG, 2007). Hence, these countries face difficult challenges to properly manage their waste, with most efforts directed towards reducing final volumes and generating sufficient funds for waste management. A substantial reduction of final disposal volumes could be achieved if most of the waste was diverted to material and resource recovery. Developed countries allocate significant resources to solid waste problems. In Jordan, solid waste is one of the major environmental problems (Tarawneh, 2007), which has been aggravated over the past 15 years by the sharp increase in the volume of waste generated as well as qualitative changes in its composition caused by a significant shift in living standards and conditions. The challenges are numerous. Financial constraints, shortage of proper equipment and limited availability of trained and skilled manpower together with massive and sudden population increases due to several waves of forced migration (Potter et al., 2009) have contributed to the poor state of SWM and the overall lack of sustainable development in Jordan (Abu Qdais, 2007b, Al- Nobani, 2008, METAP, 2008, UNDP, 2006). SWM has very low priority in Jordan, except perhaps in the capital, Amman. As a result, the budget provided by the government to the SWM sector is very limited. A number of SWM projects have been carried out in collaboration with international agencies. While some of the projects were successful, others could not support themselves or expand further when these agencies discontinued their support. A number of technical, financial, institutional, economic and social factors contributed to the failure to maintain these projects. Untreated municipal waste in landfill sites forms leachate and gases over a period of decades and pollutes the infiltrating water and recipients for centuries to come. Uncontrolled emission of methane gas to the atmosphere also increases global warming and climate change problems. The low level of awareness and education in the communities regarding the health and environmental impacts of improper management of solid waste has also made it difficult to implement recycling and disposal programmes that require the cooperation of the public to ensure their success (Aljaradin et al., 2010). Mismanagement of solid waste leads to public health risks, adverse environmental

impacts and other social and economic problems. The cost of environmental degradation (COED) in Jordan as a result of solid waste mismanagement has been estimated by country environmental analysis (CEA) to be 0.23% of the Gross domestic product (GDP) (UNDP, 2009). With more than 50% of SWM costs being subsidised from municipal budgets, none of the municipalities in Jordan recover the full cost of the services (Abu Qdais, 2007a). This has put increasing pressure on both the infrastructure and the authorities responsible for SWM. Landfills are becoming full and there is difficulty locating new ones and winning public acceptance. SWM is becoming one of the biggest challenges, which, unless properly and sustainably dealt with, will adversely impact on all other sectors in Jordan. SWM improvement plans in Jordan have focused on landfill, which has been reported to be the source of several adverse impacts (Abu Rukah, 2005, Abu Rukah and Al-Kofahi, 2001, El-Naqa et al., 2006, Obeidat et al., 2008). The main interest was therefore the promotion of resource recovery options on a formal and informal basis to minimize the amount of waste for disposal as well as the recovery of valuable products (UNDP, 2009, UNDP, 2006). The best SWM approach is the implementation of an integrated and sustainable management strategy, known as ISWM, comprising a range of methods and practices for dealing with solid waste problems. These include waste avoidance and minimization methods, reuse and recycling programmes, refuse collection, appropriate treatment methods as well as safe and sanitary disposal. These practices should be undertaken in a way that ensures the protection of public health and the environment, conservation of natural resources and that is cost-effective and affordable. Proper ISWM must involve the public and gain general acceptance for important waste management decisions. ISWM planning involves evaluating local needs and conditions, followed by selecting and combining the most appropriate waste management methods for such conditions. Planning is the first step in designing or improving a waste management system. There is a need to ensure that the waste is managed in a manner that does not leave any environmental problems for future generations by creating awareness of the fact that no single waste treatment or disposal method is suitable for all the materials in the waste stream. The need for better waste management options for the benefit of future generations has gained increased acceptance in developed countries. However, this is not the case in most developing countries where the priorities are different. Jordan is among the countries that have decided to move from traditional SWM approaches towards more integrated options (UNDP, 2009, Abu Qdais, 2007a). The Jordanian national agenda (2006-2015) emphasises the need to extend collection coverage, increase the capacity of solid waste staff and offer incentives for private sector participation in the SWM process (SWEEP, 2010). This decision was difficult to implement as Jordan lacks the necessary technical expertise and

resources. Although considerable efforts are being made by governorates and many non-governmental organizations (NGOs) to tackle waste-related problems in Jordan, major gaps remain.

1.2 Objective and scope

The objective of the research described in this thesis was to investigate and analyze the current SWM system as well as the existing policy, institutional, legal and financial SWM framework in Jordan. The problems associated with the existing practices, especially landfilling and source separation, have been identified, with focus on the environmental impact of municipal solid waste (MSW) landfills. The main obstacles to developing this sector to a sustainable level in the future are presented. Furthermore, the study aims to provide a basis for resolving some of the problems through an ISWM approach that includes social, environmental and economic aspects as dimensions of a sustainable system. In the present thesis, ISWM is based on a combination of different but complementary methods, of which waste collection, societal attitudes towards recycling, landfill design and best treatment method are important components. To achieve the main goal, four sub-aims were developed:

(1) Conducting a review of existing SWM systems and the legal framework of SWM service regulations by analysing the current level, quality and cost of waste management in Jordan and identifying the need to develop SWM to ISWM.

(2) Presenting an integrated and efficient solid waste treatment technology by comparing future scenarios for different waste management options. Anaerobic digestion of solid waste was studied, as it can provide major improvement in terms of cost effectiveness by generating revenue from the sale of landfill gas and energy. The moist and highly biodegradable solid waste that is typical for Jordan favours bioreactor rather than conventional landfilling and renders the anaerobic waste useful for the country.

(3) Developing a truly sustainable landfill to promote safe and effective control and management of waste in the future. Landfills are indispensable components of SWM. Therefore, the research focused on many technical aspects such as different municipal waste treatment options and disposal methods. The effect of the landfill daily cover, emissions and the environmental impact of landfill on air, water and human health were assessed.

(4) Analyzing the citizens' perceptions and knowledge of recycling and source separation as well as their awareness of the health and environmental impact of improper SWM. The scavengers' role in the informal SWM regime, especially in terms of waste reduction and material recovery, was also analyzed. Demonstrating and recommending best practice to

waste management authorities with a view to improving source separation, collection and recycling.

Investigating and highlighting the importance of potential alternatives for the waste managers and decision-makers. Enhancing the awareness of decision-makers may lead to changed national socio-economic and industrial development policies as well as government programmes for improving SWM systems.

It is recommended that the economic and social aspects of all pillars of the proposed ISWM system in Jordan should be included in future research. Thus, the research focuses on Jordan's experience of moving towards more sustainable waste management, which can be applied in countries and communities that have similar conditions.

1.3 Thesis structure and appended papers

This thesis is based on the research presented in seven appended papers numbered I to VII. After the **Introduction** in Chapter 1, the **Theoretical background** of the appended papers is presented in Chapter 2. The **Methodology** in addition to the field and laboratory experiments together with the studies carried out are presented in Chapter 3. In Chapter 4, the **Results and discussions** from the appended papers are summarized. Finally, in Chapter 5**, Conclusions and recommendations** are presented.

The main methods used and results arrived at are included in the following summary. However, more details can be found in the appended papers.

Paper I presents an overview of the environmental impact of MSW landfills. The migration of gas and leachate from the landfill body into the surrounding environment constitutes a serious environmental concern for groundwater, air, climate and human beings. Both the short and long-term remedial measures required to minimize these environmental and socio-economic effects in Jordan are suggested. Planning is the first step in designing or improving a waste management system. It can be achieved through reviewing and evaluating the existing systems and regulations, comparing options and identifying needs. **Paper II** compares different waste management options and their effects on climate change in the light of the local context. Four scenarios representing current and proposed technologies (increased recovery, biological treatment and advanced biological treatment) were studied using the SWM-GHG calculator and taking into account the economic situation as well as the present level of environmental and societal awareness of sustainable waste management in Jordan. Waste management planners, for example, should take into consideration institutional, social, financial, economic, technical and environmental factors. For this reason and because landfill

is an important component of sustainable waste management, the next three papers concentrate on landfill design**. Paper III**, Numerical simulation using the HYDRUS-2D/3D model investigated the impact of landfill cover type, cover thickness and antecedent water content (Mafraq landfill) on the quantity and rate of contaminant percolation during a 30-year simulation period. **Paper IV** proposed a water balance equation for predicting the leachate generation in MSW landfills located in semi-arid areas (Akaider landfill), which considered the co-disposal of wastewater due to liquid sewage mixed with municipal waste as a major water input to the landfill body. **Paper V** employed an Anaerobic lysimeter to explore the effects of landfill practices and climate on the emission potential from landfills in Jordan and similar climatic regions. It proposes Anaerobic treatment of solid waste in Jordan as a favourable method for society and the environment. Design parameters and operational methods for sustainable landfill operation are also suggested. Environmentally sound waste management must go beyond mere safe disposal and include minimization actions, reuse and recycling activities as well as proper treatment. However, success is highly dependent on an informed and participatory public. The next two papers therefore discuss public participation, which is an important part of waste management plans. **Paper VI** presents a study conducted in order to analyze the public perception and awareness of as well as willingness to contribute to recycling and to deepen the understanding of the best SWM practices. **Paper VII** describes the role of the informal sector in waste management in terms of waste reduction and material recovery.