Resources, Conservation & Recycling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Emergy based carbon footprinting of household solid waste management scenarios in Pakistan

Mustafa Ali[a,b,*], Antonino Marvuglia[c], Yong Geng[a,b], Nawaz Chaudhry[d], Shahid Khokhar[e]

[a] School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] China Institute for Urban Governance, Shanghai Jiao Tong University, Shanghai 200030, China
[c] Luxembourg Institute of Science & Technology (LIST), Luxembourg
[d] College of Earth & Environmental Sciences, University of the Punjab, Lahore, Pakistan
[e] Business Administration Department, University of Education, Lahore, Pakistan

ARTICLE INFO

Keywords:
Emergy accounting
Life cycle perspective
Greenhouse gas
Emissions
Waste disposal

ABSTRACT

Waste management is a serious challenge across many resource constrained countries of the world leading to environmental issues such as pollution and high rates of soil occupation, health issues induced by poor hygienic conditions, and financial problems linked to the high costs associated to waste management, which have high impacts on municipal budget. In this study we determined the environmental impact of different waste disposal scenarios in a major city of Pakistan. Existing studies on the subject of waste management in Pakistan fail to account for the environmental burden of waste processing technologies. To counter this, in this paper we used Emergy based accounting procedures to obtain a donor or nature based perspective for environmental footprinting. Three scenarios were considered for the analysis consisting of the current practice of open dumping as Scenario A; sanitary landfilling with composting and material recycling as Scenario B and incineration with composting and recycling as Scenario C. Results were presented in the form of Emergy based input-output tables as well as greenhouse gas emissions as measured in kg CO_2 equivalent (kCO_{2eq}/t) per tonne of waste. Scenario A was the worst option due to its high emissions and lack of any useful output. Scenario B was identified as the best alternative as it resulted in similar amount of net emissions as Scenario C but with relatively lower stress on the environment as indicated by the Emergy indicators. In view of the subject city's resource constraints we recommend inducing waste reduction and minimization practices through public awareness campaigns. Resource contributions from the civic society are also suggested for erecting the necessary waste disposal infrastructure. The results and suggestions presented herein need to be highlighted in a timely manner in order to resolve environmental and public health risks posed by the current practices.

1. Introduction

Waste management is a serious challenge across many countries of the world. This issue is especially significant in the developing countries due to their resource constraints. Such countries lack the technical skills and tools to manage their wastes effectively. Consequently, many of these countries suffer from environmental pollution and associated public health hazards (Ali et al., 2017b). In order to overcome this challenge, it is important to appraise the current situation of waste management in these countries and suggest remedial measures. To this aim, availability of site specific data is quite important (Ripa et al., 2017). Moreover, while a part of the waste management solution can be obtained from the experience of the developed countries, it is important to find local solutions to address this challenge in a sustainable manner. This is especially important as many of the developing countries in Asia and Africa are experiencing rapid urban and demographic transitions (Cobbinah et al., 2015). Currently, eight out of the ten most populated cities in the world are in developing countries in Asia (UNSTATS, 2017) and many of them have poor waste management controls leading to public health hazards such as environmental pollution and contamination (Hardoy et al., 2013). Moreover, secondary cities across many of these countries are expanding rapidly as peri-urban areas are being absorbed into urban agglomerations resulting in an increasing number of cities having million plus populations (Murtaza Haider et al., 2014). Unfortunately, public infrastructure in these countries is insufficient to feed the growing needs of urbanization (Ali et al., 2016c). Moreover, there is a lack of scientific literature regarding characterization of urban solid waste and the quality of waste management systems in these increasingly significant cities. It is important to identify current issues related to solid waste management in these cities so

* Corresponding author.

http://dx.doi.org/10.1016/j.resconrec.2017.10.011
Received 29 April 2017; Received in revised form 19 September 2017; Accepted 7 October 2017

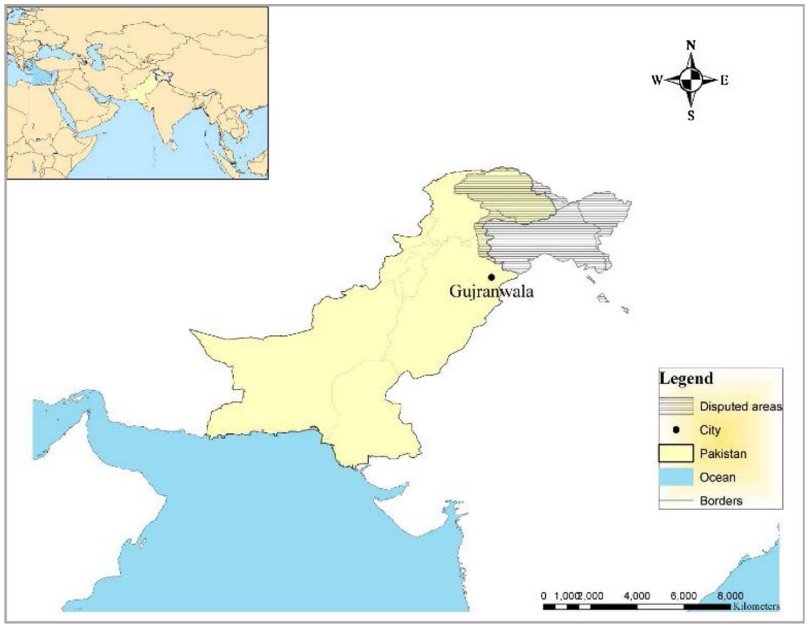

Fig. 1. Geographical localization of Pakistan and Gujranwala city.

as to avoid public health catastrophes in the future.

In this paper we will analyze solid waste disposal scenarios in a major city of Pakistan, namely Gujranwala. Pakistan is a resource constrained, developing country in South Asia. It has been experiencing rapid urbanization in its recent history. Currently 37% of the population in the country lives in the cities and this figure is expected to rise to about 50% by the year 2020 (Murtaza Haider et al., 2014). Infrastructure for municipal waste management in Gujranwala, as in many other Pakistani cities, is insufficient and requires significant overhauling and expansion. Although urban solid waste comes from many streams including municipal, industrial, construction, healthcare and other activities, in Pakistan a major portion of this waste comes from households of which the main portion consists of biomass, such as kitchen waste (Raheem et al., 2016). Most of the municipal solid waste (MSW) in Pakistan is discharged in open dumping grounds and vacant lots without any safety mechanisms (Ali et al., 2016a) and such places are haunted by drug addicts, stray animals and under-age scavengers looking for recyclable items which leads to further epidemiological problems (Rauf et al., 2013). This is due, among other things, to the fact that the country does not have incinerators or sufficient composting or recycling plants for efficient waste disposal. Most of the studies on solid waste management in Pakistan are usually restricted to waste characterization and only few of the existing studies analyze the consequences of different end-of-life waste disposal scenarios on the environment (Batool and Chuadhry, 2009; Ali et al., 2016a). Moreover, most of these studies are limited to the largest cities in the country including provincial capitals, such as Lahore or Karachi, and secondary cities remain neglected. To fill this important gap in the existing literature, this study will focus on solid waste management challenges in Gujranwala city which has a population of 4.8 million inhabitants at the district level and 2.7 million people in its predominantly urban counties (Punjab Bureau of Statistics, 2015). It is the fastest growing city in the country with an annual growth rate of 3.49% (Mayors, 2011), but unfortunately it is also seen as one of the dirtiest cities in the country with poor waste management controls (Correspondent, 2013). Pathogenic medical waste from different hospitals is often found mixed with general waste and the incidence of infectious diseases in the city borne out of unhygienic practices is higher than the average for the whole country (Ali et al., 2017a). Since the city lies only about 60 Km away from the provincial capital, Lahore, given the current rates of urbanization and population in the future the two cities might become indistinguishable (Arif and Hamid, 2009). It is thus imperative to analyze the waste management situation in the city and suggest measures for improvement. Constant monitoring and evaluation of its waste management practices is also necessary so as to ensure that the city follows sustainable growth. Hence the present study can be used in the future as a reference point for benchmarking, monitoring and comparison purposes. Fig. 1 shows the location of the city in the wider geographical setting.

2. Literature review

Studies on urban solid waste management usually focus on waste characterization, mass flow analysis and life cycle assessment (LCA) of waste disposal scenarios for the calculation of greenhouse gas (GHG) emissions (Liu et al., 2017). As solid waste collection, transportation and disposal activities consume fossil fuels and therefore contribute to GHG emissions (Friedrich and Trois, 2016), the selection of the waste disposal and treatment technology to apply should be supported by a careful calculation of these emissions. As mentioned earlier, the usual practice in such analyses involves estimation of carbon emissions of different waste disposal scenarios with the aid of an LCA tool (Meng et al., 2017). However, this approach fails to account for the impacts of all the activities related to solid wastes management, encompassing labor, transportation, machinery and natural capital involved. Moreover, LCAs of waste management systems generally cut out the impacts associated to the entire production and consumption chain leading to the waste, since the boundary normally includes only the actual disposal processes (Gala et al., 2015).

In order to get a more holistic perspective, researchers are increasingly turning towards a system's approach for analysis. Examples of models used for such analyses include social network analysis (Ali et al., 2016b; Caniato et al., 2015), system dynamics (Al-Khatib et al., 2016), data envelopment analysis (Ali et al., 2017c; Albores et al., 2016) and Emergy accounting (Gala et al., 2015). In particular, in Emergy accounting the boundary is implicitly set at the biosphere level, therefore the entire supply-chain is scanned in spatial and temporal dimension (Gala et al., 2015). Stemming from the work by H.T. Odum