Improvement of waste management practices in a fast expanding sub-megacity in Pakistan, on the basis of qualitative and quantitative indicators.

Authors & Affiliations

Mustafa Ali 1, 2, \*, Yong Geng 2, Dawn Robbins1, Dave Cooper1, Will Roberts1, [Joost Vogtländer](https://www.researchgate.net/profile/Joost_Vogtlaender) 3

1 University of Chichester Business School, Bognor Regis Campus, Upper Bognor Road, Bognor Regis, West Sussex, PO21 1HR, United Kingdom.

2 School of Environmental Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China.

3 Faculty of Industrial Design Engineering, Technical University of Delft, Netherlands.

\*Corresponding Author Details

*Address -* University of Chichester Business School, Bognor Regis Campus, Upper Bognor Road, Bognor Regis, West Sussex, PO21 1HR, United Kingdom. *Tel -* 00447342302476. *Email –* m.ali@chi.ac.uk

Abstract

 This paper deals with an analysis of waste management practices in the fast-growing city of Gujranwala with 2.6 million inhabitants, with a fast growing middle income group of 56%, and an urbanization rate of 3.49% per annum. This city is like many other cities in the developing world, characterised by hardly any waste management infrastructure. The study comprises: (1) an inventory of current waste flows, per income group as well as per season, (2) an inventory of waste management shortcomings, (3) ) a what-if analysis on the carbon footprint of three waste treatment techniques. The inventory of current waste flows is based on a comprehensive site study involving 776 samples in total. The waste management shortcomings have been qualitatively analysed by Wasteaware model, which deals with physical aspects (public health, environmental control, resource management) as well as governance factors (user & provider inclusivity, financial stability, institutions & policies). The *what-if* analysis of the carbon footprint has been based on an LCA-based tool. The findings of this study are that: (1) the optimum choice of waste treatment scenario differs for the seasons, (2) the high and middle income groups have nearly half of the share of the waste (3) the Wasteaware system appears to be a powerful tool to communicate the weak spots and to make stakeholders aware of the opportunities for improvement. The novelty of this paper is that it focused on the impact of household income groups in combination with seasonal differences while comparing different waste disposal scenarios.

Key Words

Waste management; household waste; integrated waste management; continuous improvement; greenhouse gas emissions; low carbon development.

1. Introduction
2. Waste management in Pakistani cities

Proper management of municipal solid wastes is a serious concern across developing as well as developed countries of the world. Different studies have discovered waste generation rates to be positively correlated with household expenditure levels (Qdais et al., 1997; Ramachandra et al., 2018). Thus as expenditure levels rise through the developing world, their waste generation rates might increase even further. Timely surveys and scientific studies are necessary so that waste generation patterns can be analysed for pre-emptive policy making. For cities in the developed countries, decision support tools for waste management usually include Life Cycle Analysis (LCA) (Cherubini et al., 2009; den Boer et al., 2007) and other comprehensive indicator systems (Salhofer et al., 2008). Unfortunately, LCA based tools are far too advanced for cities in the developing countries. Other comprehensive rapid assessment tools are generally limited to certain waste types such as healthcare waste (Ali et al., 2017a; World Health Organization, 2017). Studies on the topic of waste management in developing countries usually focus on larger cities such as Beijing (Qu et al.,2009), Shanghai (Ding and Xiao, 2014), Mumbai (Sharma and Chandel, 2017), Rio (Angelo et al., 2017) and Lahore (Jadoon et al., 2014). These studies show that such cities often lack basic waste collection and disposal services often resulting in open dumping of solid waste (Alavi Moghadam et al., 2009; Ali et al., 2018b). Studies on relatively smaller, yet rapidly expanding, cities in the developing world are very few. Most of the existing studies on such smaller cities usually focus on waste characterization. Such studies usually do not assess environmental impact of solid wastes management practices. Hence, there is a need for decision support tools for such small cities in the developing world. Studies on such cities focus on waste originating from different household income groups across different seasons (Getahun et al., 2012). This approach provides a comprehensive picture of the ground situation which in turn can help undertake effective policy making.

1.2 Waste management in Pakistani cities

Pakistan is a rapidly urbanizing country in South Asia (Ali et al., 2019b). While the population growth rate in the country is only 1.6%, the urbanization rate in Pakistan is 3.0% (Murtaza Haider, 2014). The public utility infrastructure in many of these cities is inadequate to meet the growing demands of a rapidly urbanizing population. One of the most pressing issues today in Pakistan involves the challenge of urban solid waste management. Urban waste comes from many sources such as households, shops and markets, industry, construction, healthcare and maintenance of parks. The collected urban waste in Pakistan is mostly thrown in open dumping grounds without any pre-treatment or environmental protection measures. There is only one sanitary landfill site in the whole country for municipal waste, and open dumping of solid waste is the norm in cities (Ali et al., 2014). This situation has led to environmental pollution and public health risks (Hafeez et al., 2016; Khan et al., 2015). Thus, there is an urgent need to remediate the environmental burden of urban solid waste in Pakistan. In this study we will use the case study of a secondary city in Pakistan using benchmark indicators and carbon footprint techniques. Existing studies on this topic lack sufficient depth in order to form the basis of a policy. For instance, (Mahar et al., 2007) present waste generation statistics across different cities in Pakistan but do neither provide any discussion regarding treatment technologies and emissions resulting from waste, nor provide any strategic advice on improvement of waste management practices. We hope that the framework used in the present study can act as a blueprint for future studies across other secondary cities in the country and the region.

1.3 The framework of this study on the city of Gujranwala

Fig. 1 provides the framework of the case study on the combined method of Wateaware indicators and the Carbon Footprint scores. The figure is divided into two parts: (1) the upper half which depicts the scheme to calculate the qualitative scores of the Wasteaware indicator system, and (2) the bottom half presenting the activities to calculate the quantitative scores of the Carbon Footprint. The Wasteaware indicators are related to general information on physical and governance data. In the Carbon Footprint calculations we focus on household income groups.

Pakistan has four seasons: (1) a cool, dry winter from December through February; (2) a hot, dry spring from March through May; (3) the summer rainy season, or southwest monsoon period, from June through September; (4) and the **retreating monsoon period of October and November**. The waste flow measurements have been done across three of the aforementioned seasons namely the cool dry winter (henceforth called winter season), the hot dry spring (henceforth called summer season) and the retreating monsoon period ((henceforth called rainy season) since households appear to have then the biggest waste flows. Seasonal variations in the carbon Footprint emissions are accounted for by focusing on summer, winter and rainy seasons.

[Insert Figure 1 here]

The city of Gujranwala has been chosen for this case study. This city is located in the North-eastern part of the country which is also the economic and political heartland of Pakistan. Gujranwala city is the central part of the Gujranwala district which is currently the 4th largest district of Pakistan with a population of over 4.8 million people The population of the city itself is currently 2.6 million (Bureau of Statistics, 2015). It is the fastest growing city in Pakistan with an urbanization rate of 3.49% per annum (Ali et al., 2016). The district Gujranwala contributes between 5% and 8% to the national GDP and the role of Gujranwala city in the district’s total output is significant due to its Small and Medium Enterprises (SME) sector (Gujranwala R&D Cell, 2010). The Human Development Index (HDI) measured for Gujranwala is 0.769 which is above national average but the city suffers from relatively lower satisfaction with health facilities than in other peer cities in the province (UNDP, 2017). Improvement in satisfaction with health can be achieved with better sanitation and waste management controls (Bouzid et al., 2018). The few existing studies on the topic of waste management in Gujranwala lack a comprehensive discussion of the environmental impacts of such wastes. (Altaf and Deshazo, 1996) focus only on waste generation rates across households in Gujranwala, and failed to account for their environmental impact of untreated waste in the form of air, water or soil pollution. Thus this study represents the first comprehensive analysis of waste management in Gujranwala.

Gujranwala city consist of the four urban townships of Aroop, Nandipur, Khiali Shahpur and Qila Dedar Singh. These townships in turn consist of 64 urban counties and 34 rural counties. Municipal waste generated from households in urban counties of Gujranwala was approximately 500 tonnes/day in 1996 with a maximum collection rate of 20% (Altaf and Deshazo, 1996). This figure rose to 821 tonnes/day in 2014 with a collection rate of 43% (Japan International Cooperation Agency, 2015). The different fractions of domestic waste consisted of 61.40% putrescible waste, 7.88% paper, 9.46% plastics, 0.13% metals and 21.13% others such as grass, textiles, wood, etc. These fractions are similar to those discovered in other developing countries (Qu et al., 2009). Most of this waste is thrown in illegal dump sites or vacant plots in the city. Gujranwala is widely considered as one of the most polluted cities in Pakistan (Correspondent, 2013). In the future this city will rapidly grow in size and population, and will require a proportional increase in public infrastructure to manage the growing municipal waste (Ali et al., 2018b). Hence, constant monitoring and evaluation will be required to ensure that the growth of city remains sustainable. In addition to all technical measures, it is necessary to implement a waste tax system to cover the waste management costs, and it will be necessary to design and implement awareness campaigns in order to reduce household waste generation per capita.

1.4 Research questions

The Research Questions of this case study are: (1) How can Wasteaware indicators be applied in fast expanding sub-megacities, where waste management is still underdeveloped? (2) What are the seasonal variations in the Carbon Footprint, and do they have impact on waste management implementation strategies? (3) Which household income group contributes the largest amount of GHG (Greenhouse Gas) emissions?

In the next sections of this paper we will first give more information on the waste flow data (Section 2.1), the Wasteaware indicator model (Section 2.2) and goal and scope of the Carbon Footprint calculations (Section 2.3). In Section 3 we show the results of the Mass Flow calculations (Section 3.1), the Wasteaware analyses (Section 3.2) and the Carbon Footprint Calculations (Section 3.3). The Discussion (Section 4), deals with benchmarking of Wasteaware indicators with other cities, and provides information on the sensitivity of the overall recycling rates in the Carbon Footprint calculations. The Conclusions (Section 5) deals with the Research Questions and with the strategic consequences with regard to the continuous improvement of waste management in the city of Gujranwala in particular, and other cities in Pakistan and other South Asian areas in general.

1. Methods
2. Waste flow data

Data regarding the waste quantity and composition was obtained from a publication of Japan International Cooperation Agency, JICA, (Japan International Cooperation Agency, 2015). JICA conducted a survey to develop a master plan for waste management across different cities of Pakistan. The results for Gujranwala are compiled in the form of a report which is accessible on the websites of both JICA and Gujranwala Waste Management Company (GWMC). The bulk of the data were collected in the form of surveys, held across three different seasons: (1) the first field study conducted was between 13 and 20 October 2014 (rainy season), (2) the second field survey was held from 9 to16 February 2015 (winter season) and, (3) the third field survey was conducted from 18 to 25 May 2015 (summer season). Overall, 97 sampling points from each type of waste generation source were assigned and waste generation rates for each of them were determined for 8 consecutive days thus resulting in a total of 776 physical samples. These samples have been analysed for a set of materials: paper, plastic, metal, leather, glass, textile, grass & wood, kitchen, and “others”. Municipal waste sources were categorized on the basis of its sources including households, shops & markets, restaurants, parks, street sweeping, institutions. Table I given below provides the necessary details.

 [Insert Table I here]

2.2 The Wasteaware model

In this paper we use Wasteaware indicators to rank the waste management practices in Gujranwala city based on physical and governance indicators in tabular format (Wilson et al., 2015). These indicators were developed according to UN-Habitat’s guidelines and they assess physical and governance aspects of MSWM (Municipal Solid Waste Management) practices. While other studies have also proposed similar indicators (Beigl et al., 2008; Greene and Tonjes, 2014; Shekdar, 2009) the advantage of using this model is the that case studies from more than 50 cities around the world have already used these indicators which makes them convenient for comparison purposes (Wilson et al., 2015). The indicators comprise background information of the city, waste characterization data, physical indicators involving environmental, epidemiological and economic aspects of MSWM and finally the governance indicators including inclusivity, financial sustainability and institutional aspects of MSWM. The indicators are based on a grading system consisting of low, lower middle, upper middle and high ranks/grades. The grades in turn are based on scores corresponding to each of the indicators and sub-indicators. Generally, all scores are colour coded with those representing poor/low grade coloured red, those representing low-medium grade coloured red & orange, those representing upper-medium grade coloured orange & green and high grades represented by green colour. For this study, the country level income and population statistics are obtained from the World Bank (2016) whereas waste related data is primarily obtained from relevant publications by the (Environmental Protection Agency, 2005) and (Japan International Cooperation Agency, 2015). On-site physical inspections were conducted to assess the quality of waste management practices as necessitated by some of the sub-indicators. This included, for instance, identification of banners and other media for public awareness regarding safe waste management practices. Similarly, items such as presence of waste around collection bins and popular places, open burning of waste and use of personal protective equipment by waste collectors could only be verified through physical inspections. Supplementary file B can be seen for further details.

One disadvantage of the Wasteaware system is the lack of quantitative assessment of pollution emanating from waste management scenarios. To resolve this issue, we calculate GHG emissions that, in addition to Wasteaware indicators, can provide a complete picture regarding the situation of waste management in Gujranwala city.

2.3 Goal and scope of the Carbon Footprint calculations

The goal of the Carbon Footprint calculations is to compare the environmental burden of municipal waste from households via different waste disposal scenarios for each of the three seasons. The functional unit of the study is defined as '1 tonne of disposable solid domestic waste’. The two related research questions are: (a) Which household income group contributes the largest amount of GHG emissions? (2) What are the seasonal variations in these emissions, and do they have impact on waste management implementation strategies?

Three scenarios have been developed utilizing different waste treatment techniques. They are described as follows:

* In scenario 1 all the domestic waste is disposed of in a municipal landfill site.
* Scenario 2 involves three waste disposal techniques. These include (a) composting of the putrescible fraction of the waste, (b) material recovery of recyclable fractions and (c) incineration of the remaining fractions at a hypothetical stoker type incinerator located at the dumping ground.
* Scenario 3 also involves three waste disposal techniques. These consist of (a) composting of the putrescible fraction of the waste, (b) material recovery of recyclable fractions and (c) landfilling of the remaining fractions.

As shown above, scenario 1 consists of landfilling of all waste. This would be considered the base scenario keeping in view the lack of any other sophisticated safe waste disposal infrastructure in the city. Scenario 2 and 3 involve composting of the putrescible fraction and material recovery of paper, plastic, etc. The remaining fractions in scenarios 3 and 2 are modelled to be incinerated and landfilled respectively. It should be noted that scenarios 2 and 3 are based on *what-if* situations as they focus on waste disposal systems that currently do not exist in the city of Gujranwala. These scenarios were included to assess whether they could lead to better environmental controls in comparison to the current situation.

The 3 systems are displayed in Fig. 2. The carbon footprint of transport is included in the calculations. Energy recovery from the incinerator are not calculated in the present study due to the unavailability of local site-specific data.

[Insert Figure 2 here]

An LCA-based tool for Carbon Footprint calculations has been applied which was developed by Institute for Global Environment Strategies (IGES), and used for developing countries in Asia-Pacific region (Nirmala Menikpura, 2013). The tool helps to quantify GHG emissions from individual treatment technologies as well as integrated systems. GHG emissions can be estimated based on weight (in tonnes) and on a time scale (per month). Required input data include not only monthly percentage wet waste quantities but also corresponding fuel and electricity consumption. The output includes direct GHG emissions as well as net GHG emissions. Direct emissions refer to GHG emissions due to fossil energy consumption, waste degradation, combustion of waste fractions, etc. Net GHG emissions are calculated on the basis of the direct emissions minus the GHG avoidance/mitigation potential of the end-of-life technologies. The IPCC 2007 100 years tables for Direct Global Warming Potential have been applied

1. Results
3.1 Mass Flow calculations

The city generates approximately 1200 tonnes/day of MSW from urban and rural households and other sources in 2014 (Japan International Cooperation Agency, 2015) of which domestic/household waste represents 94.91% of the total or 1139 tonnes/day. The remaining waste comes from sources such as parks, shops, restaurants, etc. In 2014, 72.08% of the total domestic/household waste is generated in the urban counties and the remaining is generated in the rural counties. However, waste collection service exists for the urban counties only, and waste from rural counties is not collected. On average 476 tonnes/day of MSW is discharged for collection by GWMC in the urban counties (the remaining is thrown at illegal dumping grounds and vacant plots around the city) of which only 410 tonnes of waste is collected each day, which represents 34.28% of the total waste. The remaining 66 tonnes/day of waste is recycled in the informal sector. An additional 4 tonnes/day of materials are recovered by the scavengers from the final disposal site. Table II shows municipal waste generation pattern in Gujranwala city.

[Insert Table II here]

Apart from the above mentioned data, numerical values of waste generation by source for each season are given in the Supporting Information (SI) document. The sources of domestic/household waste have been divided into three distinct groups: (1) the high income group, (2) the middle income group and (3) the low income group, representing 9.4%, 56.2% and 34.4% of the city’s population respectively. The average household incomes are respectively >$1000, $200-$1000 and $200<. Kitchen waste is *the* major waste component coming from most of the sources.

3.2 Wasteaware Indicators

Table III shows the summary statistics of the Wasteaware benchmark indicator system. A complete breakdown of calculations for each of the categories can be found in the accompanying Supplementary file B.

[Insert Table III here]

Table III shows that municipal waste from the city is mainly composed of putrescibles including kitchen waste, wood, grass, etc. Further waste fractions include plastics, paper, metals and “others” (such as glass, textiles, ceramics, stones, and sand). The waste collection service of GWMC is ranked low-medium as it covers only 54.00% of the total urban counties in the city. As MSW is not collected from any of the rural counties, the fraction of the waste captured by the system turns out to be only 34.16% of the total waste generated in the city, thus resulting in a low score in Table III.

 Most of the remaining indicators in the Table III consists of qualitative metrics. Scores for such indicators are assigned following actual field observations by the authors. The indicator of ‘quality of waste collection service’ receives a lower middle score of 33.33season 1% as we discovered poor waste management practices in waste collection and storage. These includes shortcomings such as waste accumulation around collection points, presence of litter, overflowing of garbage containers, open burning, poor public health and environmental controls and lack of universal personal protection equipment for the sanitary staff. The saving grace here is mainly a generally efficient waste transportation by GWMC.

 The indicator of ‘controlled treatment and disposal’ receives a score of zero as there is no controlled waste recycling site in operation at the time of the survey. Scavengers usually handpick and sort recyclable items from the waste dumping ground or the garbage containers in the city. These items are then sold to intermediaries who subsequently sold them wholesale in another city. Similarly, the indicator of ‘degree of environmental protection in waste treatment and disposal’ receives a low score of 20.00% as there are virtually no environmental controls for waste treatment/disposal. The waste is simply dumped in an open ground on the outskirts of the city. There are no mechanisms for landfilling, incineration or material/energy recovery. The only positive aspect noted here is the existence of a specialized company in the form of GWMC for waste disposal. Our interviews with the company management indicates that they planned to establish integrated sustainable waste management practices based on material recovery from the waste in the future. The next indicator consists of the ‘waste recycling rate’ which is obtained from JICA. Around 70 tonnes/day of waste is recycled out of the 476 tonnes/day of MSW discharged for collection by GWMC. This results in a recycling rate of 14.7% which is rated low-medium as per the Wasteaware guidelines. The guidelines show that a recycling rate of 10% to 24% can be considered as low-medium. The next indicator of ‘quality of 3Rs’ is rated low with a score of 4.17%. This is due to a lack of integration of formal and informal waste recycling sectors, lack of recycling of putrescible materials, lack of occupational safety by the scavengers and lack of a policy instrument focusing on 3Rs.

The governance indicators are mostly qualitative in nature. The indicator of ‘user inclusivity’ represents the extent to which the users have a say in waste management services in a city. This indicator receives a low medium score of 50.00% as the current scenario did not have any mechanisms for public involvement or public education or achieving behavioral change towards waste management, and there is no equity of service provision due to a limited scope of waste collection services as described earlier. The indicator of ‘provider inclusivity’ describes the degree to which service providers are involved in waste management planning and implementation processes. This indicator receives a medium score of 70%. Shortcomings, here, include a lack of monitoring as shown in Fig. 2 thus questioning the extent to which laws enabling sustainable solid waste management services are enacted in the city. Other negative points include a lack of involvement of the informal sector and lack of bidding process for MSWM. The indicator of ‘financial stability’ is used to measure aspects such as affordability of MSWM services, public scrutiny of accounts related to MSWM, adequacy of funds for future capital expenses, etc. The indicator shows a low score of 31.25% mainly due to inadequate financial strength of the current scenario. The last indicator measures the extent of regulatory practices and organizational strength for MSWM in the city. This indicator scores relatively better due to the presence of national guidelines on MSWM and waste management specialization in the form of GWMC.

3.3 The Carbon Footprint calculations

The assumptions made for the carbon footprint calculations in this study include a semi-continuous stoker type incinerator which could reduce the waste to 75% by mass and 90% by volume, however, without energy recovery. Since Pakistan did not have a municipal waste incinerator at the time of the survey, the utilities' requirements for incineration are determined using data from a medical waste incinerator at a large public hospital in the nearby city of Lahore. This incinerator is consistent with the assumptions in our model. The average electricity and natural gas consumption for waste incineration is 1 kWh/67 kg waste and 3.36 Liter/kg of waste respectively. For all scenarios average monthly fuel consumption for transportation is 1800 liters which is the reported average fuel consumption for waste collection and transportation by GWMC (Japan International Cooperation Agency, 2015). In order to track the GHG emissions, the data given in Table IV is used.

[Insert Table IV here]

For scenario 1, the input waste quantities consists of all the waste fractions shown in Table III. For scenario 2 composting fraction consists of the kitchen waste and grass and wood waste. Recyclables shown in parenthesis in the Table IV are simulated to be recovered. All the remaining fractions, are simulated to be incinerated for scenario 2. For scenario 3 composting and MRF fractions are the same as those in scenario 2. However, landfilled waste consists of all the remaining fractions. Fig. 3 shows the CO2 equivalent emissions for each of the three scenarios across: (1) the rainy, (2) the winter, and (3) the summer season. All emissions are measured in the units of kg CO2-equivalent/tonne (kCO2/t) of MSW. As discussed earlier, we estimate direct emissions and also indirect savings resulting from corresponding waste disposal techniques. This results in net emissions, which turn out to be negative in some instances, indicating emission reduction. It can be seen that the net emissions are the highest in the first scenario for all seasons. During the rainy season and summer, the third scenario yields minimum net emissions. During the winter season, the second scenario shows the greatest avoided emissions. The savings in scenarios 2 and 3 take into account the emissions that have been avoided due to landfilling and the indirect savings due to composting and material recovery technologies. Overall the net emissions in the rainy season are 511.01 kCO2/t, -711.85 kCO2/t and -1614.43 kCO2/t for scenarios 1, 2 and 3 respectively. Similarly, net emissions in the winter season are 664.37 kCO2/t, -1703.67 kCO2/t and -1523.10 kCO2/t for scenarios 1, 2 and 3 respectively. Finally, net emissions for the summer season are 541.01 kCO2/t, -1486.63 kCO2/t and -1648.61 kCO2/t for scenarios 1, 2 and 3 respectively. Negative results show net savings in emissions as discussed in previous sections.

[Insert Figure 3 here]

The results displayed in Fig. 3 show GHG emissions based on the fact that only a fraction of the waste components is recyclable. However, it would be interesting to discover the emission savings provided that all plastic, glass and paper items are recoverable. Fig. 4 displays the emissions in kCO2/t of MSW based on 100% recovery of plastic, paper and glass items in the MSW. It can be seen that emission savings are relatively greater here than those displayed in Fig. 3. Overall, net emissions in the rainy season are 511.01 kCO2/t, -1490.24 kCO2/t and -1625.79 kCO2/t for scenarios 1, 2 and 3 respectively. The net emissions in the winter season are 664.37 kCO2/t, -1934.7 kCO2/t and -1980.87 kCO2/t for scenarios 1, 2 and 3 respectively. Finally, the net emissions for the summer season are 541.01 kCO2/t, -1764.60 kCO2/t and -1705.73 kCO2/t for scenarios 1, 2 and 3 respectively. The results for scenario 1 remain the same due to the absence of any reuse or recycling technology. The largest improvement is seen in case of scenario 2 during the rainy season resulting in the savings of a further 778.39 kCO2/t. All these results show that improvements in waste segregation and collection can help reduce the environmental footprint of MSW.

[Insert Figure 4 here]

Fig. 5 given below shows the seasonal variation in GHG emissions as measured in kCO2/t of MSW with respect to different household income groups in the city. Data for calculating these emissions is given in Table IV which reports the average values for the 4 household groups across the three seasons. The emissions from the high income group vary as 606.12, 715.20 and 636.85 kCO2/t across season 1, 2 and 3 respectively. Similar values for middle income group, lower income group and the rural community are 529.31 kCO2/t, 720.13 kCO2/t & 572.56 kCO2/t across season 1; 540.42 kCO2/t, 671.36 kCO2/t & 546.87 kCO2/t across season 2 and 433.98 kCO2/t, 564.33 kCO2/t & 465.42 kCO2/t across season 3 respectively. It can be seen that waste generation increase during the second season for all the groups and it is lowest in the first season. The high income group is the source of greatest emissions in relative terms. This is mainly because this group generates relatively more kitchen and paper wastes as a percentage of its total waste.

[Insert Figure 5 here]

1. Discussion

 As compared to findings in cities in developed countries, Wasteaware indicators for Gujranwala are quite poor. However, the results are similar to other cities in developing countries in general (e.g. Lahore, Maputo, Monrovia) (Wilson et al., 2015), and in Pakistan in particular (Mahar et al., 2007). The main reasons for these poor results include a low level of controlled recycling, and the lack of infrastructure in such cities for proper waste disposal alternatives such as composting, recycling, and combustion with heat recovery. The governance aspects also display poor results as they suffer from poor inclusivity indicators and organizational and financial weaknesses of the system in place. In order to improve physical indicators, local implementation of national waste management rules (Environmental Protection Agency, 2005) is required. However, resource constraints limit the chances of sustained application of such rules. The establishment of a specialized company in the form of GWMC is a useful step. Its success in improving the physical indicators will depend upon cooperation from the local community. Financial weakness of the waste management system is a common problem across the developing world (Buenrostro and Bocco, 2003). Hence, an active public-private joint action can be used to improve this governance indicators. Such a partnership can also include public awareness drives augmented by empowerment of the local union council office bearers. These office holders and religious leaders can stress the importance of modest ways of living for cleanliness and resource conservation. Studies have discovered per capita sales of eating establishments to have the greatest influence on waste generation from the retail sector (Hockett et al., 1995) . Hence, recently, an important step to avoid such wastes has been the limitation of wasteful extravagance such as food dishes served during weddings (Punjab, 2016). Similarly, pay as you throw (PAYT) schemes can be used to ensure more responsible waste generation from public institutions, markets and other commercial areas (Elia et al., 2015). Public authorities can also improve monitoring of parks and streets and impose fines for kerb-side littering. In the end a successful implementation of any policy mechanism to improve these indicators will depend on the inclusion of public as stakeholders in the decision making process. This is important as consumer knowledge has been shown to be one of the best predictors of responsible waste management practices such as propensity to recycle (Hornik et al., 1995). Inclusionary policies should especially be adopted in rural union councils where communal/tribal ties are relatively stronger and social aspects take precedence over economic aspects of waste management decision making (Bernardes and Gunther, 2014). Thus, timely elections and accountability of the office bearers are necessary steps for the improvement of these indicators (Wahid et al., 2016).

The results highlight the importance of community based, customized waste management models and policies. In developed countries such as Japan the government policy is geared towards the establishment of a 3R society through community participation in reduction, reutilization and recycling of waste (Takiguchi and Takemoto, 2008). In theory, such a society is a stakeholder in the establishment of a Circular Economy (Geng et al., 2013; Su et al., 2013) in which all waste items are treated as resources. Such policies engage the public in MSWM activities, as stakeholders, by expounding the virtues of waste minimization and waste segregation at source. There is a need to implement such a policy across cities in South Asian countries as well. However, as compared to societies in developed countries, a large segment of the population in counties such as Pakistan is illiterate (Ali et al., 2017b) and the policy makers in such countries do not have enough financial or human resources for sustained public awareness. In our opinion, the policies in a developing country such as Pakistan should be targeted with respect to social segmentation. This is because studies show that different household income groups have different attitudes and behaviours towards conservation and environmental protection (Barr, 2007; Behera et al., 2015). Thus for the upper income group, public engagement can be based on highlighting the importance of safety, cleanliness and environmental protection. For the rural, lower income and middle income groups, public participation can be based on waste to market techniques. Studies indicate that lower income and rural households support such policies (Chung and Poon, 2001). These policies include financial incentives for source separation (Ordonez et al., 2015), development of safe small scale recycling facilities (Orlins and Guan, 2016), subsidies and tax incentives for composting and anaerobic digestion of putrescible waste (Massaro et al., 2015). These schemes can aid in reducing unemployment and promoting conservation for a resource constrained country such as Pakistan. The additional benefits of composting can also be significant for the agricultural sector in peri-urban areas of cities (Warunasinghe and Yapa, 2016) such as Gujranwala. As shown in our study most of the waste can be recycled and reused. However, Pakistan lacks the financial and technical infrastructure to establish a 3R policy. Yet with the establishment of recent initiatives such as China Pakistan Economic Corridor (Alam, 2015), policy makers might have the financial and technological tools to find regional solutions to such issues. As an example, a Chinese company has recently been contracted by the city of Karachi to manage its MSWM challenge (Correspondent, 2016). It must be noted here that although the establishment of specialized waste management companies is being promoted by the government, recent studies have shown their results to have been mixed (Ashraf et al.). Hence all relevant policies should prefer integrated local solutions (Menikpura et al., 2013) and include provisions for constant monitoring and evaluation. Moreover, 3R based waste disposal techniques should be accounted towards carbon credits (Ali et al., 2018a; Ravindra et al., 2015). These credits might be, in turn, be exchanged for financial benefits. To calculate these credits an embodied energy perspective can also be used in tandem with an estimation global warming potential of MSWM scenarios (Agostinho et al., 2013; Almeida et al., 2010) .

A limitation of this study is that it did not take life cycle costing into perspective, since history of Western Europe and the United States shows that the costs and the benefits of waste treatment systems (in combination with PAYT schemes) played a crucial role during the transition towards sustainable solutions (Barles, 2014). The reason that this study did not include an analysis of life cycle costs is a lack of relevant local data. Future studies can also include other life cycle impact categories once complete inventory data becomes available (Ali et al., 2019a). Such analyses can be conducted as a corollary of the present study in the future as more information becomes available.

1. Conclusions

In this paper we attempted to answer the three research questions of Section 1.4. With regard to Research Question 1 (“How can Wasteaware indicators be applied in fast expanding sub-megacities, where waste management is still underdeveloped?”) we conclude that the Wasteaware indicators helped the city of Gujranwala to identify the weak spots in their waste management system (see Table III). Firstly, the current scenario of waste management in Gujranwala city needs significant improvement as it suffers from poor waste collection, recycling and disposal activities. Secondly, the regulatory, organizational and financial strength of waste management in the city is also quite poor.

With regard to Research Question 2 (“What are the seasonal variations in the Carbon Footprint, and do they have impact on waste management implementation strategies?”) we conclude from the carbon footprint calculations that there are considerable seasonal GHG variations (see Fig. 3 and 4), especially for future scenarios, so that waste disposal management needs to be optimized for each of the seasons. A set of instruments needs to be in place that can be mixed and matched, based on the specific seasonal conditions.

With regard to Research Question 3 (“Which household income group contributes the largest amount of GHG emissions?”) we conclude that the high + middle income households have nearly half of the share of the GHG emissions (see Table IV). These groups should pay for their waste, not only to cover the costs of proper waste treatment, but also to be able to invest in a better waste management infrastructure. These groups, the best educated groups in our study, need also to be educated regarding the harmful effect of their waste generation habits. The focus should be on behavioural change with regard to the reduction of the large quantities of kitchen waste, as well as waste separation (glass, paper, plastics, compostable waste, and the rest)). A city wide communication project should support the required transition.

Apart from the findings as described above under the 3 research questions, there are some other general conclusions with regard to the waste flow quantities:

1. The compostable fractions are more than half of the waste, so it does make sense to focus first on this waste flow.
2. The other important flows are plastic and paper which need to be separated in the kitchen.
3. The percentage of metals is remarkably low, probably because of the fact that scrap has too much value to be thrown away.
4. The fact that the flows in the seasons are different (see Fig. 3 and 4.), requires a different waste management strategy for each season, which requires system flexibility

The main conclusion of the paper is that the combined method of Wasteaware indicators and Carbon Footprinting identifies the ‘hot spots’ (shortcomings) in waste management. It also reveals the big differences between the situation in Europe and the developing countries: the difference is not only the available infrastructure (or the money to create the required infrastructure), but also the behavioural aspects, as well as the physical differences in (seasonal) waste flows. Technical solutions of Europe cannot just be copied to cities like Gujranwala. We hope that this study triggers a further debate on waste management practices and responsible consumption.

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**Figures**



Figure 1. Framework of the case study of Gujranwala city



Figure 2. The three scenarios for the Carbon Footprint calculations*.*



Figure 3. Carbon footprint by scenario and season as measured in kg CO2-equivalent/tonne (kCO2/t) of waste.



Figure 4. Carbon footprint by scenario and season as measured in kg CO2-equivalent/tonne (kCO2/t) of waste based on 100% recovery of plastic, paper and glass items.

Figure 5. Seasonal variation in household carbon footprint as measured in kg CO2-equivalent/tonne (kCO2/t) of waste.

**Tables**

Table I. Sample distribution taking into account type and area (Japan International Cooperation Agency, 2015)

|  |  |
| --- | --- |
| Types | Waste amount survey |
| Areas | Samples per area | Number of samples | Survey Days | Total samples |
| A x B | C x D |
| A | B | C | D | E |
| Households | High Income | 2 | 5 | 10 | 8 | 80 |
|   | Middle Income | 6 | 5 | 30 | 8 | 240 |
|   | Low Income | 4 | 5 | 20 | 8 | 160 |
|   | Rural Area | 2 | 5 | 10 | 8 | 80 |
| Commercial | Restaurants | 1 | 5 | 5 | 8 | 40 |
|   | Others | 1 | 5 | 5 | 8 | 40 |
| Markets |   | 5 | 2 | 10 | 8 | 80 |
| Institution |   | 5 | 1 | 5 | 8 | 40 |
| Street sweeping |   | 1 | 1 | 1 | 8 | 8 |
| Park |   | 1 | 1 | 1 | 8 | 8 |
| Total |   |   |   | 97 |   | 776 |

Note: the sample distribution is the same for each one of the three seasons.

Table II. Waste quantity and composition in Gujranwala city. Derived from (Japan International Cooperation Agency, 2015)

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Sub-category** | **Amount** **(tonnes/day)** | **Percentage of total (%)**  |
| Waste collected by GWMC\* |  | 410.00 | 34.16 |
| Waste collected by scavengers from plots |  | 66.00 | 5.50 |
| Waste collected by scavengers from landfill |  | 4.00 | 0.33 |
| Unattended waste  |  | 720.00 | 60.00 |
| Total waste |  | 1200.00 | 100.00 |
|  | *Household waste* | *1139.00* | *94.91* |
|  | *Urban household waste* | *821.00* | *68.41* |

\*GWMC stands for Gujranwala Waste Management Company

Table III. Wasteaware benchmark indicators for Gujranwala city.

|  |  |  |
| --- | --- | --- |
| **Category** | **Indicator** | **Results** |
| **City** | Gujranwala |
| **Country** | Pakistan |
| **Background information on the country** |  |
| Country level income | World Bank income category | Lower-Middle |
| GNI/capita | 4840.00 (Purchasing Price Parity) |
| Population | persons | 192.82 million |
| Per capita waste generation | kg/day | 0.28 to 0.61 |
| **Waste related data - City** |  |  |
| Waste per capita  | kg/day | 0.38 |
| Waste composition |  |  |
| Putrescibles | Percentage | 61.40% |
| Paper | Percentage | 7.88% |
| Plastic | Percentage | 9.46% |
| Metals | Percentage | 0.13% |
| Others | Percentage | 21.13% |
| **Physical components** |  |  |
| Public health - waste collection | waste collection coverage | (54.00%) Low Medium |  |  |
| waste captured by system | (34.16%) Low |  |
| quality of waste collection service | (33.33%) Low  |  |  |
| Environmental control - waste treatment & disposal  | Controlled treatment & disposal | (0.00%) Low  |  |  |
| Degree of environmental protection in waste treatment & disposal | (20.00%) Low |  |
| Resource management - reduce, reuse & recycle  | Recycling rate | (14.7%) Low Medium |  |  |
| Quality of 3Rs - reduce, reuse, recycle - provision | (4.17%) Low |  |
| **Governance factors** |  |  |
| Inclusivity  | User inclusivity | (50.00%) Low Medium |  |  |
| Provider inclusivity | (70.00%) Medium  |  |  |
| Financial stability | Financial sustainability | (31.25%) Low |  |
| Sound institutions, proactive policies  | Adequacy of national SWM framework | (58.33%) Low Medium |  |  |
| Local institutional coherence | (75%) Medium  |  |  |

Note: Indicators receiving poor/low grade are coloured red, low-medium grade coloured red & orange, upper-medium grade coloured orange & green and high grades coloured green. GNI stands for Gross National Income and SWM stands for Solid Waste Management.

Table IV. Seasonal household waste quantities by components. All units in Kilograms.

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Rainy season** | **Winter season** | **Summer season** |
| **HI** | **MI** | **LI** | **R** | **HI** | **MI** | **LI** | **R** | **HI** | **MI** | **LI** | **R** |
| Kitchen | 44.95 | 223.62 | 167.65 | 119.77 | 46.10 | 225.24 | 158.72 | 170.03 | 48.54 | 253.59 | 171.12 | 138.20 |
| Paper (Recyclable) | 5.02 | 21.47 | 7.94 | 8.10 | 1.76 | 10.53 | 6.70 | 7.82 | 2.10 | 9.72 | 4.71 | 8.38 |
| Paper (Other) | 0.34 | 7.70 | 1.24 | 0.56 | 8.41 | 61.58 | 25.79 | 10.33 | 4.20 | 16.20 | 2.73 | 1.95 |
| Textile | 3.66 | 23.09 | 12.15 | 10.61 | 1.56 | 23.90 | 8.43 | 8.65 | 1.76 | 26.33 | 13.39 | 13.96 |
| Grass & Wood | 0.20 | 2.84 | 1.24 | 25.96 | 1.02 | 6.48 | 4.46 | 13.96 | 0.34 | 3.24 | 2.48 | 14.80 |
| Plastic (Recyclable) | 1.22 | 5.67 | 1.98 | 2.23 | 0.81 | 4.05 | 1.49 | 5.03 | 0.68 | 4.46 | 3.97 | 6.98 |
| Plastic (Other) | 6.64 | 34.03 | 27.03 | 18.43 | 3.93 | 31.60 | 16.62 | 14.80 | 7.53 | 48.61 | 26.29 | 15.63 |
| Leather & Rubber | 0.41 | 6.08 | 4.46 | 1.40 | 0.68 | 4.05 | 0.99 | 3.63 | 0.54 | 4.05 | 0.99 | 1.95 |
| Metal (Recyclable) | 0.14 | 2.43 | 0.25 | 1.12 | 0.27 | 0.81 | 0.25 | 1.95 | 0.27 | 1.62 | 0.00 | 0.28 |
| Metal (Other) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Glass (Recyclable) | 0.20 | 4.05 | 3.72 | 0.00 | 0.61 | 5.27 | 2.23 | 1.68 | 0.41 | 0.41 | 0.00 | 0.28 |
| Glass (Other) | 0.68 | 2.03 | 1.98 | 0.00 | 0.14 | 0.81 | 0.00 | 1.95 | 0.61 | 3.65 | 2.98 | 1.12 |
| Others | 4.34 | 72.11 | 18.35 | 91.02 | 2.51 | 30.79 | 22.32 | 39.37 | 0.81 | 33.22 | 19.34 | 75.66 |

HI, MI, LI and R stand for High Income, Middle Income, Low Income and Rural households respectively.