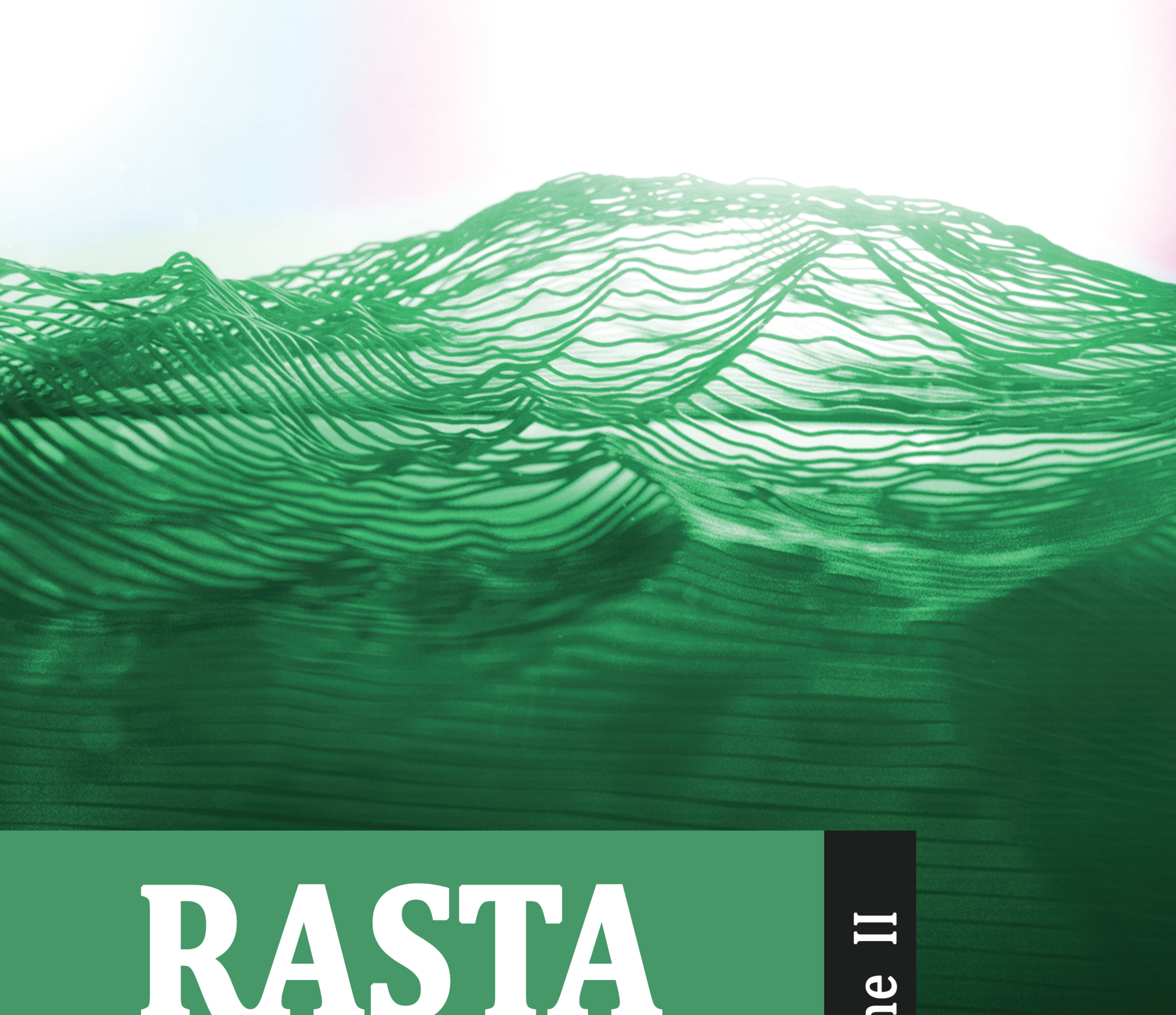

RASTA

LOCAL RESEARCH LOCAL SOLUTIONS

Volume II

URBAN DEVELOPMENT

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Pakistan Institute of Development Economics

Edited by Nadeem Ul Haque and Faheem Jehangir Khan

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URBAN DEVELOPMENT
(VOLUME II)

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November 2022

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PART I

URBAN DEVELOPMENT

Research Papers

ADOPTION OF A PERFORMANCE EVALUATION TECHNIQUE FOR THE DEVELOPMENT OF A FRAMEWORK FOR THE CLIMATIC RESPONSIVE URBAN DESIGN

Salma Sherbaz and Humera Mughal

ABSTRACT

Research studies related to urban microclimate are gaining popularity due to recent climate changes and rapid urbanization. Streets are the basic elements of a complex urban-build environment and are usually considered of simple rectangular shape, commonly known as the ‘‘urban canyon” (UC). The street orientation and geometry have a significant effect on wind and heat distribution inside an urban street canyon which in return affects the building’s energy performance and its natural and hybrid ventilation efficiencies. It also affects pedestrian comfort, pollutant dispersion, and overall air quality at the street level. For climatologists and designers, the knowledge of flow characteristics in street canyons is an important consideration for Climate-responsive urban design. The current research aims to study the effect of street canyon geometry (Canyon length, width, height, orientation, and SVF) on microclimate in a planned (Islamabad) and semi-planned (Rawalpindi) urban setup. The overall goal is to guide the designer for the early-stage climate responsive urban design.

1. INTRODUCTION

Urbanisation

The mass influx/migration of the human population from rural areas and the resulting changes in urban settings is known as urbanisation. The concept of urbanisation goes a long way back in human history, e.g., just to fulfil the water and food requirements of large populations (Elmqvist, et al., 2013). However, the Industrial Revolution in the late eighteenth century promoted rapid growth in the urban population, first in Europe and later in other parts of the world. A significant increase in the percentage of the world population living in urban areas has been observed over the past few decades. In 1950, around 30% of the worldwide population lived in urban areas. By 2007, for the first time in human history, more than 50% of the world's population was urban. As per the United Nation's updated estimates for the year 2018, 55% of the world's population was living in urban areas and is expected to increase to 68% by 2050 (Zhang, 2016).

In the case of Pakistan, a similar steady trend in the growth rate of the urban population is observed. In Pakistan, the annual percentage growth in the urban population was around 2.7% in 2019(Masson-Delmotte, et al., 2018). Therefore, to accommodate an increasing number of incoming migrants, our cities need to further develop and improve the urban environment.

Challenges of Urbanisation

Although urbanisation is mostly considered an indicator of economic, social, and political progress of a society, it can also lead to several challenges, including urban sprawl, environmental and health issues, increasing crime and human security-related problems, poor urban governance, weak financial capacity of cities, and higher living cost, to name a few. Urban areas have significant energy consumption and CO2 emissions footprint (Ribeiro, et al. 2019). Although the urban areas only cover 0.4–0.9% of the global land surface (Esch, et al., 2017), their contribution to the global CO2 emissions is more than 70% (Edenhofer, 2015; Johansson, et al., 2012) The negative impacts of rapid urbanisation on the environment are profound and reach far beyond urban settlements.(Bai, et al., 2017).

The global environment has changed for the worse and our country, Pakistan, is no exception. A slight glance at the annual mean temperature, the sea level, and rainfall patterns is ample evidence to foretell the looming crisis. During the past half-century, the country's mean temperature has gone up by more than half a degree Celsius, its coast's sea level has increased more than ten centimetres, and its rainfall and heat-wave patterns have altered alarmingly. The prediction for the next century is that there will be an estimated up to a six-degree Celsius increase in the average annual temperature and an up to sixty-centimetre rise in the mean sea level, which is horrific and unprecedented in human history (Chaudhry, 2017).

Urban Heat Island Phenomenon

The urban heat island (UHI) effect is a common environmental problem faced by urban areas in which the air temperature is significantly higher than in surrounding suburban areas. Compact development in urban areas is the main reason for UHI as the high concentration of building structures not only limits airflow but also emits heat stored from solar energy. The previous research studies suggest that due to UHI, the day and nighttime temperatures in urban areas are 1–7°F and 2–5°F higher than in the rural areas (Kershaw, 2017).

Causes of UHI

Several factors cause heat islands, some of which are discussed below.

- ***Low Plantation and Water Bodies:*** Plants trigger the process of transpiration, providing shade and evaporating surface water into the air, hence cooling the surrounding environment. On the other hand, hardscapes, paved areas, and buildings provide no moisture and less shade, and, therefore, contribute more towards temperature gain, resulting in higher temperature.

- ***Urban Building Material Properties:*** Materials such as stone, marble, and concrete used in the construction of, for example, paving and roofing, absorb and later emit more heat as compared to green, natural surfaces, such as plants and vegetation.
- ***Urban Street Morphology:*** The street orientation, length/height to width (H/W) ratios, and sky view factor have a significant effect on wind and heat distribution inside an urban street canyon. Surfaces and structures in densely-built urban areas are obstructed by neighbouring buildings, hence providing no path for heat circulation and becoming large thermal masses. Therefore, the knowledge of flow characteristics in street canyons is an important consideration for climate-responsive urban designs.
- ***Human-generated activities/sources of heat:*** Industrial facilities, vehicles, buildings, and air-conditioning units, all emit heat into the urban environment and contribute to heat island effects.
- ***Weather and Geography:*** Calm and clear weather maximises the amount of solar energy that is reached and absorbed by the urban surfaces and, therefore, increases the urban heat island. On the other hand, cloud cover and strong windy weather conditions suppress the formation of heat islands.

Effects of UHI

UHI affects us in more ways than we normally realise. A localised increase in temperature in any urban area, in general, and one in Pakistan creates a host of issues. Being an inherently energy-starved country, coping with the higher energy demands in summer has always been impossible and whatever make-shift remedy the policymakers opt for creates more problems than before the intervention had been undertaken. For instance, the rise in the urban temperature in summer can easily reach twenty to twenty-five degrees Celsius. Such an exorbitant rise in temperature causes an exponential increase in air-conditioning, which causes an up to 10 per cent surge in energy demand.

In the heated frenzy, the power plants operating on fossil fuels are turned on, completely disregarding their contribution to the emission of greenhouse gases and air pollutants that feed the fire people feel in urban areas. In desperation, even more refrigeration is deployed, perpetuating the vicious cycle of fueling the fire. The rise in temperature does not only prompt higher energy consumption but can go as far as triggering thunderstorms and altering the precipitation trend.

The UHI's ramification on the health of the masses is also incredibly significant. From mere uneasiness to the loss of consciousness, attributed to the heat waves, are exacerbated by the UHI.

Land Use Planning and Urban Climate

The economic value once dominated the economy-ecology balance in the urban expansion process around the world. But now rapid and irregular urban development has become a global concern and the current continuation in the severity of this problem is alarming. Land use planning in terms of preparation, arrangement, and allocation of land use is a vital part of sustainable land management (SLM) and can have a positive or a negative effect on the state of the environment(Metternicht, 2017). Moreover, urban land use and surface cover are considered an indicator of urban environmental and ecological landscape characteristics. The urban form has a significant effect on the thermal environment, overall air quality, and energy demand (Chen, et al., 2018; Yang, et al., 2020; Emmanuel & Steemers, 2018).

Urban Climate Modelling and Assesment

The research studies on urban climate modelling and assessment are usually performed on four different spatial scales (horizontally), i.e., mesoscale, microscale, building scale, and indoor. Mesoscale modelling is the study of phenomena in larger areas (<200 km). With the recent advancements in numerical approaches and computational resources, an increase in the number of urban mesoscale modelling studies has been observed in the past few decades (Martilli, 2007). These studies are mostly focused on the calculation and mitigating of the urban heat island (UHI) effect, air pollution assessments, weather forecast improvements, etc(Varentsov, et al., 2019; Gedzelman, et al., 2003; Göndöcs, et al., 2017; Sokhi, et al., 2018; Baik, et al., 2009). The microscale extends from less than one metre to hundreds of metres, including individual buildings, roads, trees, courtyards, lawns, etc. Building scale urban studies consider small areas (<100m) having individual buildings or few blocks. The indoor climate-related studies only consider the interior of a building (<10m) and are mostly aimed at heating, ventilation, air conditioning (HVAC) system designs, and building service engineering to create optimal indoor environments.

Urban Microclimate

Urban Microclimate Descriptors and Controlling Factors

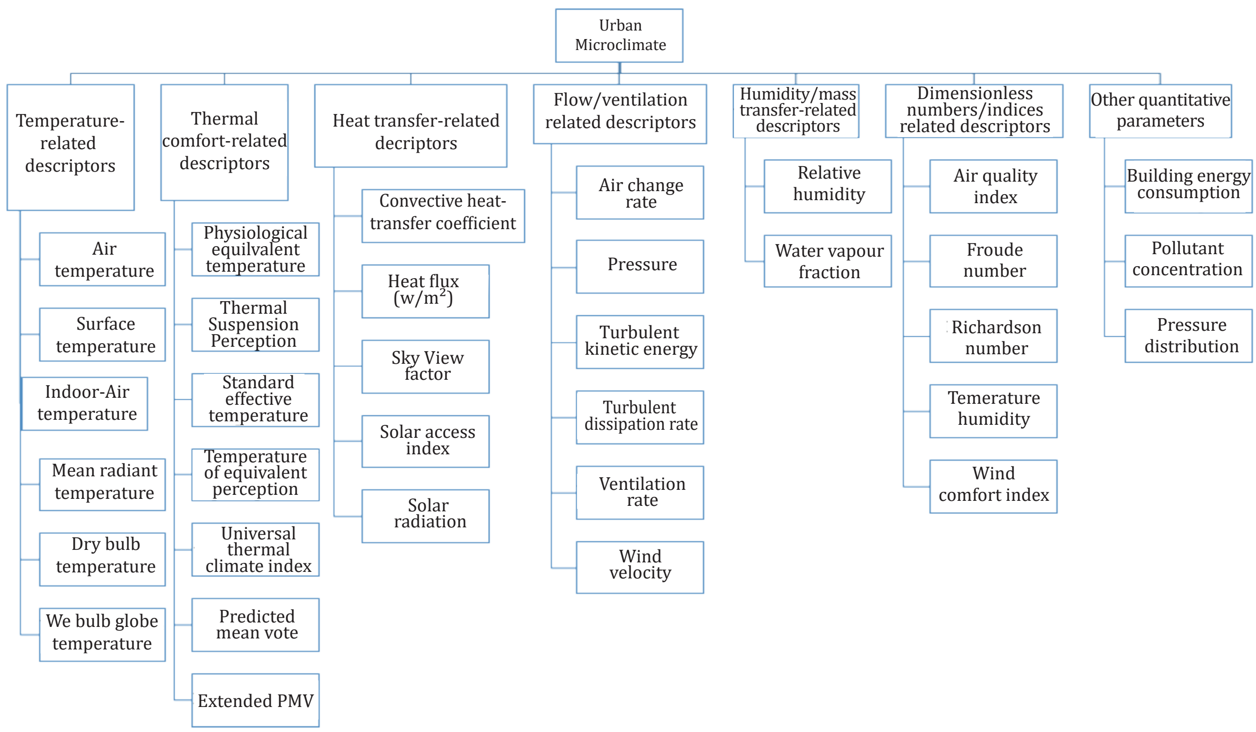
The urban microclimate is the result of several dynamic and complex processes that interact at multiple spatial and temporal scales. The varied factors that can affect the microclimate in an urban setup can be divided into the following three main categories(Bherwani, et al., 2020):

- Natural factors: wind direction, speed, precipitation, humidity, solar radiation, albedo, greenery, natural water bodies, soil type, and terrain conditions.
- Built environment: Building characteristics (material, height, shape, texture, colour, etc.), street canyon characteristics (canyon aspect ratio (AR), sky-view factor (SVF), length and orientation), urban greenery (street trees and urban parks), man-made water bodies, population density, road traffic density, anticipated traffic volumes, built-up area vs open space ratio, location, and the type of industry.
- Indirect factors: Air pollution, ongoing construction/development activities.

The different urban microclimate descriptors used in the literature are broadly divided into six categories (as shown in Figure 1.1)(Toparlar, et al., 2017):

- Temperature related descriptors
- Thermal comfort-related descriptors
- Heat transfer-related descriptors
- Flow/ventilation-related descriptors
- Humidity/mass transfer-related descriptors
- Dimensionless numbers/indices-related descriptors
- Other quantitative parameters

Figure 1.1. Urban microclimate descriptors



Urban Microclimate Assessment

Since the pioneering works of Luke Howard, numerous studies have been performed in the area of urban microclimate (Howard, 1820). These studies not only improve the general understanding of the energy balance in a built environment but also explain/elaborate interactions between urban structural forms and their microclimate. This knowledge is extremely helpful for urban designers and architects in creating a climate-responsive urban design.

Urban microclimate can be studied using several different approaches, which can be divided into two main groups (Mirzaei & Haghighat, 2010; Mirzaei, 2015). There are several advantages as well as challenges associated with each of these approaches.

- Observational approaches: field measurements, thermal remote sensing, and small-scale modelling
- Simulation approaches.

Field measurements, thermal remote sensing, and small-scale modelling of urban microclimate are the main techniques included in the first category (Mirzaei & Haghighat, 2010; Mirzaei, 2015). Collecting data from fixed weather stations is a traditional observational approach. However, this data is not considered a true representation of the city's microclimate due to several changes in impervious surfaces, vegetation cover, and waste heat from buildings and vehicles throughout the city (Rajkovich & Larsen, 2016). Similarly, the installation of different measurement devices throughout a city is generally expensive and time-consuming. With the recent advances in sensor technology, it is often used independently or combined with in situ measurements to collect data on land cover and ground surface temperatures. The temporal and spatial resolution and cost associated with remote sensing techniques remain significant limitations (Rajkovich & Larsen, 2016). Similarly, with the availability of powerful computers and new methods for modelling complex systems, an increasing trend in the application of numerical simulation approaches in urban microclimate studies has been observed. However, complex urban details and the high computational cost of such simulations are a few challenges associated with these approaches.

Research Structure

The goal of this research is to guide designers in early-stage climate-responsive urban design.

Hypothesis: It is hypothesised that different urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery have an impact on the urban microclimate, which affects the energy load and thermal comfort in a built environment.

Overall Objective

The goal of this research may be achieved by the development of a framework named CRUD (climate-responsive urban design) for the optimisation of urban street canyon geometry (canyon length, width, height, orientation, and SVF) in an urban district.

The sub-objectives of this research are:

- Study of already developed urban designs in various cities of Pakistan.
- Performance evaluation of the design by evaluating the effect of different urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery on the urban microclimate.
- Development of a framework to develop optimum design layouts based on a performance evaluation technique.
- Application of the framework for the development of a small sector in Islamabad, Pakistan.

2. LITERATURE REVIEW

The urban microclimate is affected by geographical, seasonal, and meteorological (e.g., wind speed and cloud cover) variables. In addition, several location-specific factors including site geometry and its spatial location (i.e., proximity to parks or water bodies) also control its microclimate.

Canyon Geometry Descriptors and Microclimate

Urban canyons (UCs) are considered basic urban units of a typical urban setting and the central spatial core of its climatic conditions. In literature, the urban street canyon is mostly classified based on its geometrical specifications, i.e., canyon length, sky view factor, aspect ratio (H/W ratio), and orientation (Ali-Toudert & Mayer, 2006; Arnfield, 2003). Several researchers have extensively studied the relationship between these canyon geometry descriptors and urban microclimate. The details of recent studies and important conclusions are given

Table 2.1. Summary of Previous Studies

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Campinas, Brazil	Hot and humid (subtropical)	Street Orientation (15-degree interval), Height to width ratio	Thermal comfort, physiologically equivalent temperature (PET)	1. A northeast-southwest orientation had a significant reduction in PET during the daytime. 2. A H/W ratio of up to 2 increased thermal comfort by increasing shade 3. For H/W less than 0.5, forestry management and green areas were recommended for the augmentation of shade.	(Abreu-Harbich, et al., 2014)
Bangkok, Thailand	Tropical	Street Orientation (4), Height to width ratio, Canyon height	Urban ventilation (Wind velocities)	1. The wind velocity is high in the shallow and long deep canyons.	(Jareemit & Srivanit, 2019)
Ghardaia - Algeria	Hot and dry	Street Orientation (E–W, N–S, NE–SW, and NW–SE), Height to width ratio	Physiologically equivalent temperature (PET), Mean radiant temperature	1. The thermal environment for wide streets (H/W=0.5) is highly stressful and almost independent of the orientation. 2. For a H/W≥2 N–S, NE–SW, or NW–SE orientation streets provide a much better thermal environment.	(Ali-Toudert & Mayer, 2006)
Ghardaia - Algeria	Hot and dry	Street Orientation (E-W, N-S, NE-SW, NW-SE), Height to width ratio using galleries, canyon asymmetry	Physiologically equivalent temperature (PET), Air Temperature	1. Galleries, overhanging facades, vegetation, and street canyon asymmetry have a strong effect on the thermal sensation as compared to air temperature 2. A large value of the sky view factor is linked with high thermal stresses irrespective of a particular orientation. 3. The orientation is important for canyons with a smaller sky view.	(Ali-Toudert & Mayer, 2007)

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Tunis, Tunisia	Subtropical Mediterranean (Mediterranean subtropical climate)	Street orientation, Height to street width ratio, Sky view factor	Wind speed, air temperature, mean radiant temperature, and relative humidity	1. In the summer season, the deepest streets canyons offer acceptable conditions in terms of thermal comfort 2. For all H/W ratios, NS-oriented canyons were found as most comfortable whereas E-W-oriented-oriented canyons experienced the worst degree of comfort.	(Achour-Younsi & Kharrat, 2016)
Stuttgart, Germany		Street Orientation (One street at 0–165-degree rotation), Height to width ratio	Physiologically Equivalent Temperature (PET), mean radiant temperature, air temperature, vapour pressure, wind speed	1. Around 10°C and 25°C reduction in PET values due to trees as compared to green and sealed areas respectively. 2. The northwest-southeast-oriented street canyon with an aspect ratio of at least 1.5 possesses low thermal stress.	(Ketterer & Matzarakis, 2014)
Dhaka, Bangladesh	tropical warm-humid	Street Orientation (E–W, N–S, E–W, and N–S)	3. Air temperature, mean radiant temperature, relative humidity, and wind velocity	For two urban areas with different urban geometry features 1. A 3.3°C and 6.2°C difference in average and maximum air temperature 2. 2.3 °C and10.0°C difference in average and maximum T_{mrt}	(Sharmin, et al., 2017)
Netherlands	hot arid and humid	Different urban forms (singular, linear, and courtyard) Street Orientation (E–W, N–S)	Air temperature, mean radiant temperature, wind speed, relative humidity, Physiological Equivalent Temperature	1. Courtyards provided the most comfortable microclimate during a summer day. 2. N-S-oriented street canyons had a cooler microclimate	(Taleghani, et al., 2015)
Hamadan City in Iran	the cold and mountainous climate	Street Orientation (E–W, N–S, NE–SW, and NW–SE), sky view factor	Air temperature, mean radiant temperature, wind speed, relative humidity, Physiological Equivalent Temperature	1. The north-south-oriented streets are more desirable for the Winter season with an average of 4.5-8 °C and high PET values. 2. For the Summer season, northeast-southwest and northwest-southeast oriented streets provide better thermal comfortable by providing the lowest PET (about 2 °C cooler than other orientations)	(Delpak, et al., 2021)
Riyadh City, Saudi Arabia	hot-arid climate		Outdoor Thermal Comfort, Air temperature, mean radiant temperature, Wind velocity, Energy consumption	1. NE-SW oriented canyons had the lowest PET values as compared to all other orientations	(Alznafer, 2014)

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Southern, China	Hot-Humid	Length-width ratio, canyon types, canyon axis orientation	Wind velocity, Air temperature, mean radiant temperature, PET	1. Greenery and arcades can improve pedestrian-level thermal comfort in E-W orientation streets. 2. For boulevards having an aspect ratio greater than 0.67, dense greenery is recommended. 3. Arcade streets are a better option for neighbourhoods with longer E-W oriented streets and shorter N-S orientation	(Yin, et al., 2019)
Aswan, Tingar, Egypt	hot desert climate	Urban form (Staggered Blocks, Attached Courtyards, NS Oriented Parallel Canyons etc.) and geometrical details (aspect ratio, SVF, Side profile shape)	PET	1. N-S hybrid canyon had the lowest PET values during the day. 2. Aspect ratio equal to 2 recommended for the optimum thermal performance of both N-S and E-W oriented street canyons	(Mahmoud, et al., 2021)
Trondheim, Norway	Oceanic climate	Wind sheltering through Trees and passages closure, building material	air temperature, wind speed, MRT and PM	1. Combined effect of solar access and wind sheltering is important for enhancing outdoor thermal conditions 2. Effect of increasing the albedo of the building surface materials on OTC was insignificant	(Brozovsky, et al., 2021)
Tiantan Park, Beijing, China	Hot Summer Continental Climate	Land cover, radiation condition, vegetation	Air temperature, relative humidity	1. Radiation conditions, land cover composition and vegetation type have a significant impact on air temperature 2. Grassland can increase daytime T_a in both summer and winter	(Li, et al., 2021)
Wuhan, China	Humid Subtropical Climate	Floor area ratio, building height, building density, building width, vegetation coverage ratio, and urban fraction	spatial and temporal distribution characteristics of PM2.5	1. building density and urban fraction have the most significant impact on PM2.5 concentration 2. Floor area ratio and building height have a positive correlation with daytime PM2.5 concentrations, but other	(Xu & Chen, 2021)
Lecce, Southern Italy	Warm and temperate	Urban greening, building layout, and meteorological conditions	Outdoor Thermal Comfort, Mean Radiant Temperature, Predicted Mean Vote	1. Trees decreased daytime average daily air temperature by up to 1.00 °C, Mean Radiant Temperature (MRT) by up to 5.53 °C and Predicted Mean Vote (PMV) by up to 0.53. However, increased the spatially averaged MRT by up to 2 °C during the evenings.	(Gatto, et al., 2021)

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Seongnam, South Korea	Hot Summer Continental Climate	Tree Canopy Coverage and Leaf Area Density	Air Temperature, Relative Humidity	1. Approximately 3 °C and 5.23 °C reduction in daily averaged and daily maximum temperatures respectively due to an increase in tree coverage from 4% trees to 60%.	(Tamaskani, et al., 2021)
New York City, USA	Humid Subtropical	Building materials (highly radiative “super cool” materials)	Pedestrian-level air temperature	1. Modelled super cool roofs lower pedestrian-level air temperature by up to 2.4°C. However, this effect decreases non-linearly with increasing building height. 2. Super cool roofs perform a little better than cool and green roofs.	(Sinsel, et al., 2021)
Dhaka City, Bangladesh	Tropical Savanna Climate	Green roof	Thermal comfort, carbon sequestration	1. Green roofs improve the thermal comfort in bare-roofed buildings during diurnal hours 2. Green roofs showed promising annual carbon sequestration potential (125.4 tC/ha).	(Sultana, et al., 2021)
Guangzhou, China	Humid Subtropical Climate	Canyon aspect ratio, street-wall orientation	Air and surface temperature, wind speed	1. Streets having small aspect ratios exhibited larger daily temperature range (DTR) and earlier hottest time	(Chen, et al., 2021)
Beijing, China	Hot Summer Continental Climate	Building density, average building height, mean building volume, degree of enclosure	Air quality (wind speed, co, and pm2.5)	The air quality improved with 1. Decrease in single building volume 2. Increase in the degree of enclosure 3. Decrease in width and height of the single building	(Jiang, et al., 2021)
Nanjing, China	Humid Subtropical Climate	Floor area ratio, surface area ratio, mean sky view factor	Air temperature, wind speed, direct shortwave radiation, energy loads	1. Significant negative correlations of surface area ratio with the cooling and heating loads	(Zhang & Gao, 2021)
Mashhad, Iran	Tropical and Subtropical Steppe Climate	Height to width (H/W) ratio, canyon orientation, tree canopy cover, building surface materials	Outdoor thermal comfort	1. OTC improved with an increase in the H/W ratio and a decrease in SVF 2. E-W canyon has the worst has worst thermal performance as compared to N-S, NE-SW and NW-SE	(Sanagar, et al., 2021)

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Lodz, Poland	Marine West Coast Climate	Tree Pattern	wind speed,surface temperature, air temperature, Mean radiant temperature, PET	1. Introduction of 10% green area can reduce the maximum air temperature by 0.80 °C in an east–west-oriented canyon, and 0.49 °C in a north-south canyon 2. The corresponding reduction in the PET index is around 10.80 °C in an east-west canyon and 6.66 °C in a north-south oriented street canyon.	(Bochenek & Klemm, 2021)
Guangxi University, China	Humid subtropical climate	Albedo in pavement, height-to-width ratio, orientation, sky view factor	Surface temperature	1. Reflective pavements should be built preferentially on East-West streets and the cross streets due to the higher thermal stresses in these streets as compared to N-S oriented streets 2. The effect of street orientation on surface temperature is higher than that of the sky view factor or aspect ratio. 3. At nighttime, the heat released from building blocks kept the paved street about 0.2 °C hotter than paved areas in open spaces.	(Zhang, et al., 2021)
Pathum Thani, Thailand	Tropical	Building type(row house, single house) orientation, building block shape (square, rectangular), aspect ratio, window-to-wall ratios (WWRs)	Air temperature, mean radiant temperature, cooling energy consumption	1. The row house cluster had better performance in terms of outdoor thermal comfort and PET and cooling energy consumption than a single house. 2. The cooling energy savings through increasing H/W with lowering WWR was up to 32%.	(Jareemit & Canyookt , 2021)
Imam Khomeini International University, Iran	Dry-summer subtropical	Trees and vegetation effect	Energy performance, relative humidity, air temperature, surface temperature, wind speed, MRT, PET	1. The benefits of evergreen and deciduous tree coverage are shown by the most protected microclimate and outdoor thermal comfort improvement.	(Darvish, et al., 2021)
Bandung, Indonesia	Tropical Rainforest Climate	Floor area ratio, building coverage ratio, and building elements (tower, podium, and courtyard).	Air temperature, relative humidity, wind speed, solar radiation	1. FAR has the strongest correlation with air temperature as compared to that of BCR, followed by solar radiation and relative humidity 2. The influence of the tower on wind speed is proportional to building height. 3. Open courtyards are associated with higher temperatures and lower humidity 4. The thermal performance of a combination of a closed courtyard with a hybrid block outperformed the other configurations.	(Dwiputra, et al., 2021)

Location	Climate	Urban Design Variables	Factors monitored	Important Conclusions	Ref
Hong Kong, China	humid subtropical climate	Park-design and urban-landscape characteristics (building volume ratio, distance from park boundary, road cover, distance from sea, shrub cover, sky view factor, tree cover, turf cover and water body cover)	Air temperature, relative humidity	1. For cooling benefits, the area of urban parks needs to be large enough (>5000 m2). 2. The largest park produced a mean and max. cooling of 0.6 and 4.6 °C respectively. 3. Tree cover, shrub cover, SVF and proximity to the sea can explain approximately 55% variability of air temperature and humidity in the park.	(Cheung, et al., 2021)

3. METHODOLOGY

Study Area

The present study was carried out in Islamabad (planned) and Rawalpindi (semi-planned) located at 33.662883° lat, 73.086373°lon. Islamabad is the federal capital of Pakistan and with a current area of 906 km2, it is becoming a fast-growing city in Pakistan. According to the United Nations Habitat 2020 report, the land consumption rate in Islamabad was 4.77 per cent from the years 2000 to 2015, much higher compared to other cities in Pakistan. A similar trend has been observed in the rate of population growth in Islamabad (Habitat, 2020). Rawalpindi is a city in the Potwar Plateau, near Islamabad, and the two are jointly known as the "twin cities" on account of their strong social and economic linkages. With an area of 259 km^2, the estimated population of Rawalpindi is about 2.2 million.

Table 2.1: Land consumption and population growth rates between 2000-2015

City Name	Land Consumption Rate 2000-2015 (%)	Population Growth Rate 2000 - 2015 (%)
Islamabad	4.77	2.56
Quetta	4.37	0.67
Karachi	1.72	2.23
Peshawar	1.91	1.78
Lahore	3.25	1.87

Source: (Habitat, 2020)

Urban fabric and weather

Islamabad was planned by Constantinos A. Doxiadis and Doxiadis Associates in the late 1950s on a gridiron pattern. The formal grid of 2km x 2km divides the whole city roughly into 84 sectors separated by a network of wide principal roads (600 ft.). On the other hand, high population growth has resulted in uncontrolled urban sprawl in the case of Rawalpindi, resulting in a complex urban fabric. Unlike Rawalpindi, Islamabad has a proliferating green cover. As far as the surface texture is concerned, the streets in both cities are covered by asphalt and concrete.

The street network orientation of both cities was visualised using the OSMnx tool. OSMnx is a Python package that uses geospatial data from OpenStreetMap to analyse and visualise the street grid of any city of interest (Boeing, 2017). In polar histograms (Figure 4.1(a) and (c)), the direction of each bar orientation of the streets and its length represents the relative frequency of streets with those orientations. It can be observed that in the case of Islamabad, streets are well-structured, in ENE-WSW (making 34O -angle with east) or NNW-SSE (making

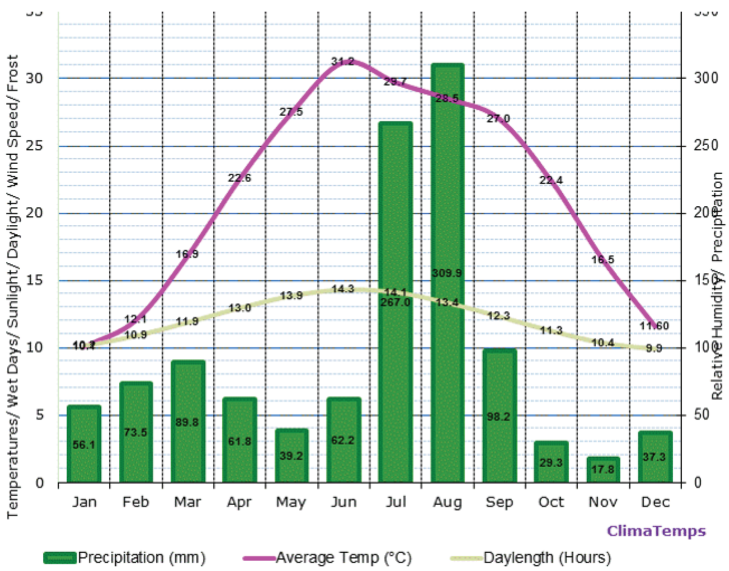
1240 with east) direction, forming the gridiron pattern (shown in Figure 4.1 (b)). As far as the texture is concerned, the streets are covered by asphalt and concrete and are mostly shaded by young trees in the middle of the streets (near street view). On the other hand, Rawalpindi features a grid in small neighbourhoods, but mostly its streets are distributed in every direction, resulting in an organic urban fabric.

Figure 3.1: Street networks and corresponding polar histograms for Islamabad

(a)

As per Koppen climate classification, the twin cities have monsoon-influenced humid subtropical climates (Cwa), i.e., the twin cities have mild dry winters and hot and humid summers (Peel, 2007).

Figure 3.2 Islamabad average climate

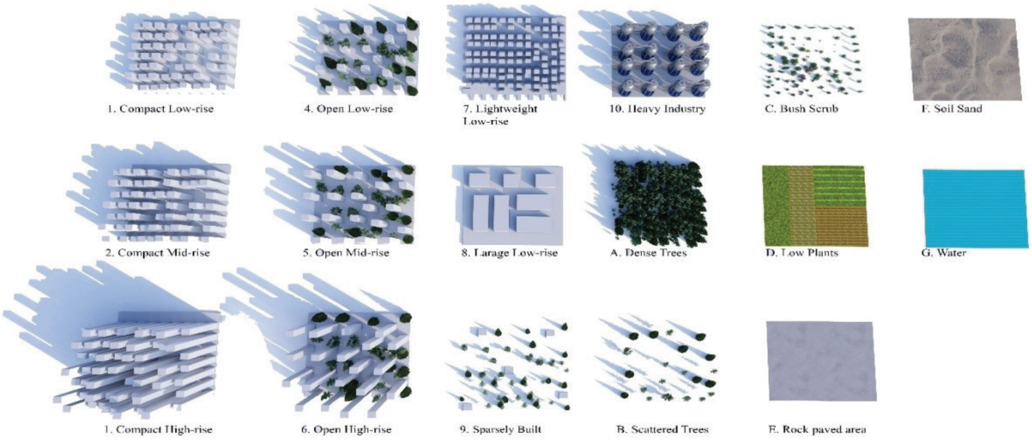


Land Cover and Land Use (LULC) Maps of Twin Cities

Land use and land cover (LULC) generally refers to the categorisation or classification of human activities and natural elements on a certain landscape. LULC can have a significant impact on the local and regional climate dynamics (Mirzaei, 2015). These classification maps are very important for a spatial understanding of local climate and the design of an urban form based on climatic considerations. Several LULC classification schemes have been developed in the past, i.e., Urban Zones of Energy partitioning (UZE) (Rajkovich & Larsen, 2016; Ali-Toudert & Mayer, 2006), Urban Climatic Map (UCMap) system (Arnfield, 2003), Urban Climate Zone (UCZ) scheme (Abreu-Harbich, et al., 2014), and Local Climate Zone (LCZ) scheme (Jareemit & Srivanit, 2019). All of these schemes have used topographic, surface geometry, land use/land cover (LU/LC) patterns, and climatic spatial information as urban indicators.

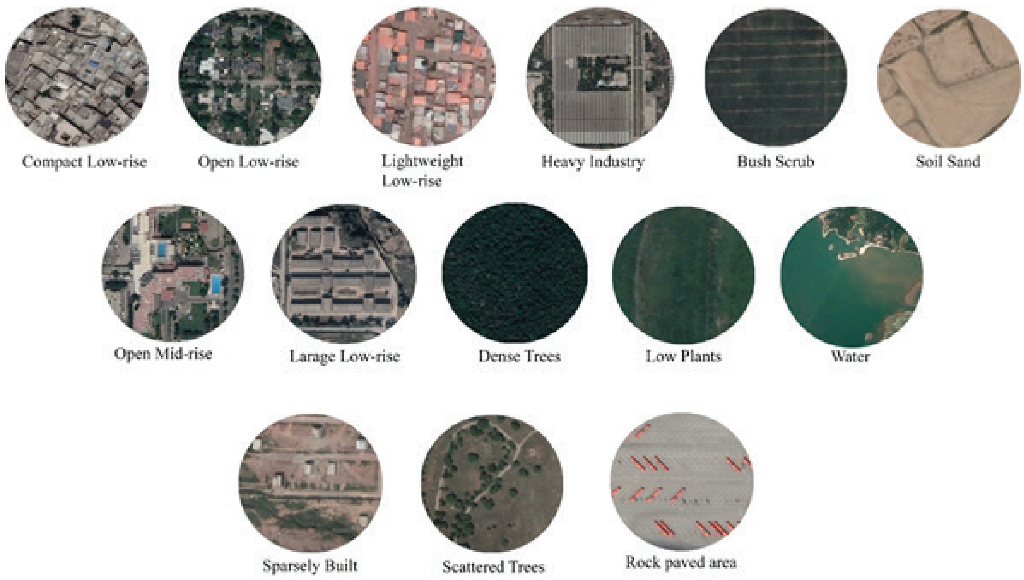
In the literature, several researchers have employed the concept of LCZ to quantify the correlation between urban morphology and UHI. The LCZ classification scheme consists of 17 classes/climate zones where each LCZ class is a depiction of "regions of uniform surface cover, structure, material, and human activity" (as shown in Figure 3.3), and has a uniform temperature. A typical LCZ class can extend from a few hundred meters to several kilometres on a horizontal scale (Jareemit & Srivanit, 2019).

Figure 3.3: LCZ concept visualisation



Therefore, following the local climate zone (LCZ) scheme, both cities, i.e., Islamabad and Rawalpindi, have been classified based on climate-relevant surface properties. The training data for the LCZ classification was generated using high-resolution satellite imagery in Google Earth Pro. The number of training samples created for each LCZ class is presented in Figure 3.4. The World Urban Database and Access Portal Tool's (WUDAPT) web-based application was used for the generation of complete LCZ maps based on our training data. WUDAPT classification tool uses Landsat images and a random forest (RF) classifier present in the System for Automated Geoscientific Analyses (SAGA) software.

Figure 3.4. Training area samples in twin cities defined using Google Earth imagery



The accuracy of the generated LCZ maps of Islamabad and Rawalpindi (shown in Figure 3.5) was assessed in terms of the producer's accuracy (PA), the user's accuracy (UA), and overall accuracy (OA), the overall accuracy of the urban LCZ classes only (OAu), the overall accuracy of the built vs. natural LCZ classes only(OAbu) and a weighted accuracy (OAw). The boxplot figure with accuracies is shown in Figure 3.6. The overall accuracy was 82 %.

Figure 3.5: Number of training areas per LCZ class

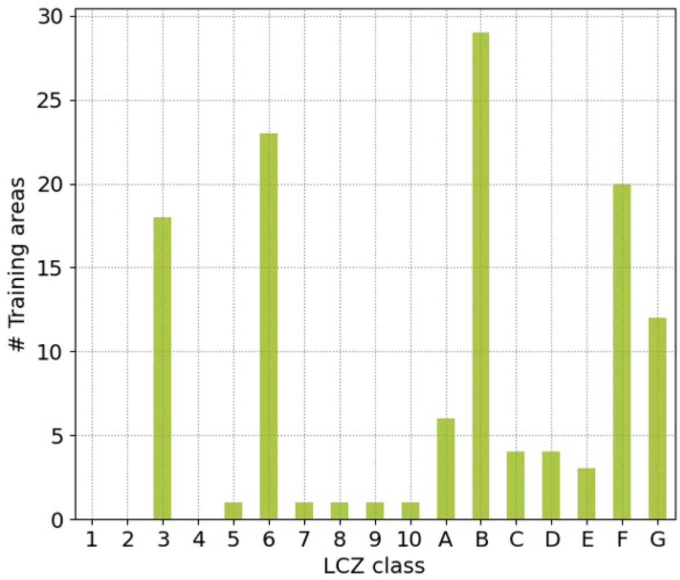
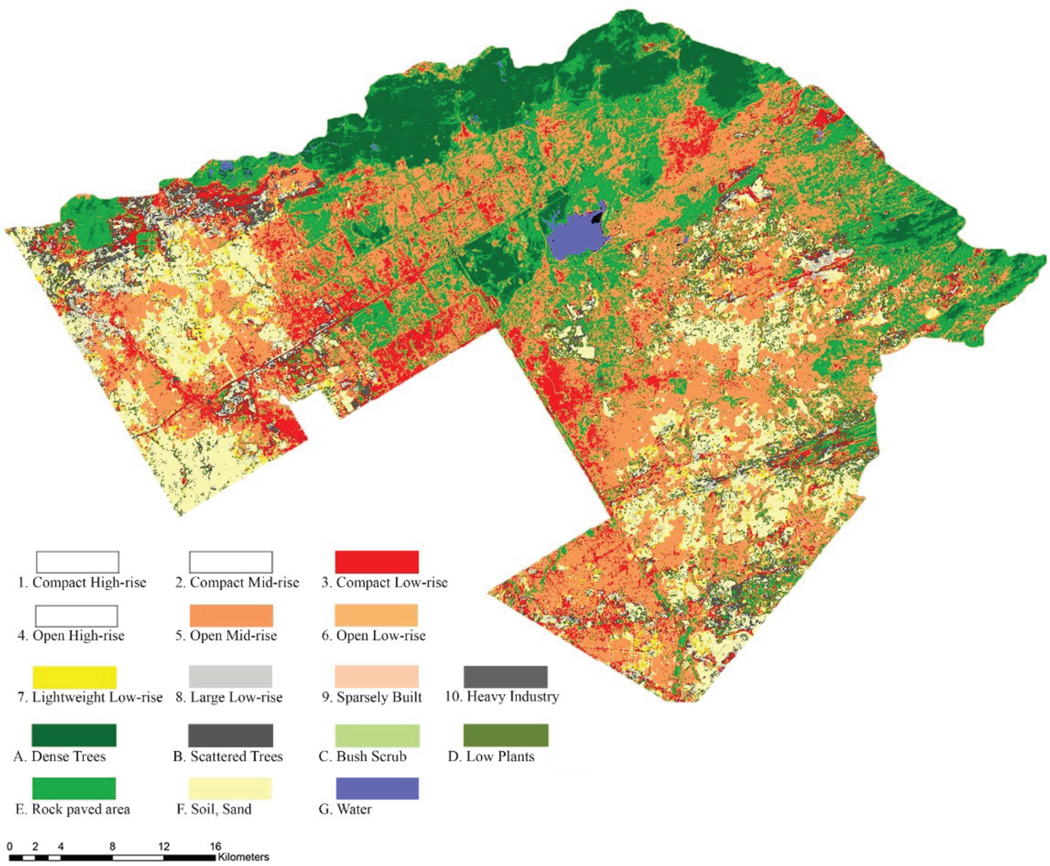


Figure 3.6. LCZ classification map of

(a) Islamabad



(b) Rawalpindi

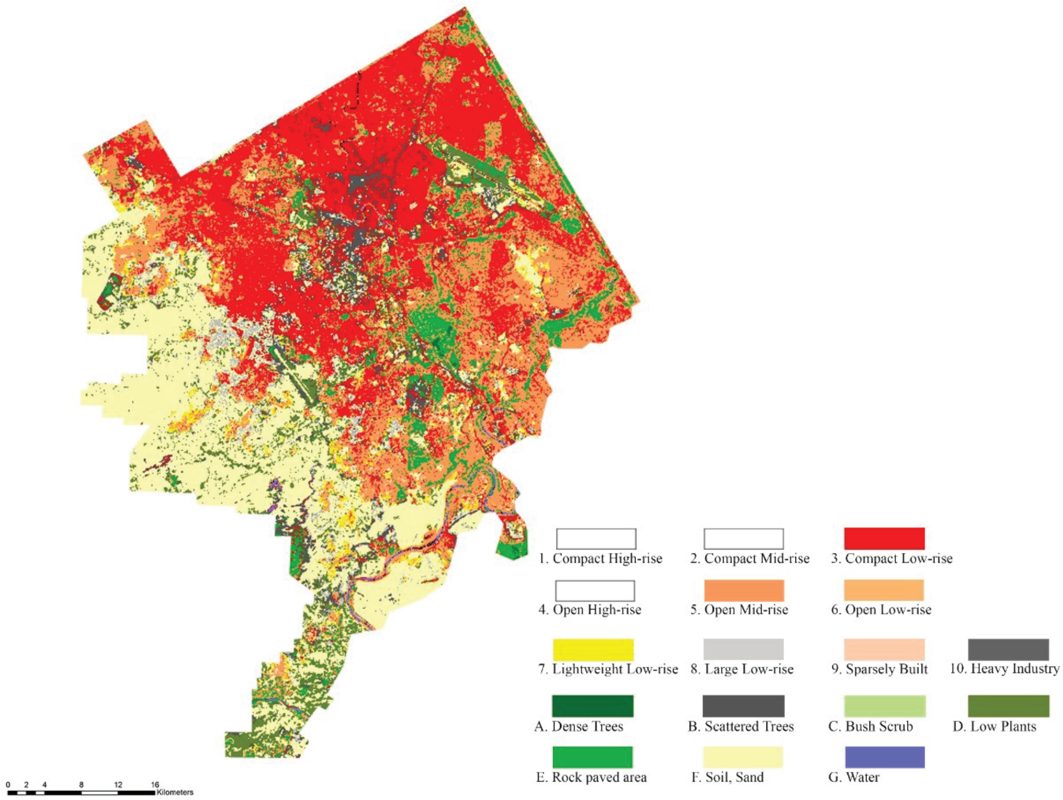
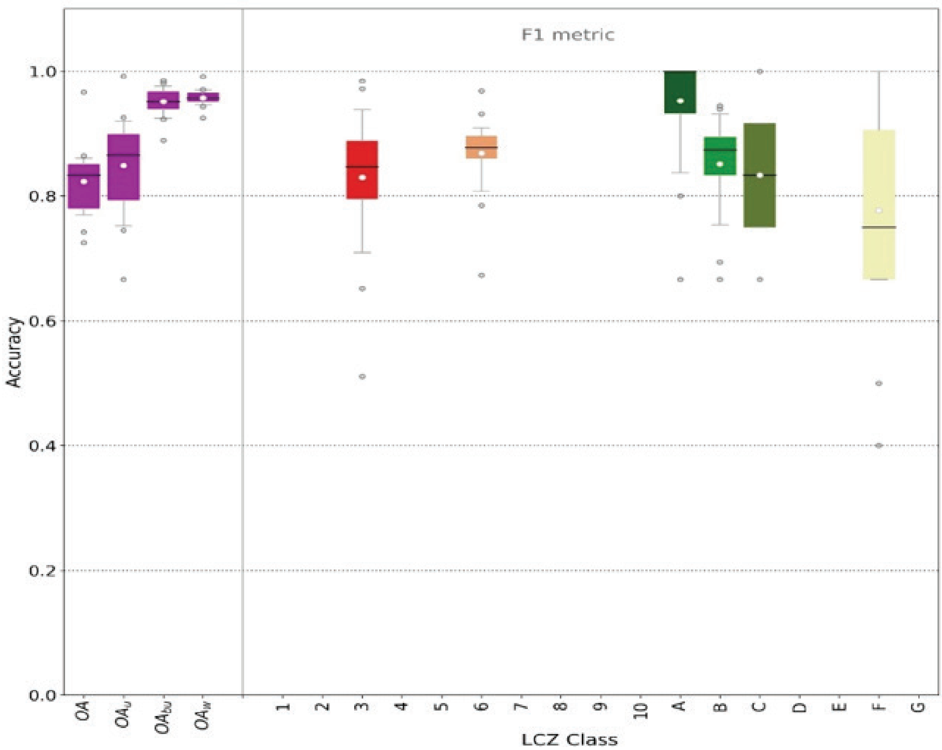


Figure 3.7: Boxplot figure with accuracies



Data Collection

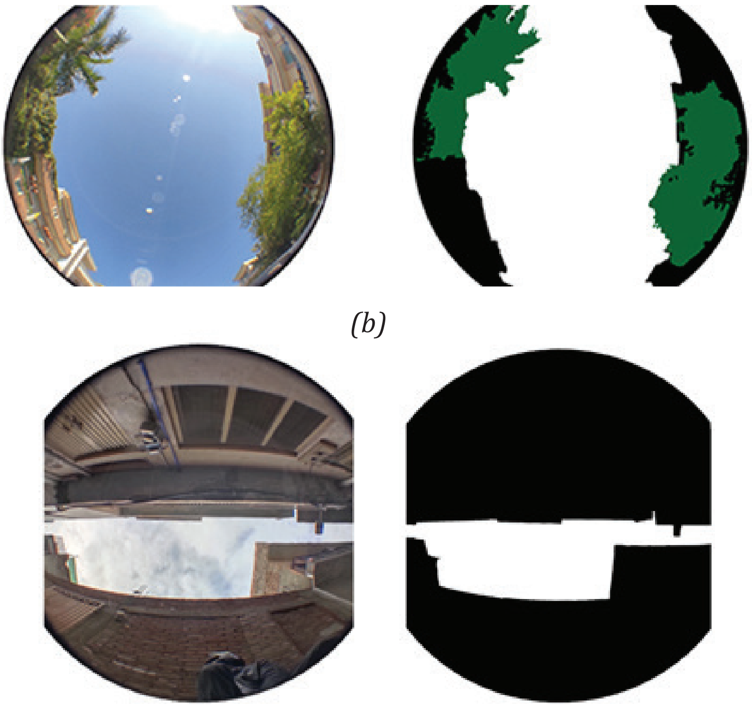
The accurate measurement of the different urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery is required to assess the impact of these variables on urban microclimate. In the case of Islamabad, the data on the lengths, widths, heights, and orientations of the different street canyons is acquired from the capital development authority (CDA). These measurements were further confirmed in the field survey.

In the case of Rawalpindi, lengths, widths, heights, and orientations of different street canyons were calculated during the field survey. For both Rawalpindi and Islamabad, the greenery type and distribution within different street canyons were recorded during field measurements. To calculate the sky-view factor of the different street canyons in twin cities, fisheye images were captured during the field survey. These images were then segmented into the sky and non-sky pixels (shown in Figure 3.8).

Figure 3.8: A fisheye image of a street canyon in (a) Islamabad; (b) Rawalpindi

(a)

(b)



Remote-Sensing (RS) Based Assessment of Urban Microclimate

Land surface temperature (LST) is an important microclimate parameter as its temporal and spatial variations within a city indicate the city's thermal environment and behaviour (Ziaul & Pal, 2016). The retrieval of the LST from remotely sensed thermal infrared (TIR) data has attracted a great deal of attention in recent years (McMillin, 1975). Since then, different methods having different mathematical formulas and input parameters have been developed to retrieve the LST from space-based remote sensing images (Soleimani & Akhoondzadeh, 2018; Sobrino, et al., 2004). However, all these methods include the estimation of spectral radiation and brightness temperature (Kant & Badarinath, 1998).

In the present study, freely available satellite (LANDSAT 8) images were used for the retrieval of LST. The required data weres downloaded from the United States Geological Survey (USGS) (http://landsat.usgs.gov) website. The Landsat-8 imagery of Twin cities used in the present study was acquired at 05:42 UTC (about 10:42 am local standard time) on July 02, 2021. The TIR band 10 was used for the estimation of brightness temperature, whereas visible red (R) and near-infrared (NIR) bands 4 and 5 were used for calculating the Normalised Difference Vegetation Index (NDVI). The steps involved in the calculation of LST are given below:

Step 1: Top Of atmospheric spectral radiance

The top of atmospheric (TOA) spectral radiance ($L\lambda$) was calculated using the following relationship:

$$L\lambda = M_L * Q_{cal} + A_L - O_i$$

where $M_L$and A_L are the band-specific multiplicative and additive rescaling factors, Qcal is the Band 10 image, and Oi is the correction for Band 10 (Kant & Badarinath, 1998).

Step 2: The conversion of radiance to at-sensor temperature

The band-specific thermal conversion constants $K1$ and $K2$ were employed to calculate brightness temperature (BT) using the following relationship:

$$BT = \frac{K_2}{ln\,[(K_1/L\lambda) + 1]} - 273.15$$

The absolute zero (approx.−273.15∘) was added to get the result in degrees Celsius (Tan, et al., 2010).
Step 3: NDVI Calculation

The visible red (R) and near-infrared (NIR)bands of Landsat8 were used for calculating the Normal Difference Vegetation Index (NDVI).

$$NDVI = \frac{NIR\ (band\ 5) - R\ (band\ 4)}{NIR\ (band\ 5) + R\ (band\ 4)}$$

Where R represents the red band (Band 4).

Step 4: Proportional vegetation (PV) Calculation

NDVI values obtained in Step 3 were used for the calculation of proportional vegetation (Pv) employing the following relationship (Sobrino, et al., 2001):

$$PV = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2.$$

The NDVI index is close to one in the area having dense vegetation and to −1 in case of poor vegetation (Rouse, et al., 1974).

Step 5: The calculation of land surface emissivity (LSE)

The following equation was used to determine the LSE (ε):

ε=0.004*PV+0.986

Step 6: LST calculations

$$LTS = \frac{BT}{1+\left\{\left(\frac{\lambda BT}{\rho}\right)ln\varepsilon_\lambda\right\}}$$

Where LST is the land surface temperature in Celsius (oC), λ is the average wavelength of band 10, ε_λ is the land surface emissivity calculated in Step 5 and ρ = 14,380.

Computational Fluid Dynamics-Based Assessment of Urban Microclimate

The use of computational fluid dynamics (CFD) simulation for urban microclimate assessment makes it possible to consider the detailed modelling of every building and the parameterisation of other obstacles within a selected urban area. With the recent advancements in numerical approaches, computational resources and the establishment of CFD best practice guidelines on the relevant topics (Tominaga, et al., 2008; Blocken, 2015; Franke, et al., 2007) , the use of CFD for urban microclimate assessment studies is becoming increasingly popular (Toparlar, et al., 2017). Different open source and commercial CFD software, including CFD series, ENVI-Met, OpenFOAM, AnsysFluent, Phoenics, etc., are being used for the urban microclimate simulation (Stavrakakis, et al., 2021). Any CFD software is based on the three basic principles of physics, i.e., mass, momentum, and energy conservation expressed mathematically as:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0$$

$$\frac{\partial \rho u}{\partial t} + \nabla.(\rho u u) = -\nabla p + \nabla.\tau + F$$

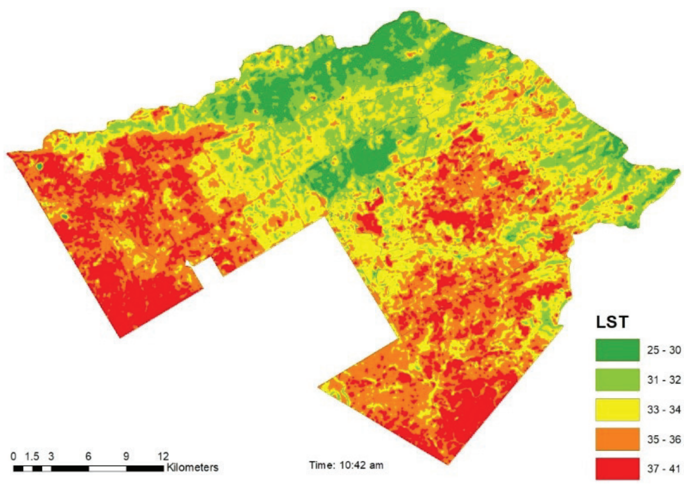
$$\frac{\partial}{\partial t}\left[\rho\left(e + \frac{1}{2}u^2\right)\right] + \nabla.\left[\rho u\left(e + \frac{1}{2}u^2\right)\right] = \nabla.(k\nabla \mathrm{T}) + \nabla.(-pu + \tau.u) + u.\mathrm{F} + Q$$

The solution to the above system of coupled nonlinear partial differential equations gives the temporal and spatial variation of velocity (v), pressure(p), and temperature (T) of the fluid in the entire flow domain.

In the present study, urban flow simulations were performed using Envi-met software. The Envi-met is a frequently used software for environmental analysis and urban planning. Ever since its first release in 1998 until 2017, more than 1,900 registered users worldwide used Envi-met in microclimate-related research applications (Tsoka, et al., 2020). The main reason for its wide popularity is that it allows the possibility of considering the complex urban geometry, position of the sun, various surface types, building materials, and vegetation.

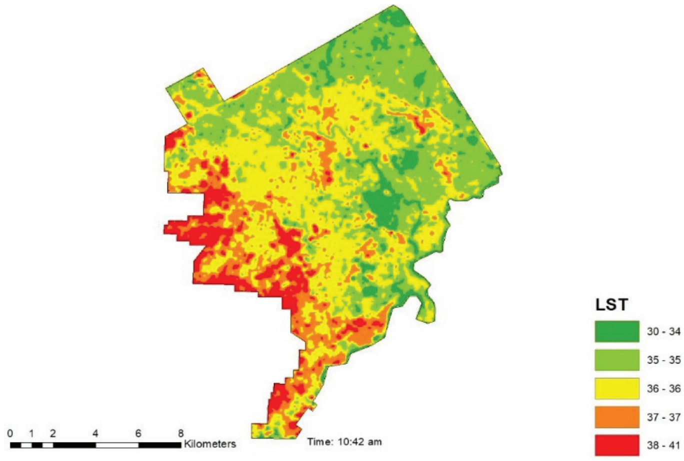
Every CFD simulation problem has the same workflow that can be divided into three basic steps, i.e., pre-processing, processing, and post-processing. Preprocessing includes model development and mesh generation, specification of flow properties, and initial and boundary conditions. Processing implies specifying the solver parameters and discretisation schemes, etc. Post-processing is the last step in the CFD workflow, and it involves the visualisation and interpretation of simulation results. The details on the preprocessing performed in the present study are given in the following paragraphs.

Figure 3.9: LST (0C) map of
(a) Islamabad



(b) Rawalpindi

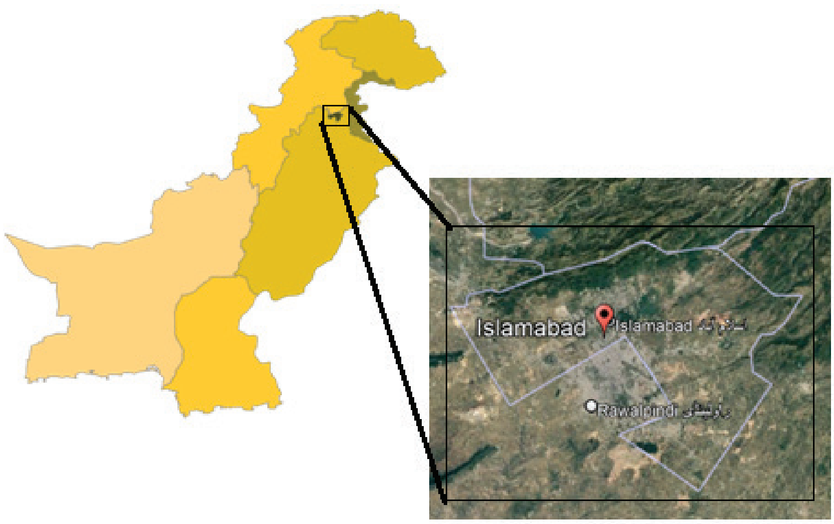
LST MAP 2ND JULY 2021



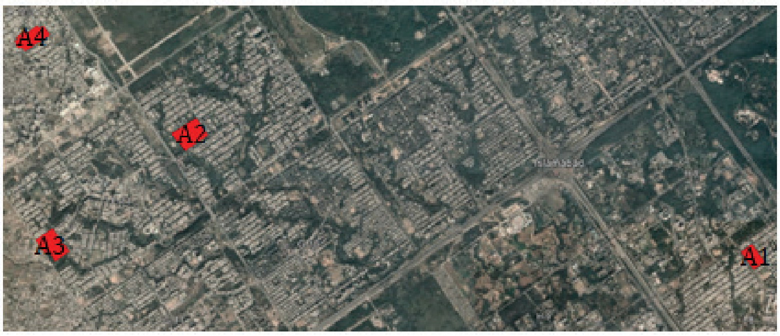
Model development and mesh generation

The ENVI-met study areas of the twin cities are shown in Figure 3.10. The field survey as well as the satellite imagery within the Google Earth Pro software was used to visualise the building footprint, vegetation type, and distribution within each study area of twin cities. AutoCAD was used to delineate building features in the imagery for the generation of 3D models.

Figure 3.10: Study area maps showing :
(a) Twin Cities



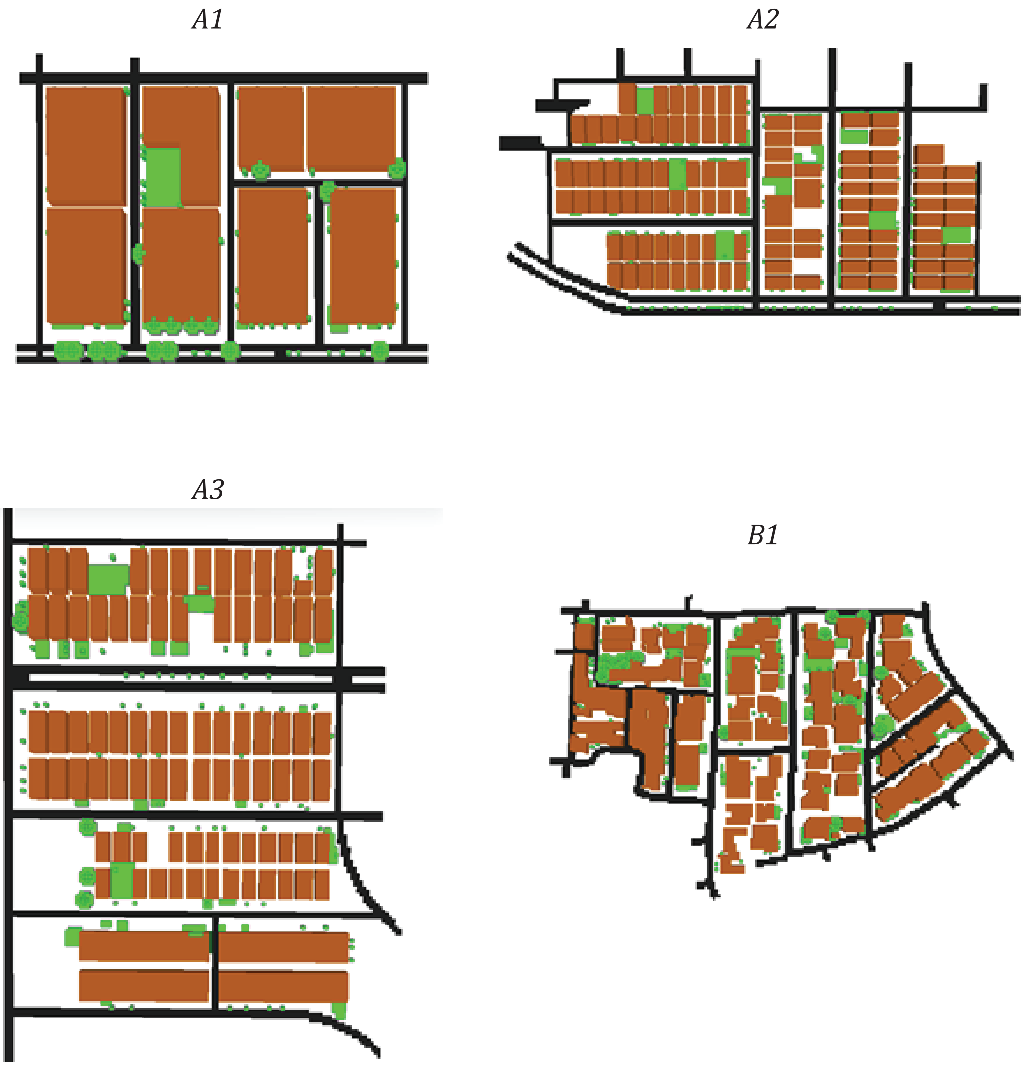
(b) ENVI-met study-areas of Islamabad



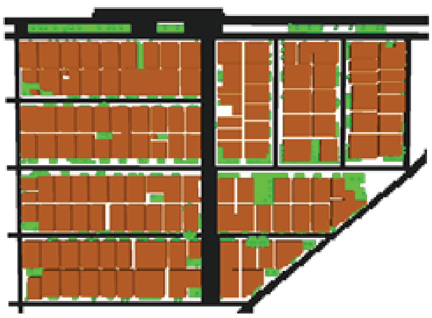
(c) ENVI-met study-areas of Rawalpindi

As per CFD best practice guidelines, the computational domain around each study area extends up to 10h in both lateral and vertical directions (h is the height of the tallest building). ENVI-met can simulate microclimate with spatial resolutions of 0.5-10m and a temporal resolution of 10 seconds, depending on the complexity of the problem and the availability of computational resources. In the present study, a constant grid resolution of 2.5m in the horizontal direction and 1m in the vertical direction was considered a good compromise between resolution and computation time.

Figure 3.11: ENVI-Met 3D models of different study sites in Islamabad (A1, A2, A3, and A4), and Rawalpindi (B1, B2, and B3)



B2



B3

Initial and boundary conditions

The simulations were performed on 10th June 2021, the hottest day of summer with the highest temperature of 43o C in the afternoon. The meteorological conditions to force ENVI-met simulations are site-specific hourly air temperature, relative humidity wind speed, and direction data. The forcing of the metrological variable has been proven to be the best measure to increase the accuracy of the results (Salvati & Kolokotroni, 2019).

Building, soil, and pavement material properties

Building, soil, and pavement properties used as ENVI-met input data are summarised in Table 3.1.

Table 3.1 ENVI-met Input data

Material Type	Properties
Building Material (Wall & Roof)	The thickness of layers =0.12 and the roughness length=0.02m
Soil	Emissivity for longwave thermal radiation=0.98 and roughness length=0.015m
Pavement	Emissivity for longwave thermal radition= 0.9 and reflectivity for shortwave thermal radiation= 0.2 and roughness length=0.01m

In all cases, 14 hours (04:00 am to 06:00 pm local standard time) simulations were performed on a desktop computer with an Intel Core i7-3770K CPU with 16 GB of RAM.

4. RESULTS AND DISCUSSION

Effect of Urban Design Elements of Microclimate

As mentioned earlier, the effect of different urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery are evaluated on microclimate, thermal comfort, and energy consumption. The three important microclimate indicators considered in the present study are:

- LST
- Global radiation flux
- Air temperature

Relationship between the LST and urban design variables

To evaluate the relationship between the LST and different street canyon geometry variables (canyon length, width, height, orientation, and SVF), around 80 different street canyons of Islamabad and Rawalpindi were selected. The LST values inside this street canyon were extracted from the LST map of the twin cities.

The following fitted regression models were obtained using the response surface-based method.

LST (Islamabad) = 34.97 + 0.004 **Canyon Orientation** + 2.4011 **SVF** + 0.0568 **Canyon Width** -0.0486 **Canyon Height**-0.0028**Canyon Length**-0.3190**SVF*Canyon Width**

LST (Rawalpindi)= 35.24-0.0013 **Canyon Orientation** + 0.8863 **SVF**-0.0451**Canyon Width** -0.0524**Canyon Height**-0.0086**Canyon Length**-0.0065 **SVF*Canyon Orientation** 0.0001**Canyon Orientation*Canyon Length**

For the above relationships, the values of R2 (47.6% for Islamabad and 77.6% % for Rawalpindi) represent the proportion of variation in LST that can be explained by these regression models.

To check the statistical significance of the individual estimated coefficients, the t-test was performed (results shown in Tables 4.1 and 4.3). It can be observed that the most of estimated coefficients are statistically significant at 5% levels of significance. The simultaneous significance of the estimated regression coefficients was checked using the analysis of variance and the results are presented in Tables 4.2 and 4.4, respectively. The corresponding p-values of the F-statistic show that both models are adequate at a 5 % level of significance.

Table 4.1: Coefficients of the estimated regression model for Islamabad with standard errors and t-values

Coefficients	Estimates	SE (Coefficient)	t- value	p-value
Constant	29.0734	0.8684	33.479	0
Canyon Orientation	-0.0054	0.00086	-6.267	0
SVF	6.9123	1.3095	5.279	0
Canyon Width	0.6721	0.08283	8.114	0
Canyon Height	-0.0482	0.0185	-2.604	0.011
Canyon Length	-0.0004	0.00068	-0.568	0.572
SVF*Canyon Width	-0.8601	0.11655	-7.38	0
R-Sq = 71.83%, R-Sq(pred) = 65.00%, R-Sq(adj) =69.38% Note: SE (coefficients) is the standard error of coefficients				

Table 4.2: Analysis of Variance

Source	Degree of freedom	Sum of square	Mean Square	F-ratio	P-value
Regression	7	2.83829	0.405469	10.26	0.000
Error	79	3.12304	0.039532		
Total	86	5.96133			

Table 4.3: Coefficients of the estimated regression model for Rawalpindi with standard errors and t-values

Coefficients	Estimates	SE (Coefficient)	t- value	p-value
Constant	34.9514	0.157896	221.356	0
SVF	0.6709	0.298323	2.249	0.027
Canyon Width	-0.0498	0.019848	-2.508	0.014
Canyon Height	-0.0337	0.011971	-2.816	0.006
Canyon Orientation	-0.0014	0.000653	-2.188	0.031
Canyon Length	-0.0058	0.001144	-5.094	0
Canyon Orientation * Canyon Length	0	0.000009	3.233	0.002
R-Sq = 46.14% R-Sq(pred) = 38.67% R-Sq(adj) = 42.46%				

Table 4.4: Analysis of Variance

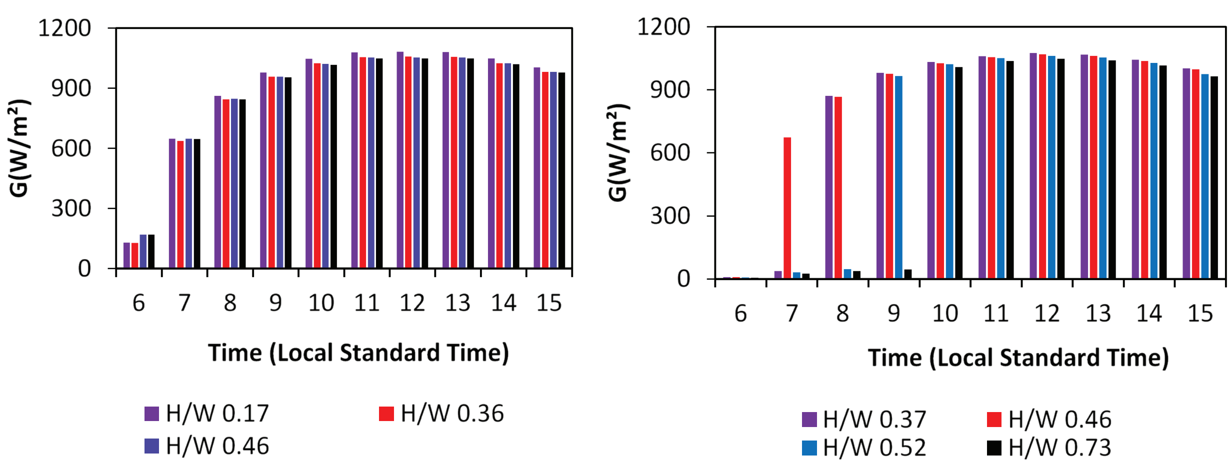
Source	Degree of freedom	Sum of square	Mean Square	F-ratio	P-value
Regression	7	4.46664	0.63809	33.21	0.000
Error	67	1.28723	0.01921		
Total	74	5.75387			

It was observed for both Islamabad and Rawalpindi that Canyon height had a significant inverse correlation with LST. This is because increasing the canyon height provides shade and prevents solar radiation from reaching the ground (Wang & Xu, 2021; Yu, et al., 2019; Watanabe, et al., 2014). Similarly, canyon width had a positive correlation with LST at 5% levels of significance in the case of Islamabad and a negative correlation in the case of Rawalpindi. This is because increasing the canyon width amplifies the absorption of solar radiation thus influencing the LST. However, in the case of Rawalpindi, street canyons are deep and irregular. Therefore, the increase in LST is due to the combined effects of radiative trapping and reduced wind speed in these canyons.

Effect of urban design variables on global radiation fluxes

The hourly mean global radiation at the four different streets having the same orientation but different H/W ratios are presented in Figures 4.1 (a)and (b). It can be observed from these figures that the intensity of global radiation decreases with an increase in H/W ratios. A similar trend in the short-wave radiation fluxes behaviour is observed by other researchers (Ali-Toudert & Mayer, 2006).

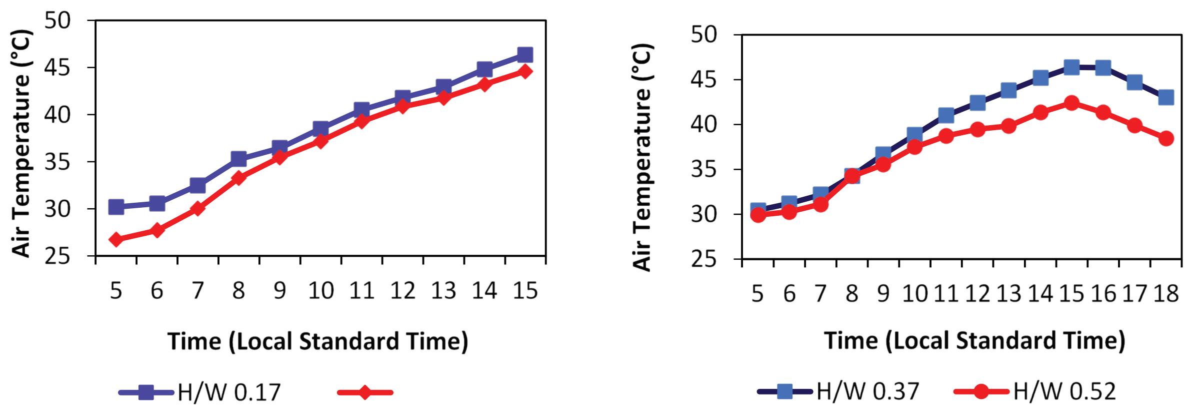
Figure 4.1 Shortwave radiation fluxes received at 1.5 m above the ground for (a) ENE-WSW oriented streets in Islamabad and (b) N–S oriented streets in Rawalpindi



Effect of urban design variables on air temperature

Hourly evolution of the air temperature in urban streets having different H/W ratios is shown in Figures4.2 (a) and (b). An inverse relation between the air temperature and the H/W ratio can be observed from both figures. This is because the number of radiations reaching the street space decreases with the increase in the H/W ratio, which results in a decrease in air temperature. A reduction of 2.10 C and 40 C in the peak air temperature can be observed due to the increase in the H/W ratio, for Islamabad and Rawalpindi, respectively.

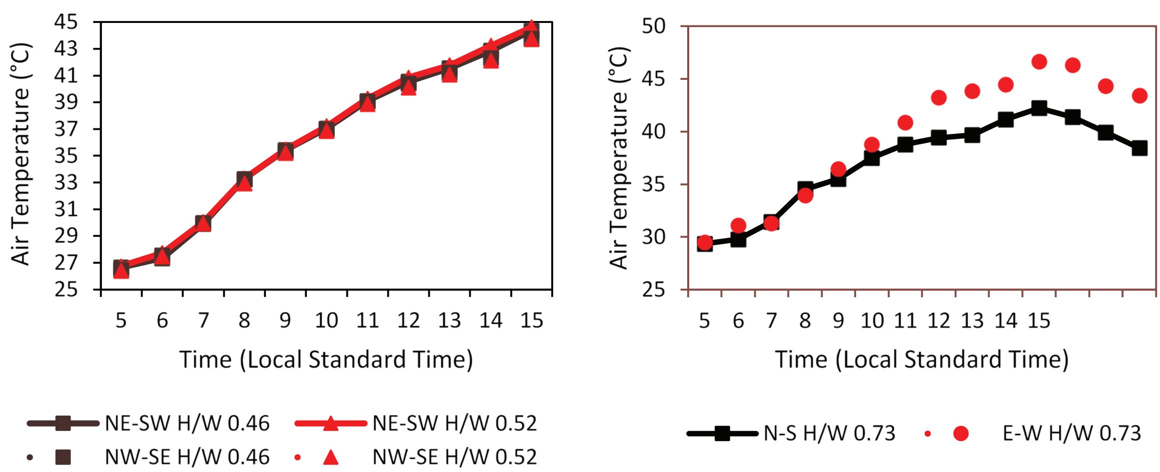
Figures4.2 Hourly evolution of the air temperature for (a) ENE-WSW oriented streets in Islamabad and (b) N–S oriented streets in Rawalpindi

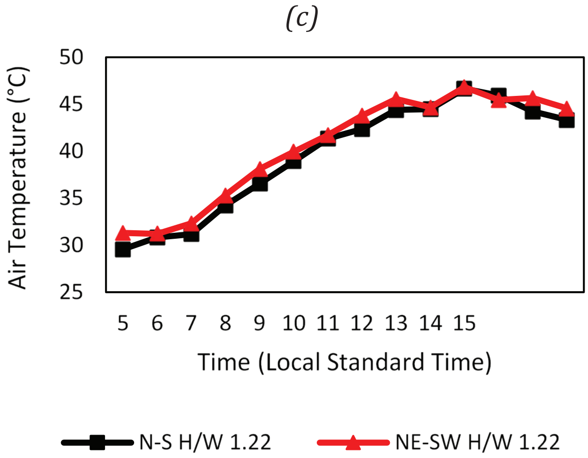


Figures 4.3 (a) and (b) and (c) demonstrate the air temperature variation trend inside the street's canyon having fixed H/W ratios and different orientations (NE-SW and NW-SE in the case of Islamabad and E-W, N-S and NE-SW in case of Rawalpindi). It can be observed from Figure 4.3 (a) that street canyons oriented in the NE-SW direction were slightly warmer than NW-SE oriented canyons. Similarly, irrespective of the H/W ratio, the street canyons oriented in the E-W direction were warmer canyons oriented in other directions (N-S and NE-SW) as shown in Figures 4.3 (b) and (c). This is because the warming of the air in a canyon is related to the solar exposure of canyon surfaces. The prolonged solar exposure of E-W and NE-SW-oriented street canyons was the main reason for the high heat stress inside these streets.[27]

Figures 4.3: Variation in simulated air temperature for (a) NE-SW and NW-SE, oriented street canyon having H/W=0.46 and 0.52 in Islamabad(b)and (c) E-W, N-S and NE-SW oriented street canyon having H/W=0.73 and 1.22 in Rawalpindi

(a) *(b)*





Effect of Urban Design Variables on Thermal Comfort

For the current research, the effect of urban design variables was evaluated on two thermal comfort indices, i.e., mean radiant temperature (T_{mrt}) and physiologically equivalent temperature (PET). Mean radiant temperature (MRT) is a measure of the average temperature of the surfaces surrounding a particular body, with which it will exchange thermal radiation. It measures the linkages between the outdoor environment and human well-being. ENVI-met calculates Tmrt using the following relation (Yang, et al., 2011).

$$T_{mrt} = \left[\frac{1}{\sigma}\left(E_t(z) + \frac{\alpha_k}{\varepsilon_p}\left(D_t(z) + I_t(z)\right)\right)\right]^{0.25}$$

σ is Stefan-Boltzmann constant, E_t (z)represents total longwave radiation from ground, walls, and atmosphere, α_k is the absorption coefficient for short wave radiation of the irradiated body surface, ε_p is the human body emissivity, D_t (z) is diffusely reflected solar radiation, and I_t (z) is direct irradiance.

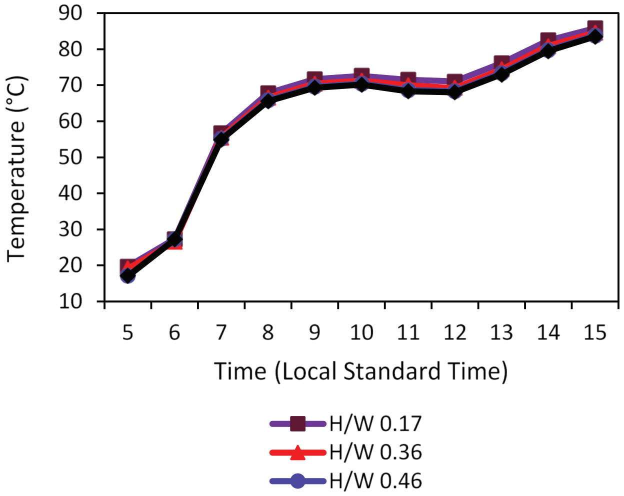
PET is considered to be one of the most popular thermal indexes and is widely used for the assessment of human outdoor thermal comfort. PET is based on the "Munich Energy Balance Model for Individuals" and considers all the relevant environmental factors (i.e., solar radiation, air temperature, humidity, and wind) while keeping thermo-physiological actors (e.g., age, clothing, activity, etc.) to be constant (Höppe, 1999).

Effect of urban design variables on Tmrt

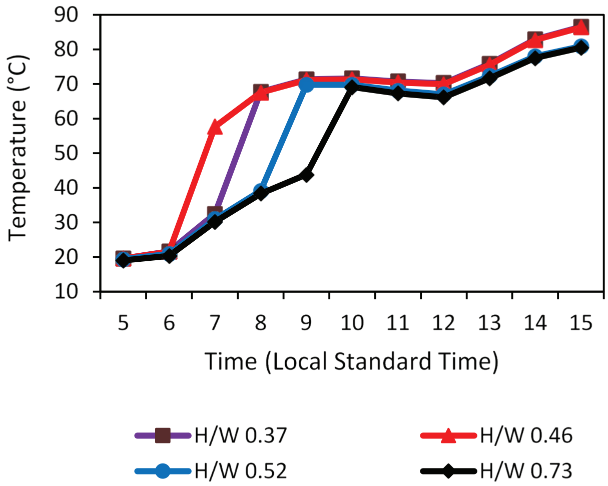
Figures 4.4 (a) and (b) present the relationship between T_{mrt} and different H/W ratios per hour of the day. It can be observed that for both Islamabad and Rawalpindi, T_{mrt} had relatively low values in the deep street canyons. This is in agreement with Q. Dai et. al Dai et al., (2012). who demonstrated that Tmrt decreases with increasing H/W ratios. By increasing the H/W ratios, the reduction in daytime peak Tmrt observed for Islamabad and Rawalpindi were 2.28°C and 6.02°C, respectively.

Figure 4.4: Trend of Tmrt against increasing H/W for (a) ENE-WSW oriented streets in Islamabad, (b) N–S oriented streets in Rawalpindi

(a)



(b)

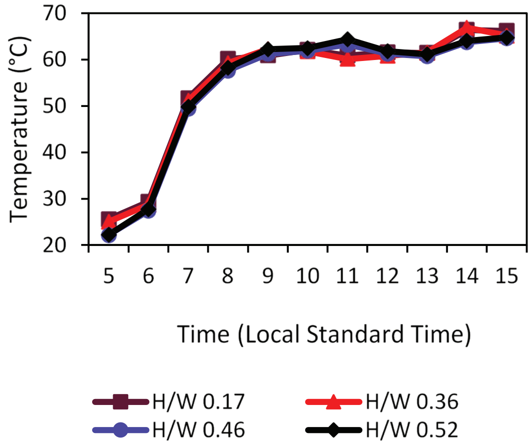


Effect of urban design variables on PET

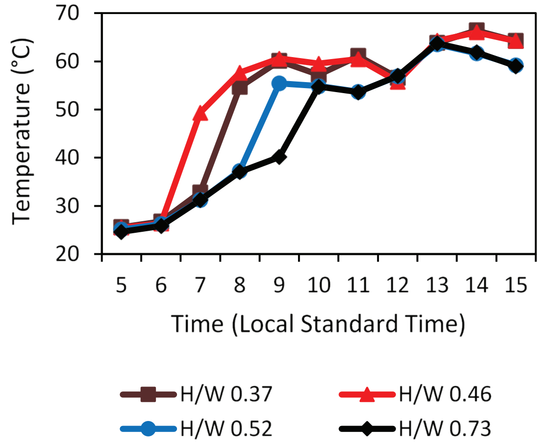
Figures 4.5 (a) and (b) depict the hourly evolution of PET in the street having different H/W ratios. Although PET >410 (corresponding to an extreme heat stress level) most of the time, a significant increase in the PET peak values with the decrease in H/W ratios was observed. In the case of Islamabad and Rawalpindi, there was a reduction of 2.30C and 4.60C, respectively in PET peak values. These results are consistent with findings from previous relevant studies (Lobaccaro, et al., 2019).

Figure 4.5: Variations in daytime PET for (a) ENE-WSW oriented street canyons in Islamabad and (b) N–S oriented street canyons in Rawalpindi

(a)



(b)



Figures 4.6 (a), (b), and (c) represent PET differences inside the street canyons having fixed H/W ratios and different orientations (NE-SW and NW-SE in the case of Islamabad and E-W, N-S and NE-SW in the case of Rawalpindi). It is evident from these figures that regardless of H/W ratios, E-W and NE-SW-oriented streets experienced more heat stress for a longer time than N-S and NW-SE-oriented streets. In the case of Islamabad, NE-SW streets at both H/W ratios are up to 7.5 °C (on the PET scale) warmer than NW-SE streets during peak PET times. Similarly, in the case of Rawalpindi, E-W streets having H/W= 0.73 were up to 5.15 °C (on the PET scale) warmer than N-S streets during peak PET times.

Figure 4.6: PET differences inside the streets canyon (a) NE-SW and NW-SE, oriented street canyon having H/W=0.46 and 0.52 in Islamabad (b)and (c) E-W, N-S and NE-SW oriented street canyon having H/W=0.73 and 1.22 in Rawalpindi

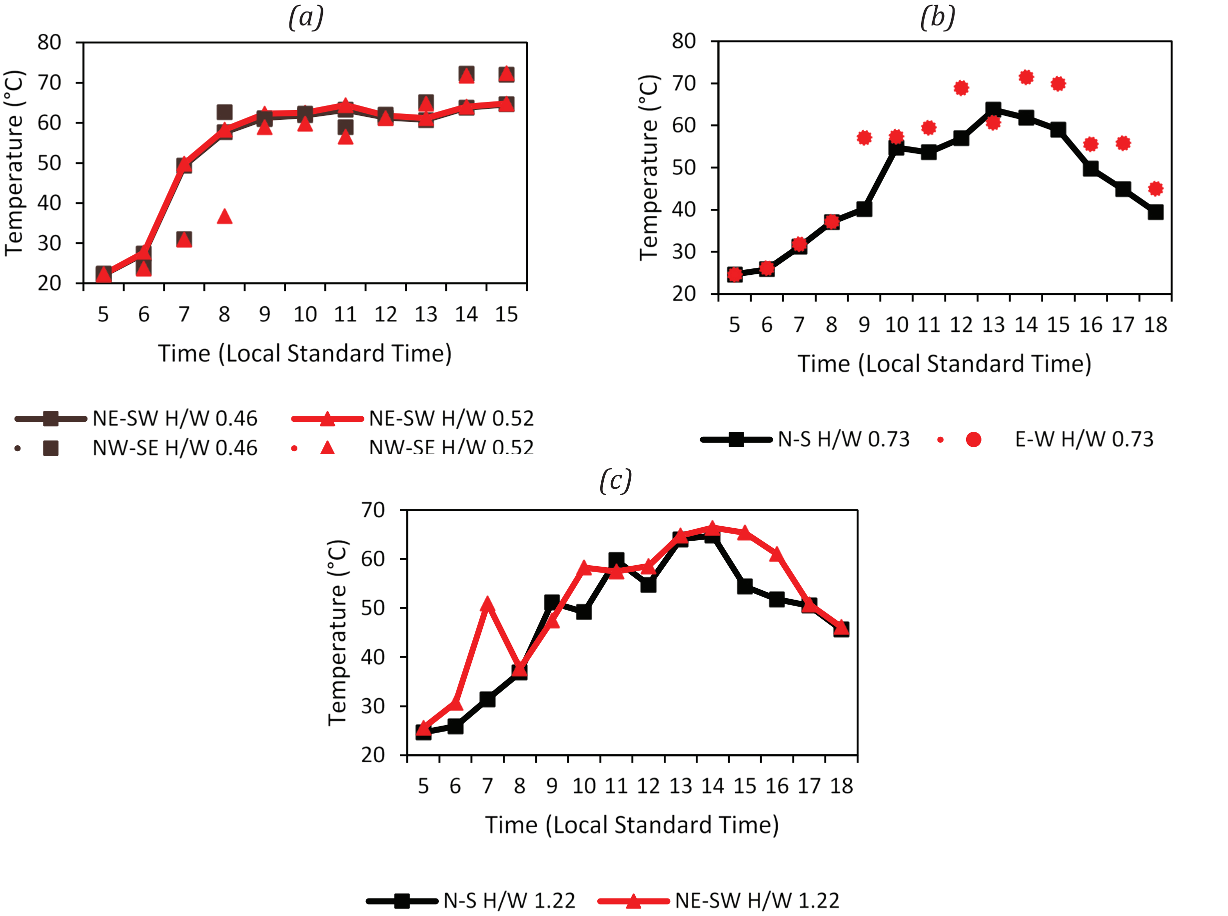
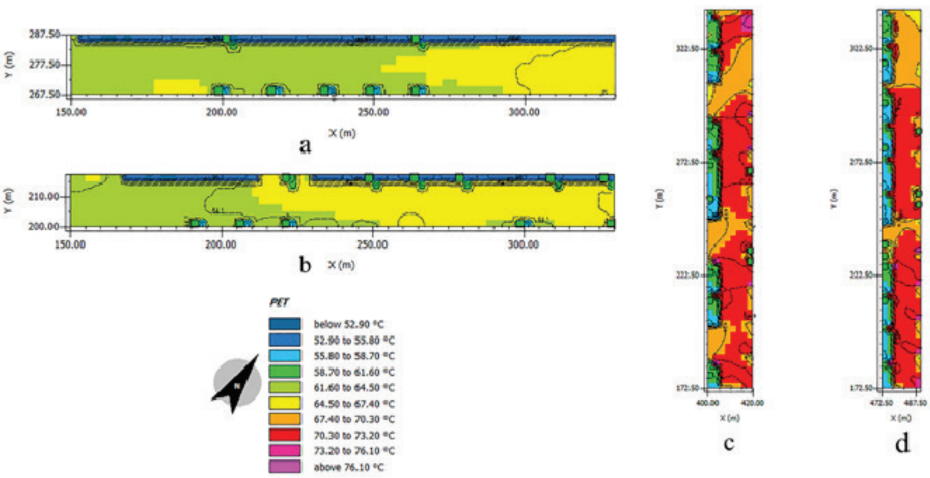


Figure 4.7 (a), (b), (c), and (d) visualised the spatial distribution of PET within a street canyon at 1.5m height for NW-SE oriented streets (a and b) and NE-SW oriented streets (c and d). From Figures 4.7 (b) and (c), extreme thermal stress (≥ 41°C PET) can be observed that can observed within the NE-SW oriented street canyon at both H/W ratios. However, a significant reduction in the PET intensity can be observed in the vicinity of trees. Thus, the thermal performance of NE-SW oriented street canyons can be improved by increasing the tree coverage of these streets.

Figure 4.7: Spatial distribution of PET within a street canyon at 1.5m height for (a) and (b) NW-SE oriented streets (H/W= 0.46, 0.52); (c) and (d) NE-SW oriented streets (H/W= 0.46, 0.52)



5. CONCLUSIONS

Our study investigated the effects of urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery on the urban microclimate using remote sensing and computational fluid dynamics-based techniques. The important conclusion derived from the current research can be used by designers for climate-responsive urban design in case of the future extension of these cities. The important results of the current research are:

- LCZ-based LULC classification of the twin cities revealed that the residential areas of Islamabad mostly consist of open low-rise buildings, whereas Rawalpindi residential areas are dominated by compact low-rise infrastructure.
- Being highly urbanised regions, most of the urban areas in twin cities are associated with high LST.
- According to the regression analysis results, canyon height, width, and length had a significant inverse correlation with LST for both cities. This implies that increasing the values of these parameters will bring a prominent cooling effect. The sky view factor had a significant positive correlation with LST in both cities. Therefore, decreasing sky view factors either by (i) introducing the deep street canyons or (i) increasing the greenery inside the wide canyon will reduce the LST intensity inside these street canyons.

  According to the CFD simulation results:

  - The intensity of global radiation decreased with an increase in H/W ratios.
  - An inverse relation between the air temperature and the H/W ratio can be observed for both cities. A reduction of 2.10 C and 40 C in the peak air temperature was observed due to the increase in H/W ratios for Islamabad and Rawalpindi, respectively.
  - In the case of Islamabad, street canyons oriented in the NE-SW direction were slightly warmer than NW-SE oriented canyons. Similarly in the case of Rawalpindi, irrespective of the H/W ratio, the street canyons oriented in the E-W direction were warmer than canyons oriented in other directions (N-S and NE-SW).
  - For both cities, i.e., Islamabad and Rawalpindi, Tmrt had relatively low values in the deep street canyons.
  - In the case of Islamabad and Rawalpindi, a reduction of 2.30C and 4.60C, respectively, in the PET peak values was noticed due to the increase in H/W ratios.
  - In the case of Islamabad, NE-SW streets were up to 7.5 °C (on PET scale) warmer than NW-SE streets during peak PET times. Similarly, in the case of Rawalpindi, E-W streets having H/W= 0.73 were up to 5.15 °C (on the PET scale) warmer than N-S streets during peak PET times.
  - However, a significant reduction in the PET intensity was observed in the vicinity of trees. Thus, the thermal performance of a street canyon can be improved by increasing the tree coverage of these streets

6. POLICY RECOMMENDATIONS

- The instant study underscores the significance of altering contemporary regulations and bylaws to encourage more efficient layouts and elevations, such as vertical construction.
- The magnitude of the impact of different urban design variables on urban microclimate, and outdoor comfort may vary from city to city, therefore, an appropriate scientific intervention ought to be followed at the very inception stage to ensure climate-responsive urban planning and design.

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PROSPECTS FOR THE DEVELOPMENT OF SOLID WASTE MANAGEMENT SYSTEM: A CASE STUDY OF METROPOLITAN CITY KARACHI

Shaista Alam (Late) and Ambreen Fatima

ABSTRACT

The study aims to explore the public and private institutional structure, its weaknesses, and the obstacles it faces in managing the solid waste system in Karachi. Specifically, the study aims to make (1) a capacity assessment of the public sector in providing the service, (2) an assessment of the role of the private sector and workers managing solid waste formally or informally, and (3) an estimation of households' willingness to pay and the ability to pay for the better management of the solid waste in Karachi. For assessment purposes, the study conducted a comprehensive household survey and interviewed key players involved in the management of solid waste. The study covered all 6 DMCs and 18 towns of Karachi. Based on the information collected from the secondary reports shared by the SSWMB and other officials of the KMC, a detailed descriptive assessment was done regarding (i) generation, (ii) collection, (iii) the cost of collection, and (iv) human and physical input involved. To explore the role of private contractors and informal players, separate interviews (KIIs) were conducted. Information collected from the private contractors not only helped us to understand the system hierarchy in managing solid waste but also the cost and profit involved in each step – a kind of value chain analysis. The study also developed a detailed household questionnaire to evaluate (i) the current practices in handling solid waste by households, (ii) the perception regarding the clean environment, and (iii) household willingness and ability to pay in managing solid waste in Karachi. The study summarised all the findings by conducting a SWOT analysis.

1. INTRODUCTION

Currently, Pakistan is experiencing rapid urbanisation and environmental degradation, especially in its major cities such as Karachi mainly because of the improper handling of solid waste. Though the local and municipal governments are responsible for collecting waste, only about 60-70 per cent of solid waste in the cities gets collected. Karachi being the industrial and commercial hub and having a large residential area, comprising a population composed of multiple cultures, is facing many types of socio-economic issues with solid waste at top of the list. The population is touching around 20 million and waste generation is causing a serious problem for the social and economic development of the mega city. The literature on solid waste management predicts a sharp increase in waste generation. For example, ESCAP/IUCN/UN HABITANT (2013) estimated that the average household solid waste generation in Karachi is around 0.44 kg/cap/day, ranging from 0.19 to 0.84 kg/cap/day. Fruit and vegetable market generates 1.795 kg/shop/day and 11.77 kg/shop/day, respectively. In 2016, Sabir et al. highlighted that on daily basis nearly 12,000 tons of solid waste was generated in six districts of the city (Sabir et al., (2016). KCCI Research & Development Department (2018) reported that solid waste generation in Karachi hovers between 12,000 to 15,000 tons per day of which only up to 10,000 tons per day gets collected. More recently, Korai et al. (2019) estimated that Karachi generates around 0.57kg/cap/day. Studies also estimate that around 55 thousand tons of waste is generated per day in urban areas of Pakistan, and almost 60 per cent of it is transported by districts' municipal councils (DMCs). The municipal authorities face many constraints in managing solid waste in cities, and the provision of better services has become a nightmare. The city is now managing solid waste through private contractors' cooperation, both international (China and Spain) and local.

The issue is not new and has remained under debate for since long. For example, Ali & Hasan, (2001) reported that most of the solid waste was dumped at kuchra kundis, which was supposedly collected and transported to landfill sites by the district municipal councils (DMCs) of Karachi. But in practice, a part of that waste (about 1,400 tons) was picked by scavengers daily from the kuchra kundis, with no records available. The role of the private/informal sector in managing waste has not been highlighted in detail. Keeping in view the economic development, population growth, greater urbanisation and higher average income of the households, the production of waste is projected to increase further. In this situation, the magnitude of waste produced, formal and informal employment, and the possibilities of recycling would also increase.

Solid waste management has, therefore, become one of the most debated issues, especially in developing urban areas because of rising consumption (Abas & Wee, 2014; Marshall & Farah bakhsh, 2013). Shahid & Nargis (2014) found that most developing countries face problems to manage solid waste material, which is rapidly growing due to the increase in population and the rate of development. Municipal solid waste is generated from various activities of daily life and usually increases with the growth of population and income (Tseng, 2011).

Mahar (2014) reviewed the practice of solid waste management in urban areas of Pakistan. The study found that not a single city showed a proper solid waste management system. Haider et al. (2013) studied a household-level analysis of SW generation rates across different income groups in Rawalpindi, Pakistan. The results revealed that the SW generation was greater in higher-income groups than in lower-income group households. Altaf & Deshazo (1996) study surveyed a solid waste disposal area in Gujranwala city and the results revealed that households were willing to pay for improved SWM service.

Sabir et al., (2016) inspected the situation of solid waste management procedures employed in Karachi and the challenges faced by the responsible authorities. This study found that the citizens were disappointed with the performance of the solid waste system in Karachi. The study also found that municipalities faced a lack of financing and appropriate instruments to ensure their effectiveness. The citizens of Karachi are also a contributing factor to the growing waste through their participation in unlawful disposal. With the increasing solid waste per day in the city, there is a need to implement an adequate system of dumping or recycling solid waste on daily basis.

There is substantial literature available on the topic (see Annex A1) but after experiencing urban flooding and the establishment of the Sindh Solid Waste Management Board – the creation of a parallel system instead of removing inefficiencies and strengthening the old system – has diverted the literature towards exploring the inefficiencies prevailing in the system. The available literature remains focused on exploring generation, collection, and recycling issues. Literature also provides evidence of environmental hazards as well. The literature that explores the institutional structure, its weaknesses, and the obstacles it faces in managing the system is very limited.

Aims and Objectives

Given the scenario discussed above, the study aims to, firstly, provide a comprehensive review of the existing system and practices in managing solid waste. Secondly, it provides an in-depth assessment of the role of private contractors and the informal sector in SWM. Based on the information gathered through the interviews of key officials, private contractors, players working informally and households, the study aims to suggest an efficient waste disposal policy. Specifically, the objectives of the study are to:

- Understand the current process/practice of solid waste management (SWM) in the city of Karachi by categorising the type of waste generated and the process of managing the different types of waste.
- Evaluate the capacity of the public sector in managing solid waste, i.e., the assessment of the public sector to highlight the major problems faced by the public authorities in managing solid waste and point out the inefficiencies within the system.
- Identify the incapacity/gap in the provision of services delivered by the public sector.
- Evaluate the role of the private sector (contractors directly hired by the public authorities or informally) in managing solid waste, highlighting their motives and interest in entering the business. The type of activities performed by the private sector is also examined.
- Estimate the extent of informality in managing the SW.
- Evaluating prospects of collected waste for recycling and reuse.
- Estimate households' WTP for managing SW

By assessing the roles of public, private, and informal sectors in managing solid waste, the proposed study aims to provide policy options for the efficient management of solid waste using SWOT analysis.

2. METHODOLOGY AND SCOPE OF STUDY

The above-stated objectives were assessed by conducting a comprehensive analysis of all the stakeholders involved at different levels starting from the waste produced, collected, transported, and disposed-off/recycled/reused. The study is based on a survey of 18 towns in Karachi. This helped in evaluating the role of DISTRICT MUNICIPAL COMMITTEES (DMCs) in managing solid waste in localities across all 6 districts. The study collected primary information through key informant interviews and household surveys. We interviewed almost all the key stakeholders, i.e., households, officials of DMCs, private contractors, and informal players in the system. In addition, small scrap dealers (kabarias operating both at large and small scale) and small-scale industries involved in recycling were also contacted for a value chain assessment. To assess the objectives, the study performed:

- Capacity Assessment Analysis: Given the information collected through KIIs of public officials, the capacity of the public sector in providing the service was assessed
- An Assessment of the Role of Private and Informal Sectors: Both qualitative and quantitative analyses were performed to evaluate the role of the private sector and informal workers in managing SW.
- Value Chain Analysis: To evaluate the prospects of recycling and reuse, a value chain analysis was performed to explore the profit margin of private/informal players involved in SWM, given that the SSWMB is not involved in recycling/reuse.

- WTP analysis: Socioeconomic conditions of the households surveyed were assessed in-depth for the estimation of households' WTP. The detailed methodology is discussed in section 4.4

- Assessment of Linkages vs. Leakages: To understand the current practices/process of solid waste management a comprehensive framework is developed. The framework explores linkages and leakages at each level. The leakages identified were based on the qualitative and quantitative assessments performed.

- SWOT Analysis: In the final stages, the study identified the strength, weaknesses, opportunities and threats involved in managing solid waste in Karachi.

Data Collection, Designing of survey Instruments and Field Visits

As the study mainly aims to collect information through KIIs of public officials and private contractors, and surveys of informal players and households, the methodological design of the study put comprehensive effort into highlighting the issues to be probed during KIIs and household and informal player surveys. The step followed included:

- The finalisation of all the survey instruments (see attachments: A3.1 (private contractors), A3.2 (informal players) and A3.3 (households)).
- The pre-testing of the instruments to iron out field-level problems, if any, and the finalisation.
- Identification of the sampled households using an appropriate randomisation process.
- Developing a field plan for efficient coverage of the sample.
- Actual face-to-face information collection, using a set of issues, from public officials and private contractors, by employing thoroughly trained interviewers.
- Data entry and data cleaning.

Finalisation of the Survey Instruments

Public officials

As the first step officials from both KMC Solid waste and SSWMB were selected for interviews. In order to cover the hierarchy, the director SSWMB and the deputy director KMC (the list of interviews conducted with names and designations are in Annexure A3-) were interviewed before conducting interviews of officials at each DMCs of of Karachi. The information collected is related to the following issues:

- An assessment of capacity
    - o Generation by district
    - o Collection by district
    - o The magnitude of unattended waste by district
    - o The cost of collection by district
- Assessment of management inefficiencies
- Identifying gaps in SWM planning
- Public-private partnership models with informal system reforms
- The process for recycling and reuse of SW, if any

Table 3-1: Selected Interviews – Public Officials

Selected Interviews	Conducted
1. SSWMB Department - Director and Deputy Director	2
2. KMC Solid Waste Department -Senior Director and Director	2

3. Cantonment Board	1
4. SITE – Industrial Area	1
5. District Municipal Corporation - Director/ Deputy Director /Director Operation	6

Private Contractor and Informal Players/Workers

The information gathered is related to:

- Motives and incentives
- the type of agreement with the public sector
- The type of waste collected per day
- Management process
  - The hiring of workers and the number of workers
  - The hiring of vehicles, the number of vehicles, and transportation cost
  - Subcontracting to individuals working informally
  - The process of hiring an informal subcontractor
  - The process of collecting waste
  - Disposal process by the type of waste
  - Cost of service provided
- The process of and prospects for managing reusable solid waste
- Profit and expenditure patterns

Table 3-2: Survey of Contractors and Informal Players

Selected Interviews	Conducted
1. Private Contractors from 18 towns	36
2. Informal Worker under each Contractor	50

Household Survey

- Profile (covering occupation, sources of income and educational attainment)
- The type of waste usually generated
- The process of the collection; the cost of collection
- Major concerns related to solid waste management
- Awareness regarding the current process of dumping and recycling
- Existing system; satisfaction with the current system
- Amount willing to pay for the improved system

Sampling

Table 3.3 provides details of the sample of households selected from each town. To reach an appropriate household sample, different combinations of confidence interval and specification error were considered so it remains statistically valid and representative. Given the above, it was considered appropriate to determine the sample size with 95% confidence and less than 10% specification error. The following formula was used, which yielded an optimal sample size of 445 households:

Optimal Sample Size = Z^2 [p (1-p)]/e^2 (for known population)

where Z = the specification of the confidence coefficient
p = estimated proportions
e = Specification error

Table 3-3: Household Sample

Town Name	Total	Proportion	Sample (Proposed)	Sample (Materialised)
Baldia	616,721	0.043	20	21
Bin Qasim	480,855	0.034	15	15
Gadap	439,675	0.031	14	14
Gulberg	688,581	0.048	22	21
Gulshan-e-Iqbal	949,351	0.067	29	30
Jamshed	1,114,138	0.078	34	39
Kemari	583,641	0.041	19	19
Korangi	829,813	0.058	26	28
Landhi	1,012,393	0.071	31	32
Liaqatabad	985,576	0.069	30	34
Lyari	923,177	0.065	29	29
Malir	604,766	0.042	19	18
New Karachi	1,038,863	0.073	32	34
North Nazimabad	753,423	0.053	24	23
Orangi	1,098,858	0.077	34	35
Saddar	935,565	0.066	29	28
SITE	709,944	0.050	22	23
Shah Faisal	509,916	0.036	16	17
City Total	14,275,256		445	460

Source: Data was extracted from the website of pbs.gov.pk

3. FINDINGS

Given the objectives of the study, the result section is divided into 6 parts. The first part assesses the capacity of the public sector, SSWMB, and KMC in managing solid waste. The second part assesses the role of the private or informal sectors in managing SW. Their role and motive were assessed by estimating the income or profit generated during the process starting from the collection, segregation/sorting, selling of recyclables, transporting, and dumping of waste. The third performs a value chain analysis to assess the value of recyclable waste in Karachi by type as well. The fourth part of the report explores the socio-economic condition of the households to evaluate their willingness to pay for managing solid waste. The last part develops a comprehensive framework to understand the linkages and leakages within the system. Based on linkages and leakages, the report summarises the findings by performing a SWOT analysis.

Capacity Assessment Analysis

Historical Understanding of SWM in Karachi

Local government has been acknowledged across the civilised world as an essential democratic and administrative unit. The municipal body is selected by residents to effectively manage public affairs as well as to satisfy the needs of local inhabitants and promote efficient delivery of services at the community level to ensure people's long-term quality of life. The municipal government of Karachi has a long history [see Annexure Table A4-1 for reference].

More recently, the KMC reemerged in place of the city district government of Karachi in 2013, following the enactment of the Sindh Local Government Act 2013. Many critical duties have been removed from the scope of KMC by the Sindh government. According to the Sindh Local Government Act 2013, all development schemes/works must be carried out by the concerned councils, i.e., the Karachi Metropolitan Corporation.

The Sindh Solid Waste Management Board (SSWMB) was established in 2014 under the Sindh Solid Waste Management Act. Before the formation of the SSWMB, districts were the responsibility of the KMC, town councils, and union councils (DMC). The principal collecting agencies are town councils that manage and operate the primary collection system either with their equipment or by contracting private sector operators. The CDGK is in charge of the two “official” open dumping sites, one at Jam Chakro and the other at Gond Pass. After the establishment of the SSWMB, the distribution of power and responsibilities remain shuffled between the two. Currently, the KMC is responsible mainly for managing medical waste.

Organisational Structure and Functions - SSWMB

The SSWMB is responsible for collecting and disposing of waste throughout Sindh, including municipal solid waste, industrial solid waste, and medical/hospital waste. However, the Board is expected to gradually take charge of the solid waste management function from the councils and other bodies and until that time the DMCs are allowed to handle solid waste in their respective areas.

Solid waste management in Karachi has three operational segments, i.e., (i) front-end collection, (ii) middle-end services, and (iii) back-end services. There are ten garbage transfer sites located all around the city. The capacity of the existing infrastructure is insufficient. The institutional structure of the sector is fragmented with an uncoordinated division of functions. Key institutions managing SW are (i) SSWMB, which is the primary service delivery agency and (ii) DMCs, which have a more limited role.

Front-end collection services, collection from primary collection points (bins or kuchra kundis) and moving it to designated GTS are divided between the SSWMB and DMCs. Both are using different operational mechanisms.

Table 4 1: Existing Structure

No. of KMC	01
No of DMCs	06
Cantonment Boards	05
Karachi Port Trust	01
Pakistan Steel Mills	01
Port Qasim	01
Sindh Industrial Trading Estate	01
Export Processing Zone	01

Source: Based on KII's

The SSWMB is also responsible for the remaining segments of the transportation of waste till disposal to the sanitary sites. The Board also performed operational and maintenance (O&M) infrastructure of the GTS and the disposal sites. Board manages its functions by contracting out functions to the private sector as well. On the contrary, the DMCs do not currently have the technical capacity in terms of facilities to handle waste scientifically. Capacity building is the need of the day. The DMCs also lack the financial capacity to handle waste properly.

Overall, the institutional capacity of the public sector needs to be assessed. Though legal and regulatory framework with specific policies exists, implementation is improper, which may be due to the heavy involvement of informal private contractors. Institutions are also generally directed by politicians or public sector workers who do not have enough skills to manage waste. There is little knowledge about the environmental hazards generated by untreated or dumped waste among the workers as well. The assessment helps identify weaknesses or strengths of the existing system in a structured way and, hence, highlights the factors that need attention leading to proper management of SW. The literature identifies many assessment tools designed to assess capacity for institutional, organisational, technical, and financial aspects. However, this study remains focused on organisational, technical, and financial aspects only.

Generation

As the responsibilities are shared by two institutions, it is essential to have some estimate of the amount of waste generated by districts reported by the two institutions. This will help in estimating the manpower, vehicles, and equipment needed for primary collection, transportation, and disposal of waste in each district. Municipal solid waste generation per capita per day as estimated by Kawai and Tasaki (2016) for Pakistan is 0.65, while EPMC estimates (1996) indicate solid waste generation as 0.61 per capita per day for Karachi. As the two factors do not have much variation, the present study employed the EPMC estimates for Karachi. Using the EPMC statistics and population census (2017) study estimated the waste generation per ton per day in the districts of Karachi. The estimated generation is not much different to what KMC has estimated (from the document provided by KMC officials during KIIs).

Table 4-2: KMC Estimates

Total Garbage (Town wise)	12000 tons/day
Estimated Garbage 2020	17000-19000 tons/day
KMC Area	80% Area (Only 40% capacity)

DHA, CD, SITE.	20% Area
Vehicles (KMC)	168
Vehicle (DMC)	567

Source: Provided by KMC during KIIs

Table 4-3: Waste Generation Estimates using EPMC waste generation rate

District	Population		Rate of Waste generation per capita / per day	Waste generated (Tons per day)		KMC Estimates (tons/day)
	1998	2017	EPMC(1996)	1998	2017	-
South	1468579	1769230	0.614	901.7	1086.3	1700
East	1447529	2875315	0.614	888.7	1765.4	1600
West	2127765	3907065	0.614	1306.4	2398.9	2100
Central	2289071	2971382	0.614	1405.5	1824.4	2000
Malir	914765	1924346	0.614	561.6	1181.5	900
Korangi	1608609	2577556	0.614	987.7	1582.6	1500
Total	9858316	16026911	-	8049.6	11856.1	9800

Source: Authors' estimations

Collection

The information provided in the tables below is extracted from the bidding document of the SSWMB highlighting the minimum requirement a bidder needs to fulfil to win the contract. The information presented in the tables on collection and vehicle requirements is extracted from the bidding documents of SSWMB for different districts.[1] Considering that minimum waste collection requirements requested in bidding documents were inflated by the contractors (100% lifting), the unattended waste ranged from 85 tons per day to around 482 tons per day. Furthermore, as reported by KMC, the actual lifting was only 60% of the generation of which only 50% reached the designated site. Therefore, the unattended waste ranged between 435 tons per day and 960 tons per day. According to the EPMC estimates (1996), the waste collection was around 51% to 69%.

Table 4-4: SSWMB's Estimated Minimum Waste Collection

District	Waste generated	Waste Collected	Waste Unattended
South	1086.3	1000	86.3
East	1765.4	1465	300.4
West*	2398.9	2000	398.9
Central**	1824.4	1600	224.4
Malir	1181.5	700	481.5
Korangi***	1582.6	1500	82.6
Total	9839.1	8265	1574.1

Source: From the bidding documents of SSWMB.
*District West comprises only Orangi, Baldia, Kemari, and SITE town
**District Central includes Gulberg, Liaquatabad, New Karachi, and North Nazimabad
***District Korangi includes Model Colony, Shah Faisal, Landhi, and Korangi.

[1] The information placed here is as per directions of the officials of SSWMB given during the KIIs. The documents are available on the official website of SSWMB as well.

Table 4-5: KMC Estimates of Collection and Disposal

District	Waste generated	Collection – KMC @ 60% of Generation	Disposal – Landfill Site @ 50% of the Total Collected	Waste Unattended
South	1,086.3	651.78	325.89	434.52
East	1,765.4	1,059.24	529.62	706.16
West	2,398.9	1,439.34	719.67	959.56
Central	1,824.4	1,094.64	547.32	729.76
Malir	1,181.5	708.9	354.45	472.6
Korangi	1,582.6	949.56	474.78	633.04

Source: Rates provided by KMC during KIIs

Resources

As far as human and physical resources required for operation are concerned, the KMC reported the number of employees and vehicles in possession in each DMCs of Karachi. The KMC also claimed that of the total vehicles in possession only 25% were functional.

Table 4-6: KMC estimate of DMC's Human and Physical resource

District	Human Resource (No.)	Different types of Vehicles (No.)
South	2,083	124
East	1,531	116
West	1,741	88
Central	3,157	118
Malir	336	27
Korangi	1,544	59

Source: Information provided by KMC officials during KIIs

The SSWMB again provided a minimum requirement of vehicles in each district by type enough to cater for the estimated waste need to be collected. Table 4-7 and Table 4-8 below are based on the information provided. However, district-wise information was also gathered during interviews with DMCs to confirm the availability of resources.

Table 4-7: SSWMB's Estimated Vehicle Requirement for Managing SW by Vehicle type

Vehicle	Requirement
Loading Machinery (Small & Large)	10 to 12
Dump Trucks (Small and Large)	15 to 20
Three Wheeler	40 to 50
Wheel Excavator	1
Tractor with trolley	10 to 12

Source: SSWMB tender documents

Further to this, based on the KIIs with the officials of DMCs, the study reassessed the physical resources available and the collection estimate provided by the DMCs. According to the information provided by the DMCs, the unattended waste ranged around 43% (for the districts Malir and West) and 80% (for district Central). District East is the only district where DMC East reported no leftover waste. Furthermore, if we consider that the DMCs are operating with full resources available, it means that the resource needs to be increased from 40 to 80%.

Table 4-8: Resources Reported by DMCs and SSWMB in Districts

	East		Malir	West		Central	South*	Korangi
	CK- Eng.	DMC/ SSWMB		Kemari	West (Rest)			
Labour	1,147	654	450	950	666	-		200
Mini Dumper/ Compactor	32	4	34	18	26	16		60
Side Compactor	45	0	0	25(Bin /Tray Compactor)	0	0		0
Arm Hook	19	16	0	9	0	0		0
Dumper	10	29	10	22	18	16	15-25	12
Loader/Mini Loader	11	5	4	11	10	8	3-5	3
Tractor Shawwal	0	0	0	0	0	7		
Tractor Trolley	0	0	0	0	0	28	1	
Tractor/Tractor Blade	0	3	3	2	1	4	1	1

Mini Tippers	0	0	0	5	0	0		0
Bobkit	0	4	0	0	0	0		0
Mechanical Sweeping Machine	5	0	0	4	0	0		0
Water Bowser	3	0	0	0	0	0		0
3-Wheeler (Qingqhi)	237	0	0	172	129	0		33
UC Covered (Collection/day/ tons)	31 (1,600)	7 (200)	NA (670)	23 (1000)	18 (378)	N/A	N/A	13 (300)

Source: Based on KIIs. For District South, information obtained from tendering documents.

Funds, Grants and Collection Cost – Financial Resources

Funds, grants, aid etc. all diverted to manage the SW in Sindh, particularly in its main hub Karachi. Sindh also receives international funding. For example, the Asian Development Bank's (ADB) Infrastructure and Service Delivery Reform Program has provided $400 million to the Sindh Cities Improvement Investment Program (SCIP), which aims to improve solid waste management services in its 20 secondary cities as well. The total receipts/income of SSWMB was Rs. 8,042.69 Million. Of the total receipts, the salary and non-salary expenses of the board were Rs. 1,070 million and Rs. 5,348 million, respectively. The operating expenses of the board were budgeted at around Rs. 5,058.65 million, while the board also incurred expenses for acquiring physical assets worth Rs. 26 million. However, as far as the cost of collection or total operational cost is concerned, no comprehensive information is available at the district level. As SSWMB has outsourced the task to Chinese contractors in four districts, the cost of collection bids by the Chinese firms is available for these districts only. The cost estimates are taken from the agreement copy available on the website of SSWMB.

Table 4-9: Front End Collection, Sweeping and Transportation

District	Contractor	Amount US Million $
WEST	M/S Hangzhou Jinjiang Group of Sanitation Services Co. Ltd	22.35
EAST	M/S Changyikangjie Sanitation Engineering Co. Ltd	9.651
SOUTH	M/S Changyikangjie Sanitation Engineering Co. Ltd	14.254
MALIR	M/S Hangzhou Jinjiang Group of Sanitation Services Co. Ltd	6.134

Source: SSWMB tender documents

The agreement also provides a bill of quantity/price list of different activities related to managing solid waste. The per unit cost of collection and sweeping was also projected to go up with the cost of collection in other districts of Karachi, assuming that the per unit price of the collection remains unaffected in a district.

Table 4-10: Cost as per bid by M/S Hangzhou Jinjiang Group for Malir

Item	Unit	US $	Pak Rs.
Cost of Collection	Tons	18	2,906
Manual Sweeping of Roads and Street	Per Km	12	2,006
Manual Sweeping of Footpath, open spaces, green Belts, roundabouts etc.	Per Sq. Km	6,188	1,016,645
Mechanical Sweeping of Roads	Per Km	36	5,894
Mechanical washing of main Roads	Per Km	208	34,103

Source: SSWMB agreement documents

Table 4-11: Estimated Cost @ Rs. 2,906 per ton per day

District	Waste Generated	Waste Collected	Waste Unattended	Cost by Generation	Cost of Collected	Cost of Unattended
South	1,086.3	1,000	86.3	3,156,788	2,906,000	250,788
East	1,765.4	1,465	300.4	5,130,252	4,257,290	872,962
West	2,398.9	2,000	398.9	6,971,203	5,812,000	1,159,203
Central	1,824.4	1,600	224.4	5,301,706	4,649,600	652,106
Malir	1,181.5	700	481.5	3,433,439	2,034,200	1,399,239
Korangi	1,582.6	1,500	82.6	4,599,036	4,359,000	240,036

Source: Authors' estimates based on the unit rate of collection extracted from the agreement of Malir.

From the assessment above (Section 4.1), overall the waste unattended ranged from around 43% to 80% and to manage this unattended waste the resource needs to be increased from 40 to 80 per cent.

Evaluating the Role of Private Contractors and Informal Players

This section explores the role of private contractors and informal players in managing solid waste in Karachi. Their point of entry, contracting mechanism, if any, the motive of involvement, and profits or income they make from the waste are assessed in detail here. This section starts by exploring the point of entry for a contractor. The purpose is to understand the system that manages solid waste in Karachi.

System Hierarchy Followed

Currently, the system that exists in Karachi can be grouped into 3 different models: solid waste properly handled by the public sector through formal subcontracting (model 1), operations through town/UC, contracting out informally to private contractors either on personal relation basis or political grounds (model 2), and completely informal operations, mainly in Orangi town, which was the among the lowest income areas in Karachi (model 3).

Table 4-12: Process of Collection

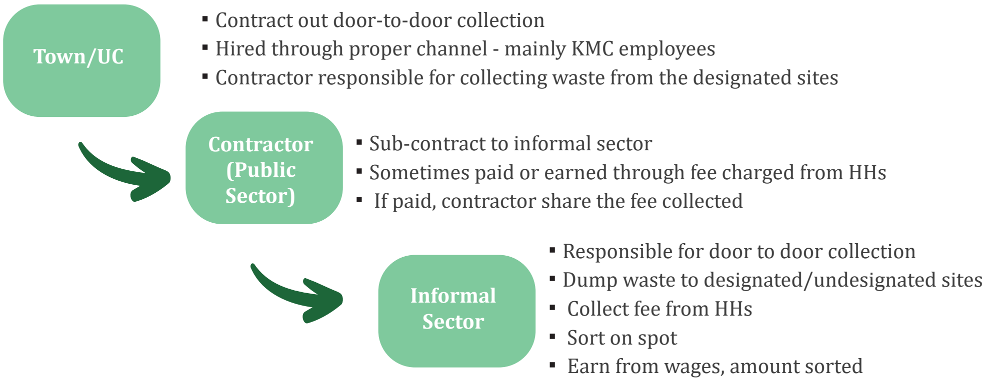
	ALL	Central	East	South	West	Korangi	Malir
Contractor							
Private (%)	91.7	100	75	100	80	100	100
Public (%)	8.3	-	25	-	20	-	-
Hiring Process (%)							
Tender	19.4	87.5	25	50	40	-	16.67
Informal	69.4	-	25	50	50	100	83.33
Personal Relation	8.3	-	50	-	10	-	-
Experience	2.8	12.5	-	-	-	-	-
Agreement Period (%)							
yes	25	12.5	50	50	40	-	16.67
No	75	87.5	50	50	60	100	83.33
Agreement Period							
Average (Years)	1 to 2	.25	2	3.5	2.8	.66	1.2

Source: Based on KIIs and primary survey

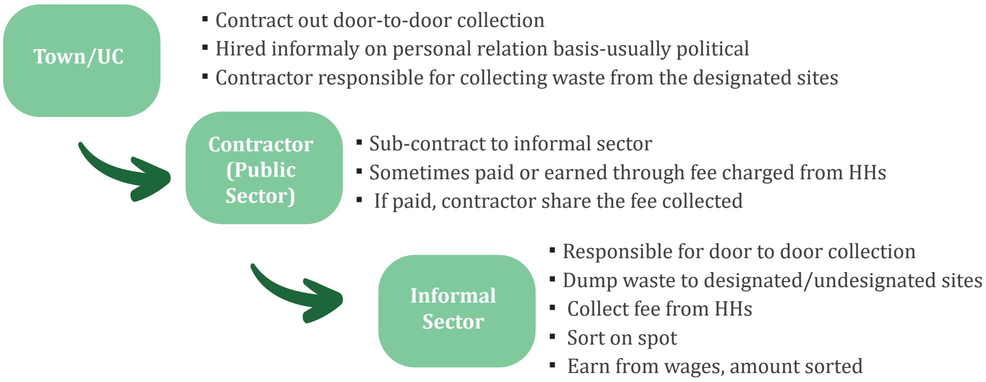
Based on the survey of contractors and informal players (employees hired by contractors), the current study confirmed that solid waste in Karachi was still managed by private contractors (around 92%), while 8 per cent of the public sector managing solid waste came under the SSWMB contractual agreement made with the Chinese firms (Kangjie and Hangzhou). However, the door-to-door collection through outsourcing to a Chinese firm was very little; the door-to-door collection by a Chinese firm (SSWMB) was evident in some areas of Korangi and East only. Furthermore, the hiring of contractors was around 69 per cent informal, 19 per cent formal, and 8 per cent based on personal relationships. Moreover, only around 3 per cent was based on experience, i.e., contractors are hired based on having experience with the work.

Once the contractor is hired, they either sub-contract to others or operate through informally hired workers. The hired workers of informally hired contractors are usually responsible for door-to-door collection. The collected waste is usually dumped on an undesignated site and left for the KMC or SSWMB to pick. The formally designated points are either very limited in number or far off. The contractor earns through a fee charged to households while informal workers if hired earn wages otherwise share the income generated through the fee charged. The collected waste is usually sorted by informal workers on the spot, while the remaining waste is sorted at the designated or undesignated sites. Contractors, informal workers, and ragpickers all are involved in sorting.

Model 1



Model 2



Model 3

As mentioned earlier, model 3, reported above, is at work in Orangi Town mainly, where in some areas (UCs) households have hired a contractor responsible for door-to-door waste collection. The system operates through Mohalla committees. The UCs have also hired contractors but the contractors collect waste only 2 to 3 times a week. In some UCs, NGOs also work to manage solid waste. Orangi Town is a unique example where the system is completely in the hands of informal channels.

Income and Expenditure pattern

This sub-section discusses the cost of collection reported by the contractors. The study only explored variable costs (fuel cost and wage cost). We did not ask about fixed costs in interviews as the fixed costs in the public sector (KMC and SSWMB) are much higher than in the private sector. The private sector mainly operates using horse carts and 4-wheelers known as Qingqi. The cost of the public sector is higher as they are mainly involved in collecting waste from designated/undesignated sites and moving it to landfill sites. The public sector is not involved in the door-to-door collection, for which they require heavy machinery. Hence, the comparison between the fixed costs in the public sector and the private sector would not have been valid. Furthermore, since informally hired workers who collect waste, receive wages and fuel costs if using Qingqi from the contractor, cost estimates for them were not available. According to Table 4.13, on average, one contractor is responsible for the collection of waste from around 2,000 households. They mainly operate by hiring 1 to 2 vehicles and employing 3 to 4 employees. The average fuel cost per house was minimal, i.e., almost less than Rs. 1, while the average wage per household was around Rs. 15.6 resulting in an average total cost of only Rs. 16 per household borne by a contractor.

Table 4-13: Cost of Collection

	ALL [Cost/HH]	Central	East	South	West	Korangi	Malir
# Household Per UC	1983.6	3618.75	550	800	2790	983.3	810
# Vehicle	1 – 2	1	3-4	1	1	2	1-2
# Employee	3 – 4	2	10	1	2	3	4
# UC Covered	5 - 6	3	9-10	23	6-7	1	3
Fuel Cost [per Month/ UC]	Rs. 426.67 [Rs. 0.45/HH]	393.75	400	475	446	441.66	425
Wage [Monthly]	Rs. 14,133 [Rs. 15.6/HH]	7,725	16,375	16,500	16,600	8,166.6	22,250
Total Cost	Rs. 14,560 [Rs. 16/HH]	8,118.8	16,775	16,975	17,046	8,608.3	22,675

Source: Based on KIIs and primary survey

Table 4.14 reports income from fee collections only. For simplicity, this sub-section avoids incorporating income generated from the sale of sorted recyclables. The income generated by the sorted recyclable waste is discussed in detail in the value chain analysis (next section). The income generated as reported by contractors was almost 65 per cent higher than the amount collected through fees. The estimated revenue was also very high. Furthermore, the study also explored if the income was shared with hired workers or with the contractor hired by UCs.

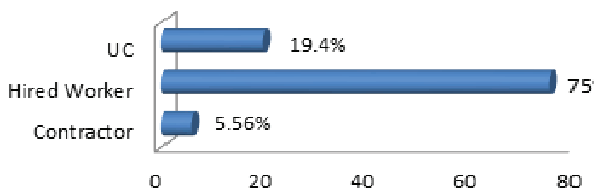
Table 4-14: Income from Collection - Contractor

	All	Central	East	South	West	Korangi	Malir
Fee per Household	179.7	227	325	125	90	200	166.7
Income Reported	128,472	234,375	75,000	60,000	99,000	1,38,333	85,000
Income Generated (# Household*Fee)	358,583	798,750	173,750	100,000	371,000	196,667	122,333
Revenue [Fee Collected – total Cost]	344,023	790,631	156,975	83,025	,53,954	188,058	99,658
Revenue Per Household	163.7	221	293	104	73	191	144

Source: Based on KIIs primary survey

We found that both contractors and hired employees shared the income generated from fee collection. 75% of the collected fee was shared with the hired employee, 19% by the UC, and 6% was kept by the contractor.

Figure 4 1: Who Takes the Fee?



The table below provides some interesting facts related to income generated and waste collected per kg per household per day.

Table 4-15: Income from Collection – Hired Workers

	All	Central	East	South	West	Korangi	Malir
# Household Covered	1,056	1592	483	750	1137	939	811
Fee per Household – Rs.	217	262.5	317	50	97	211	350
Income Generated (# Household*Fee) – Rs.	226,018	456,667	145,000	35,000	99,000	200,556	273,333
Wages if Hired – Rs.	11,678	8,383	11,167	15,667	16,733	8,444	9,889
Total Amount of wast e Collected (per day /worker)Kg	1,910	3,017	915	1290	1890	1797	1452
Amoun t of waste Collected (per HH/ day) Kg	1.76	1.96	1.8	1.7	1.6	1.8	1.7

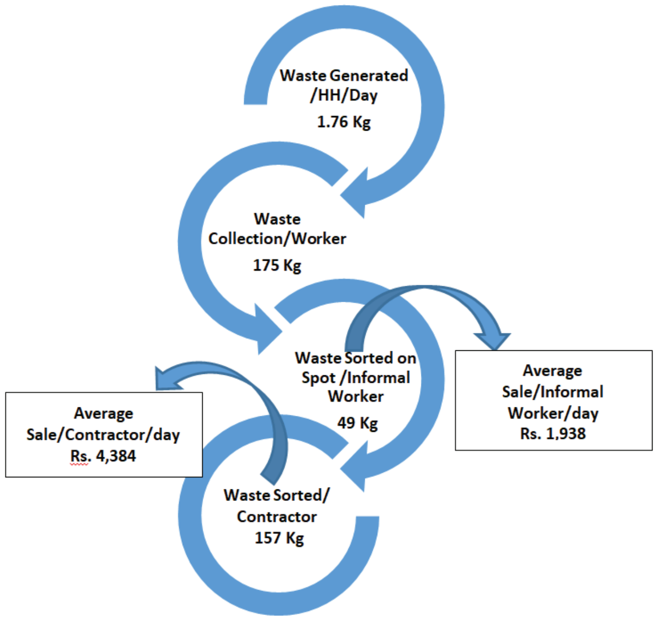
It is evident from the table that, informally hired workers usually covered around 1,000 households per day, waste collected per worker per day was around 1,900 Kg, while the waste collected per day per household by a contractor was around 1.76Kg.

Value Chain Analysis

The above sub-section helped in developing an insight into the mechanism followed for waste collection in Karachi. Given the understanding developed above, in this section, we analyse the opportunities available within the system, which if utilised efficiently, will help in improving the solid waste management process in Karachi, i.e., the development of the recycling industry.

As evident from the findings above, solid waste management in Karachi is heavily dependent on the informal sector for the collection as well as disposal of waste. Informal waste pickers have a noteworthy contribution to the collection, sorting, disposing, and recycling of waste material. Contractors hiring these workers are sometimes also involved in segregating waste and in recycling. However, the public sector is not involved in reselling recyclable material because the public sector is not for profit. The below figure provides a flow of waste from collection to segregation of recyclable material.

Figure 4-2: Generation, Collection, Segregation, and Income from the sale of Recyclable



Source: Based on the survey of private contractors and informally hired workers.

The main recyclable component identified by both contractors and workers includes plastic, paper, cardboard, and scrap (mainly steel and iron). Our household survey also confirmed that households were also mainly interested in the sale of these goods as well. As there is vast variation in the quality of the recyclable material segregated, the rate at which the material is sold also shows much variation. The table below provides information on the rate per Kg (sample average) as reported by the surveyed contractors. For authenticating the rate reported, the price per kg was also verified by the team from the market during the survey. The market rate was not much different from what surveyed contractors reported except in the case of plastic and steel/iron. The variation is maybe because of the variation in quality.

Table 4-16: Rate per Kg

Item	Reported by Contractor (Rs.)	Market Survey (Rs.)
Plastic	34	15 - 40
Paper	18.4	15 – 25
Cardboard	23	25
Glass	20.8	12 - 20
Steel/Iron	68	80
Wood	12	10 – 12

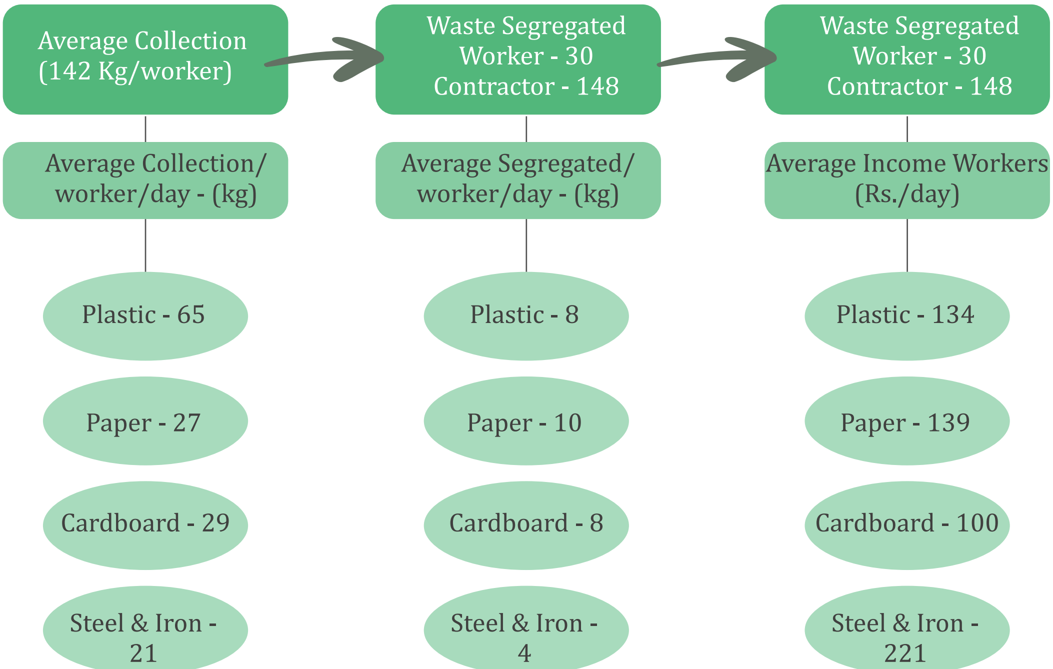
As mentioned earlier that the main recyclable items are plastic, paper, cardboard, and scrap (steel and iron), we further undertook a detailed assessment of these three items in terms of the amount collected, amount segregated by the contractors and informal workers, and the income generated from the sale of these products.

Table 4-17: Amount Collected, Segregated, & Income Generated - Selected Items

	Plastic	Paper	Cardboard	Steel & Iron
Collection (Kg/Worker)				
Central	95	32	38	24
East	25	20	29	12
South	60	23	25	25
West	63	33	30	15
Korangi	60	21	23	33
Malir	63	21	22	21
Average- Collection (Kg)	65	27	29	21
Segregated -Per Contractor (Kg)				
Central	0	0	0	0
East	53	57	30	10
South	0	0	0	0
West	90	250	133	6
Korangi	0	0	0	0
Malir	3	8	8	13
Average - Contractor (kg/Cont.)	35	69	37	7
Segregated on Spot- per Hired Worker (Kg)				
Central	5	7	4	1
East	19	19	19	18
South	0	0	0	0
West	20	27	18	7
Korangi	1	0	0	0
Malir	2	4	4	2
Average Hired Worker (Kg /worker)	8	10	8	4
Income Contractor (Rs)				
Central	0	0	0	0
East	1125	965	675	375
South	0	0	0	0
West	2700	2500	1988	510
Korangi	0	0	0	0
Malir	138	200	200	875
Total Cont. Income (Rs/day)	925	842	643	388
Income Hired Worker (Rs.)				
Central	90	82	73	73
East	60	328	40	700
South	0	0	0	0
West	443	307	301	514
Korangi	0	0	0	0
Malir	120	109	109	119
Average Worker Income (Rs/day)	134	139	100	221

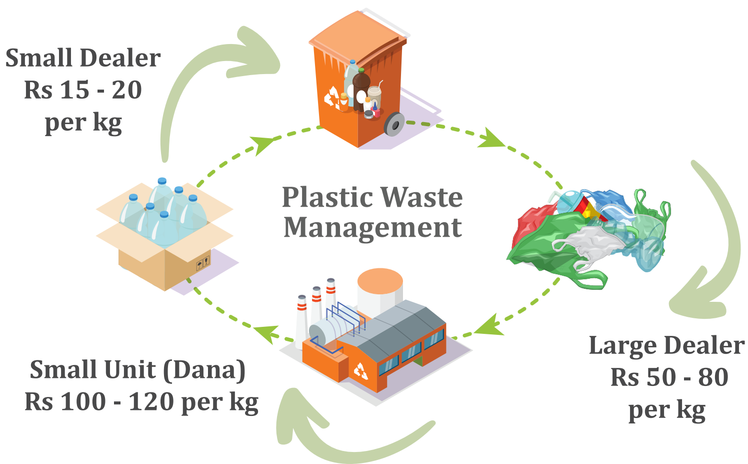
Table 4-17 provides information on plastic, paper, cardboard, steel, and iron, the amount collected, sorted, and sold in the local market. The average income generated by the contractors from the sale of these products was much higher than the income generated by informally hired workers per day. Further, in some cases, both contractor and hired worker reported that they did not sell the sorted item daily; rather, they usually sold the items in local marker after every two days.

Figure 4-3: Flow of Recyclable Material



Both, contractors and waste pickers (hired workers) sell these items to small dealers (chota kabaria). Small dealers purchase these items from a large number of waste pickers and again sort the recyclable material. They make bundles of the selected items and sell them to large dealers (bara kabaria). The large dealers just work as a bridge between small dealers and small-scale industry usually operated within the premises of a house or under a small unit. Though a detailed survey of small and large dealers, small and medium scale industries, and large recycling industry is beyond the scope of the study, we collected some information on the making of "dana"[2] from the collected plastic, and the making of boxes from the collected paper and cardboard. Figure 4-4 and 4-5 shows the value chain analysis for plastic and paper/cardboard. It can be concluded from the two flow charts that the income generated by each stakeholder involved steeply increases, making the two recyclable items highly profitable.

Figure 4-4: Value Chain for Plastic



[2] Plastic granule

Figure 4-5: Value Chain for Paper/Cardboard

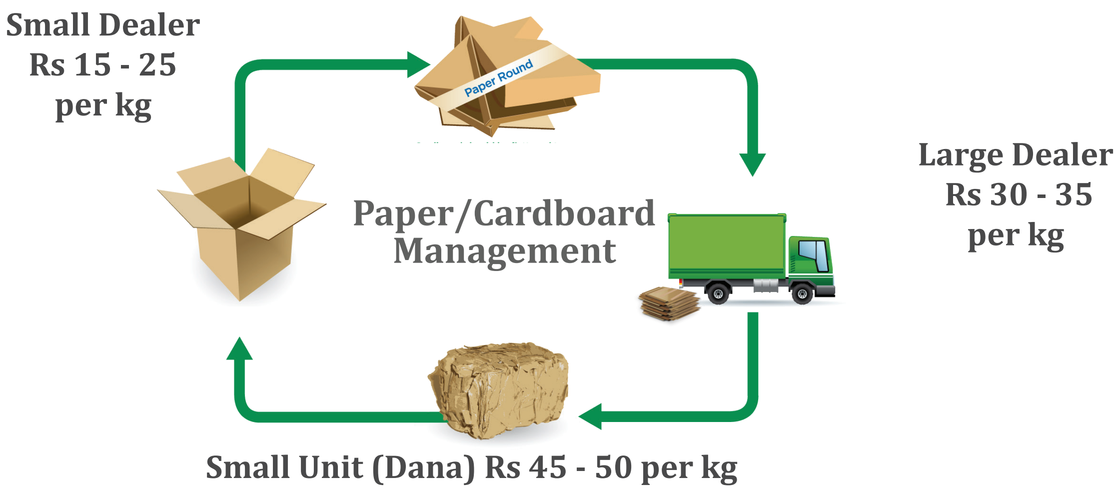
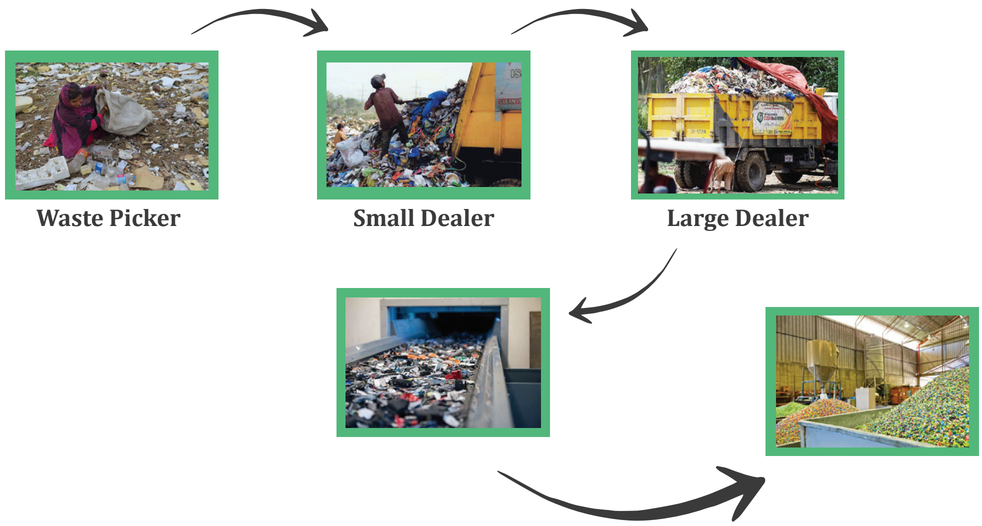


Figure 4-6: Value Chain for SWM



Source: Author illustration.

The above assessment shows that if solid waste is properly segregated and managed, it can result in a profitable industry.

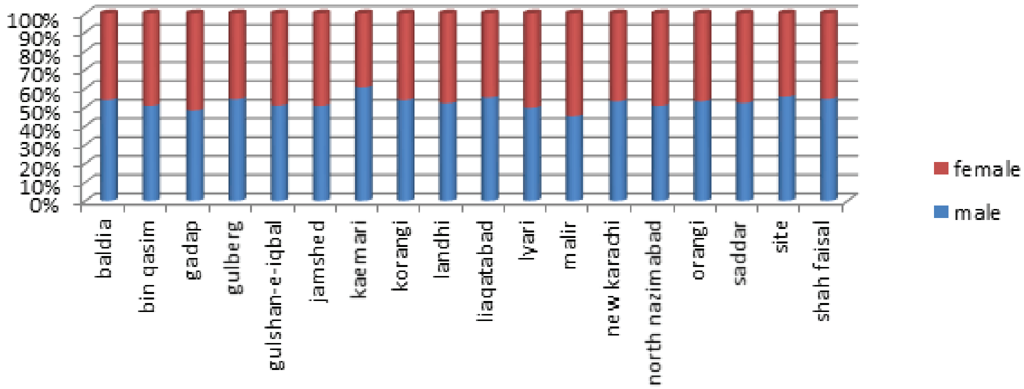
Household Socioeconomic and Demographic Conditions

This section outlines basic information gathered during the household survey. The section starts by highlighting the socioeconomic profile and then moves to discuss the solid waste management practices followed by households. During the KIIs, households' perceptions, behaviour, and awareness came up as obstacles in handling solid waste in Karachi. Therefore, the household survey was designed to explore these issues in depth. Recycling and reuse activity at the household level was also investigated. Finally, households' expenses and their willingness to spend on solid waste management are discussed as well.

Household Socio-economic and Demographic Profile

Figure 4-7 shows the gender distribution of the surveyed population. The gender distribution is almost equal.

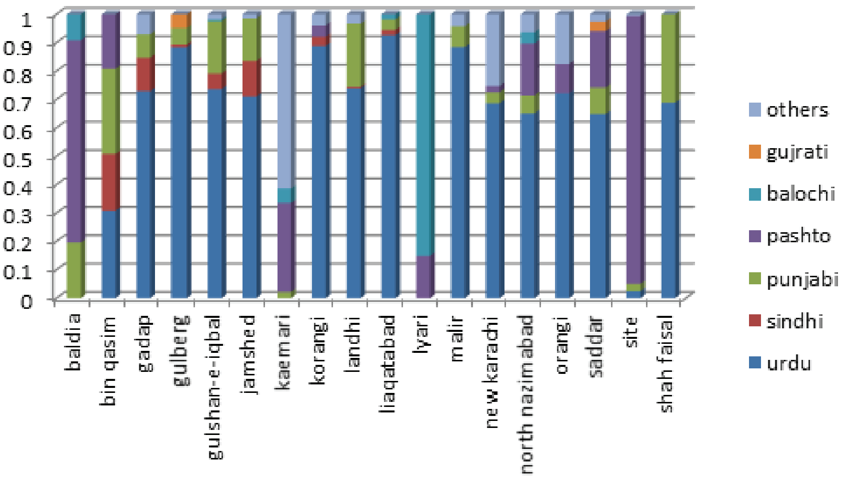
Figure 4-7: Survey Proportion by Gender across Towns



Source: Author Estimation

Figure 4-8 shows that the commonly spoken languages were Urdu (58%), Pashto (15%), and Punjabi (8%). The variation based on languages was examined to show the multicultural environment of Karachi. The variation can also be analysed in terms of ownership. Since the migrants in Karachi are not natives of the city, their interest in the development of the city can be considered limited.

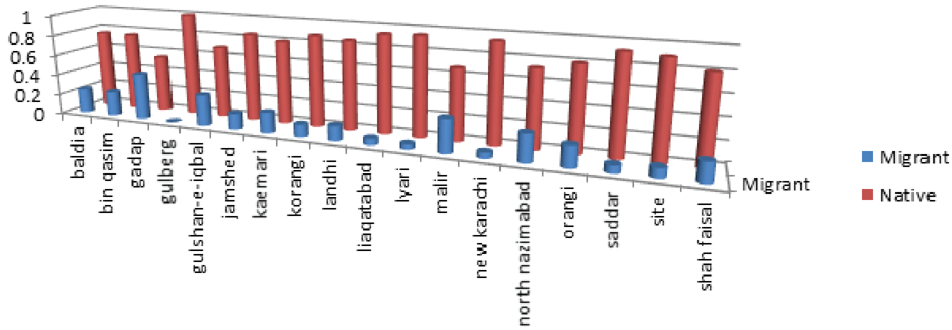
Figure 4-8: Proportion of Individual by Mother Tongue and Town



Source: Author's Estimations

Figure 4-9 specifically shows the migration status of the surveyed population. Overall out of surveyed population 16% were migrants and 84% were natives.

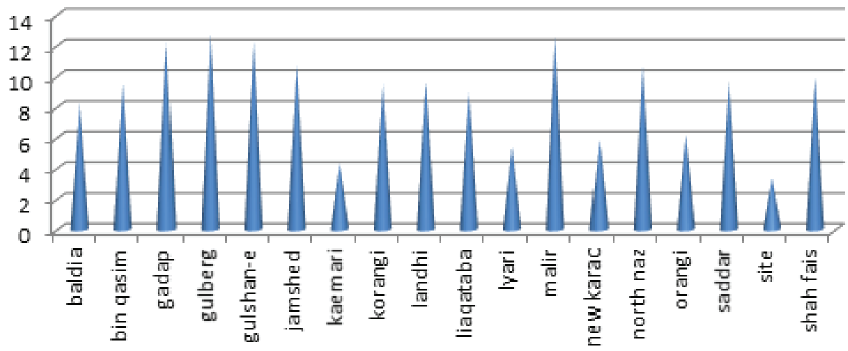
Figure 4-9: Proportion of Individuals by Migration Status by Town



Source: Author Estimation

Figure 4-10 highlights average years of education (highest education level at the time of interview).

Figure 4-10: Education Profile of Individual

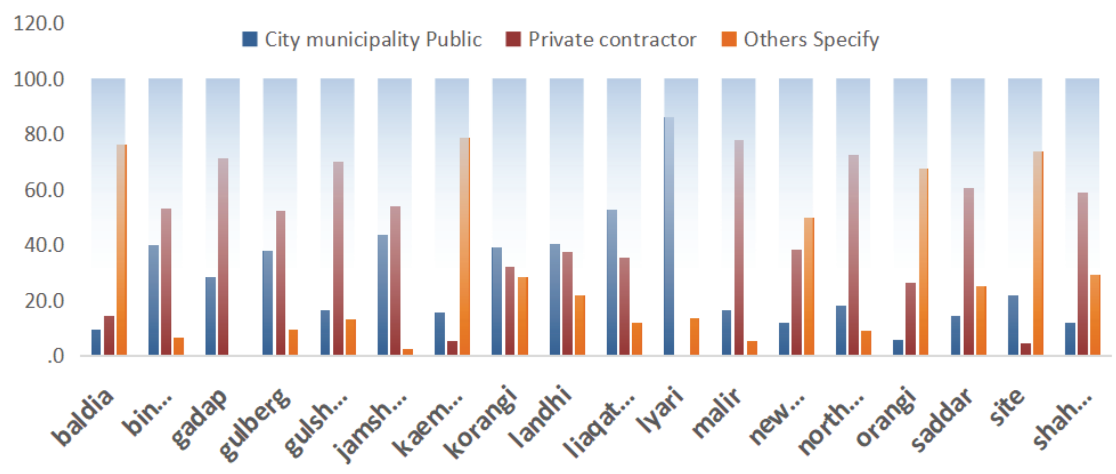


Source: Author Estimation

Household Assessment of Waste Collection

The figure below provides information on the waste collection mechanism. The figure shows that solid waste management in Karachi is in the hand of private contractors. The second largest waste collector is the informal sector (mainly Afghanis), mentioned as "other" in the figure. Some part of the city is also managed by the city municipal system, i.e., the DMC. The proportion is highest for Lyari, which is mainly managed by DMC. The towns operated under complete informality are Baldia, Orangi, SITE, and Kemari. This further endorses our findings presented in Section 4.1 and Section 4.2.

Figure 4-11: Who collects waste from households?



Source: Authors' Estimations

Table 4-18 highlights the time preferred by households to collect waste. Households mainly preferred their waste to be picked up in the morning. Individuals did not prefer waste to remain at home for long, which shows their willingness to have a clean environment.

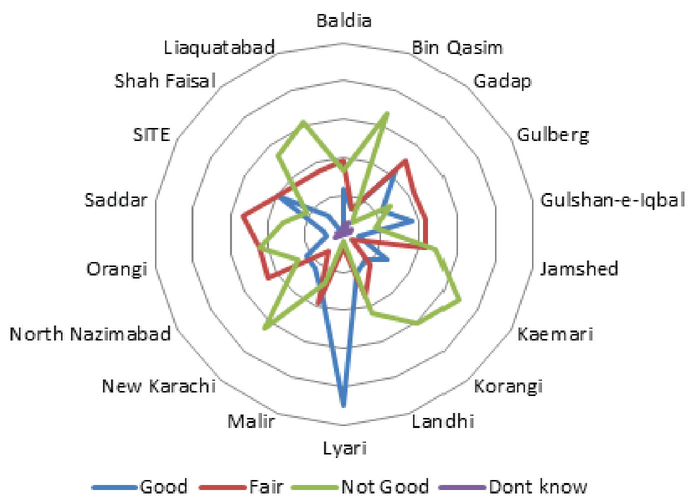
Table 4-18: Waste Collection Frequency

Towns	Morning	Noon	Afternoon	Evening
Baldia	81.0	9.5	4.8	4.8
Bin Qasim	93.3	6.7	0	0
Gadap	85.7	14.3	0	0
Gulberg	85.7	4.8	9.5	0
Gulshan-e-Iqbal	93.3	3.3	0	3.3
Jamshed	48.7	41.0	7.7	2.6
Kaemari	78.9	15.8	5.3	0
Korangi	50.0	32.1	3.6	14.3
Landhi	87.5	9.4	0	3.1
Liaqatabad	35.3	61.8	0	2.9
Lyari	58.6	10.3	6.9	24.1
Malir	77.8	0	0	22.2
New Karachi	82.4	8.8	8.8	0
North Nazimabad	77.3	13.6	4.5	4.5
Orangi	70.6	8.8	17.6	2.9
Saddar	96.4	3.6	0	0
SITE	60.9	17.4	13.0	8.7
Shah Faisal	100.0	0	0	0

Source: Authors' estimations

Households' perceptions regarding the solid waste collection mechanism were mainly not good, Except for the households in Lyari, almost all the households surveyed rated the service provided to them as either "not good" or "fair."

Figure 4-12: Evaluation of the state of solid waste collection



Source: Authors' estimations

Recycling and Reuse Activity

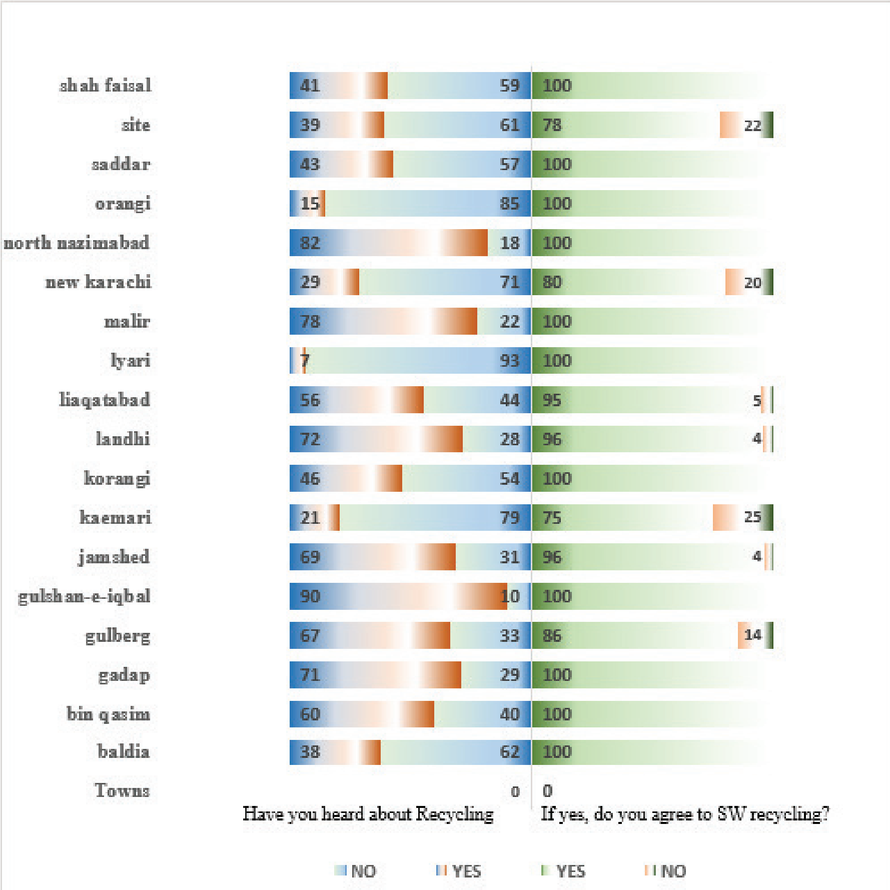
To evaluate the knowledge of households regarding recycling, three interrelated questions were asked. The questions were:

- Is the household aware of recycling?
- If yes, do they agree to be involved in recycling?

- If they agree, have they ever earned income from recycling?

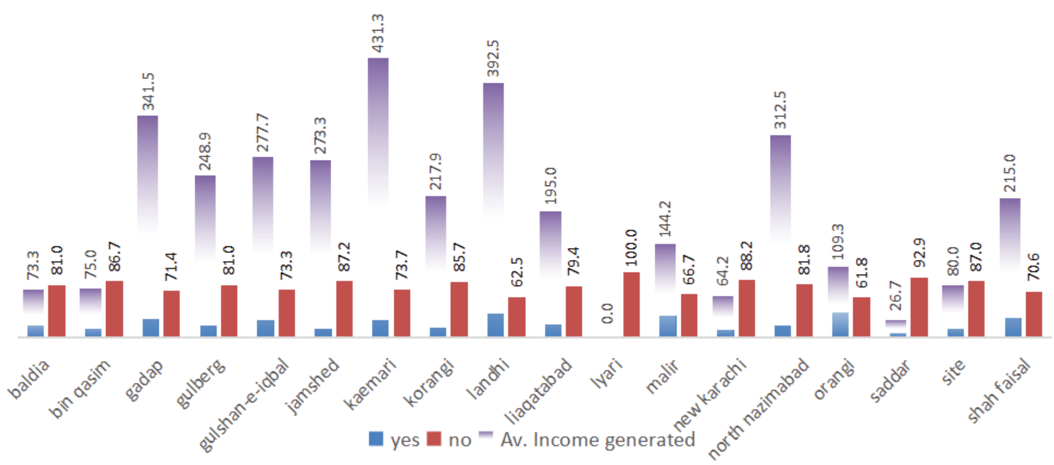
Figures 4-13 to 4-15 show that households in Karachi were not only aware of recycling but also generated income from recycling. The households generated, on average, around Rs. 400 per month from the sale of recyclable materials. The main recyclable materials were paper/cardboard, plastic, and metal.

Figure 4-13: Awareness Regarding Recycling



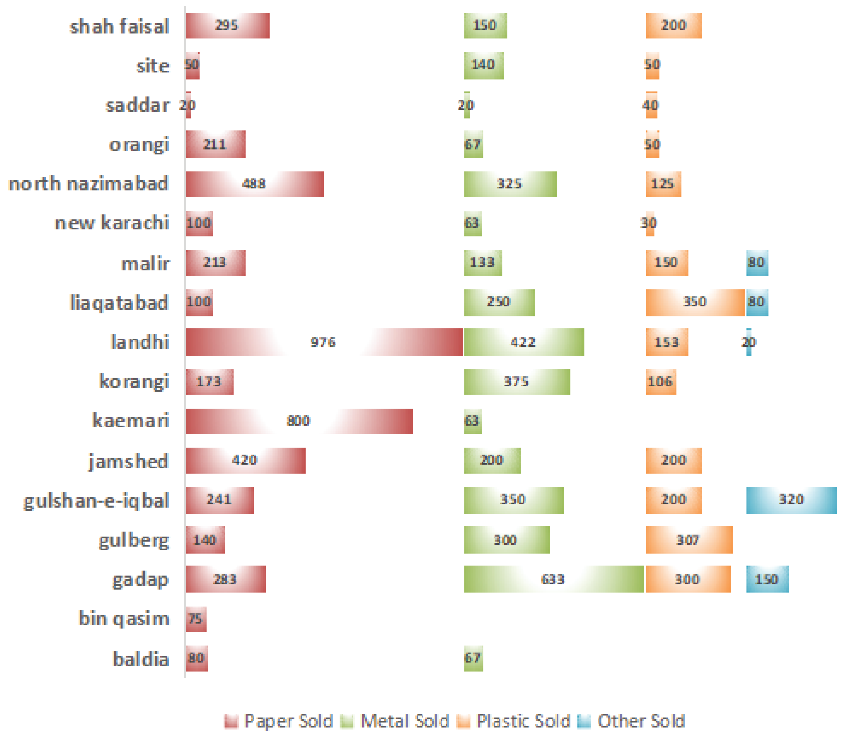
Source: Authors' estimations

Figure 4-14: Did the household generate any income from selling waste?



Source: Authors' estimations

Figure 4-15: Average Income generated by Waste Type

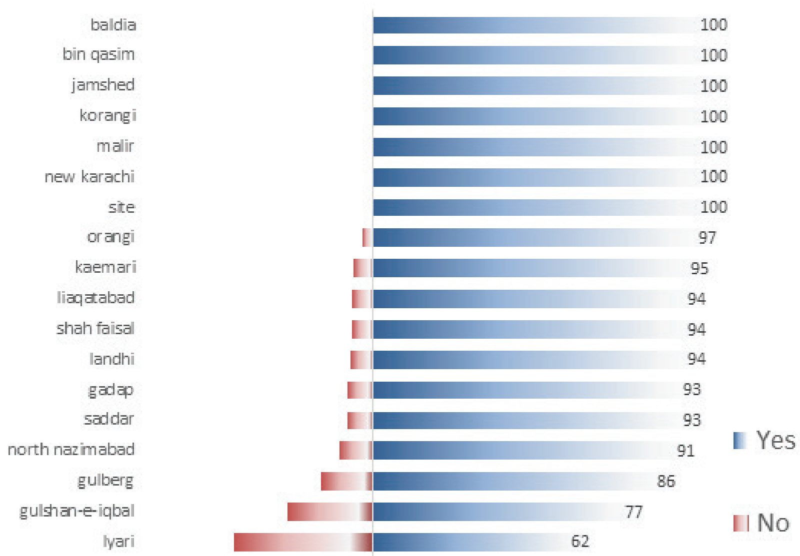


Source: Authors' estimations

Perception and Behaviour Regarding solid waste management

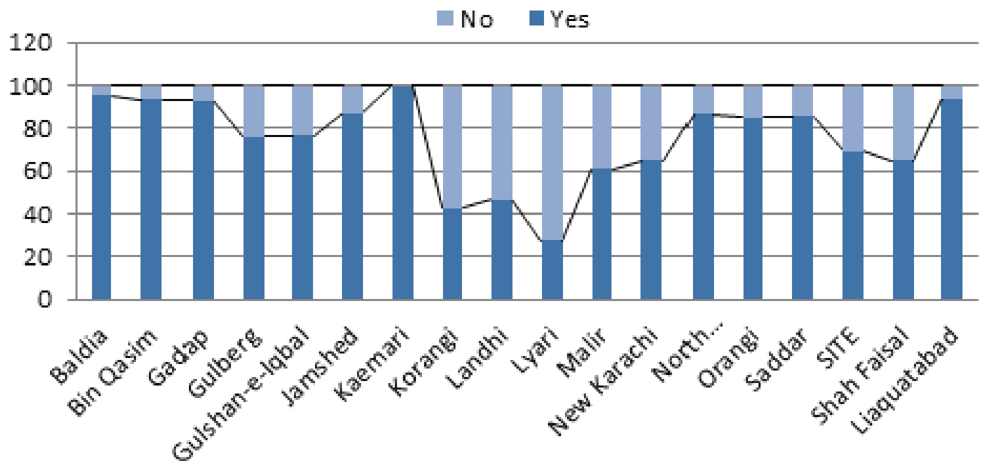
Public officials claimed that the main hurdle in handling solid waste was individual behaviour, we explored the perception, behaviour, and awareness of the surveyed households regarding solid waste management. The figures below show the results. The majority of the surveyed households said that they were aware of the environmental consequences of waste. We also enquired whether they dumped the waste alongside the bin (not in the bin). The majority responded with yes. We further asked the households if they were aware of the environmental consequences of the waste, why did they not use a bin.

Figure 4 16: The current waste disposal system is polluting the environment



Source: Authors' estimations

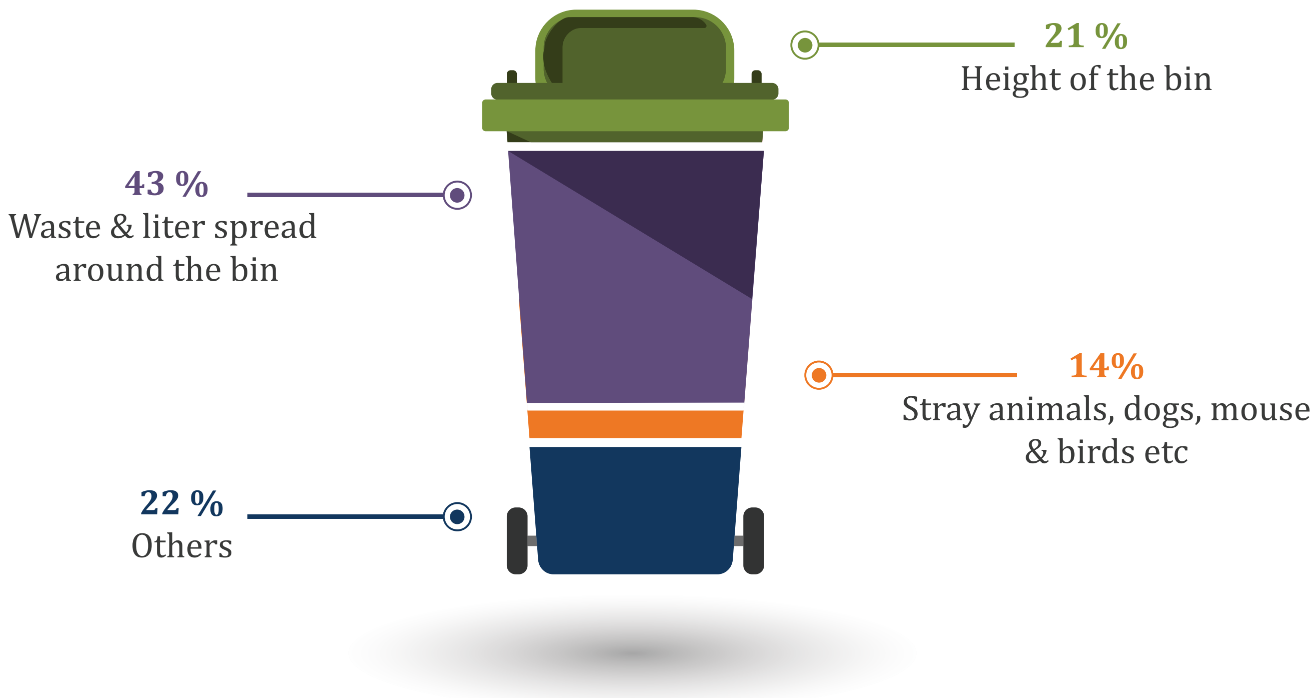
Figure 4-17: % of People dumping their waste alongside the garbage bins



Source: Authors' estimations

Around 43% of households replied that they threw the waste alongside the bin, (not in the bin) because the place where the bin was placed was too smelly. Around 21% said the bin was too high, and 14% said that they did not go near the bin because of the animals around the bins.

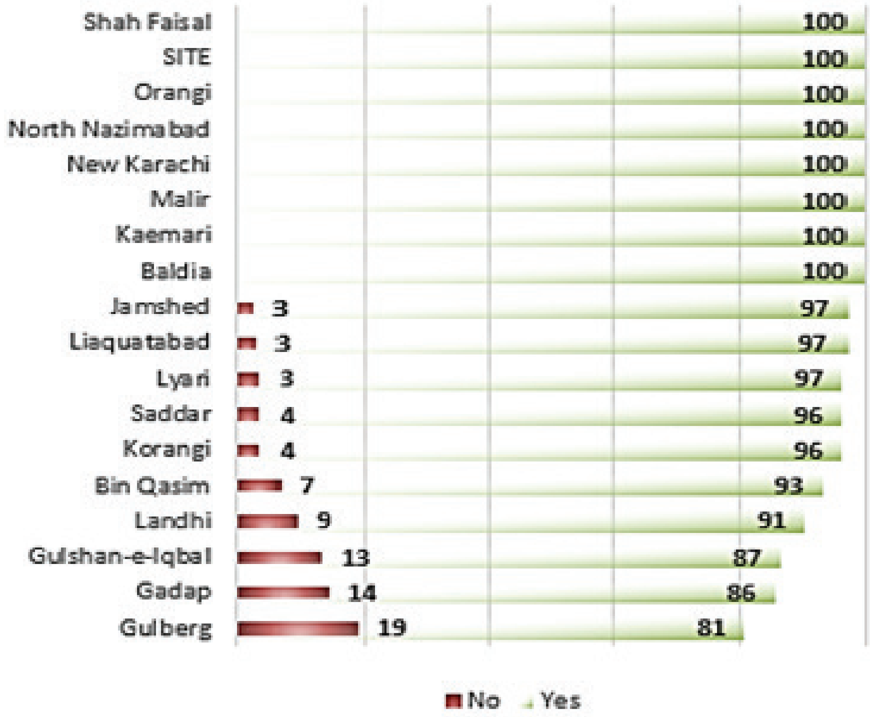
Figure 4-18: Particular reason for dumping outside bin



Source: Authors' estimations

Furthermore, the surveyed households also showed their concern for environmental degradation caused by waste.

Figure 4-19: Environmental degradation has a negative effect

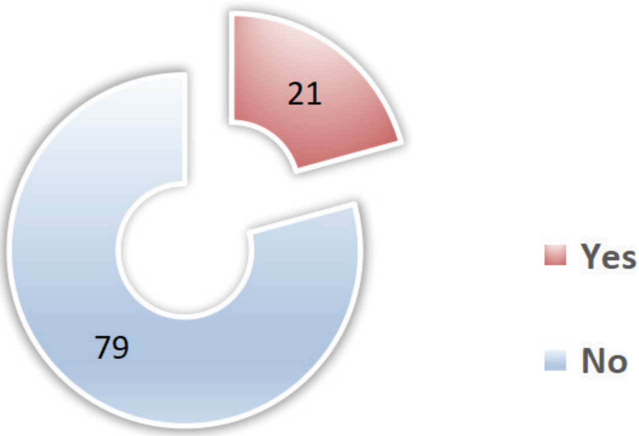


Source: Authors' estimations

Knowledge and Awareness regarding the Current System

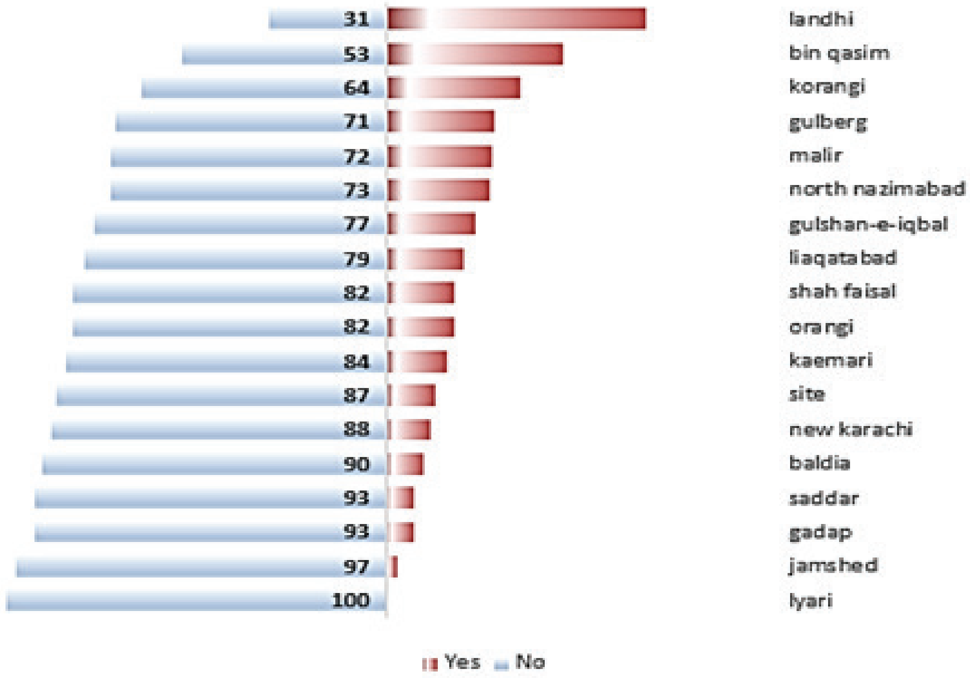
The two figures below show how many households took interest in the management of solid waste. This gives an idea of how serious a household was in managing the solid waste problem. Though Figure 4-20 highlights that around 79% of households were aware of their service providers, it is evident from the next figure that the majority of the households were unaware of how waste was disposed of by their service providers. This further highlights that their interest or concerns were limited.

Figure 4-20: Knowledge regarding disposal of waste by the service provider



Source: Authors' estimations

Figure 4-21: Do you know how your service provider disposes of your collected waste



Source: Authors' estimations

Household Willingness to Pay for Solid Waste

The purpose of this section is to measure and identify factors that influence households' willingness to pay for solid waste management. In addition, this part also assesses the collection charges households are already paying for availing some sort of services. A contingent valuation method/approach (CVM) was applied to determine households' willingness to pay. According to Carson et al. (1999), the CVM is the standard methodology that includes both the use and non-use value of a product. As the households' decision to demand a service is based on both use and non-use values, in this study it was assumed that the amount households were willing to pay (WTP) for the more improved system was based on its use and non-use values. Furthermore, following Fujita et al. (2005), matching WTP with the ability to pay (ATP) was also considered important. The ATP was derived from the income and expenditure patterns of the households. The compression of the two (WTP and ATP) adds another dimension to our research. For example, the WTP less than the ATP means that a household is reluctant to spend money on SWM. It means that a policy framework is needed to motivate households to invest in the service. But if the ATP is low, it reflects the inability of a household to pay for the service regardless of WTP. This further means that public investment is needed. In sum, if the ATP is less than the WTP it means that public/government support is needed. On the contrary, if the WTP is less than the ATP, it implies that motivational support is needed.

The analysis presented in this part is based on the descriptive assessment presented in Section 4.4. To analyse the association between the WTP and the factors influencing households' demand for the SWM, the Heckman two-step technique was employed.

Methodology

The concept of 'economic value' is usually defined as the measurement of changes in personal well-being. The theory was extended to measure the changes in the prices and quantities of marketed goods as well as non-market goods and services such as managing solid waste. The economic valuation of a service is an assessment of the preferences held by people.

If a service is not available in an area, the willingness to pay for the services cannot be properly inferred from the expenditures that are supposed to occur. This issue further pushed us to use the "stated preference" approach, i.e., the contingent valuation approach (CVM) as many surveyed households currently were not paying for solid waste management in their area. Under the CVM, the households were directly asked exactly what they would be willing to pay to avail of the SWM service.

Given the stated preference approach, we included an open-ended question in the household questionnaire on how much a household was willing to pay. The study considered this as more reliable than a dichotomous choice question with a "yes" option in case people were willing to pay or otherwise "no". Moreover, the advantage of using the open-ended variable is that it does not require the assumption that the households having the same characteristics also have identical preferences. The stated WTP can, therefore, be directly regressed on the characteristics of the households. The following simple function was estimated to assess a household's willingness to pay:

$$wtp=\beta' X+\varepsilon \qquad (1)$$

Where X is the vector of independent variables hypothesised to be influencing the willingness to pay for the service. The independent variables used in the estimation of the above-stated model are presented in Table 4-19 below with the expected signs. The demand for the solid waste management system is hypothesised to be a function of the households' socio-economic conditions (per-capita income, occupancy status, and congestion), demographic factors (gender of the household head, dependency ratio, age, and the education of the primary contributors), satisfaction with the current service, awareness, and the knowledge of solid waste management, use and non-use values (bequest – leaving a better environment for the future generation), and the environmental impact of waste. The choice of variables and the effect hypothesised were based on the descriptive analysis presented in the preceding section.

We computed the age and education of the individuals contributing to the household income, i.e., the primary contributor's age and education. Primary contributors are those who are assumed to have more say in the family's decisions since they are the earning members of the family. After identifying the primary contributors, the mean age and average education of the primary contributors to the household were estimated. We assumed that the higher the age and education of the primary contributors in a house the higher the amount the households were willing to pay.

Table 4-19: Explanatory Variable with Expected Sign

Explanatory Variables in WTP model	Expected Sign
Household Per Capita Income	+ve
Male Headed Household	+ve
Average Years of Education of Employed Household Members	+ve
Average Years of Age of Employed Household Members	+ve
Ownership of the house - Own House	+ve
congestion [room per person]	-ve
Index- Knowledge regarding SW Impacting Environment	+ve
Bequest Worth – Managing SW for better Future	+ve
Selection Model - Participating in MSW equals 1 otherwise 0	
Male Headed Household	+ve
Dependency Rate	-ve
congestion [room per person]	-ve
Average Years of Education of Employed Household Members	+ve
Average Years of Age of Employed Household Members	+ve
Index- Satisfaction Score with the current System	+ve
Index - Awareness/ Knowledge regarding SW	+ve

However, the key issue in estimating the above WTP model for the solid waste management services was that we did not observe the whole surveyed household. Since many of the surveyed households were currently not paying for solid waste management, their stated preference could lead to a problem of sample selection bias. However, in our study, we applied Heckman's two-step selection procedure to correct the sample selection bias. Heckman (1979) approached this as an omitted variable problem. He proposed that an estimate of the omitted variable would solve this problem of the sample selection bias. Therefore, Heckman's two-step procedure was used to control the selection bias of the sample. The selection equation was estimated using the maximum likelihood approach as an independent probit model. The variables' inverse Mills ratios were generated from the parameter estimates. The willingness to pay (amount) can be s observed only when the selection model equals 1, which is then regressed on the explanatory variables and inverse Mills ratios using ordinary least squares (OLS). The lambda is introduced in the second stage as an additional variable. If the coefficient of lambda is significant, we reject the null hypothesis of no selection bias.

Table 4-20 below provides the descriptive statistics of the variables of interest. According to the table, the households' willingness to pay varied from Rs. 50 to Rs. 5,300 per month. The average numbers of households currently paying for availing some sort of service (our selection variable) were around 70 per cent (323 out of 459), and the average per-capita income of the surveyed household was around Rs. 19,000. Table 4-20 also reports the indices developed. It shows an average score of 0.66 for the environmental knowledge index (ranges between 0 to 1, where 1 means perfect knowledge), a score of around 1.9 for the satisfaction index (ranges between 0 to 3, where 3 means complete satisfaction), and a score of 0.67 for current solid waste management process.

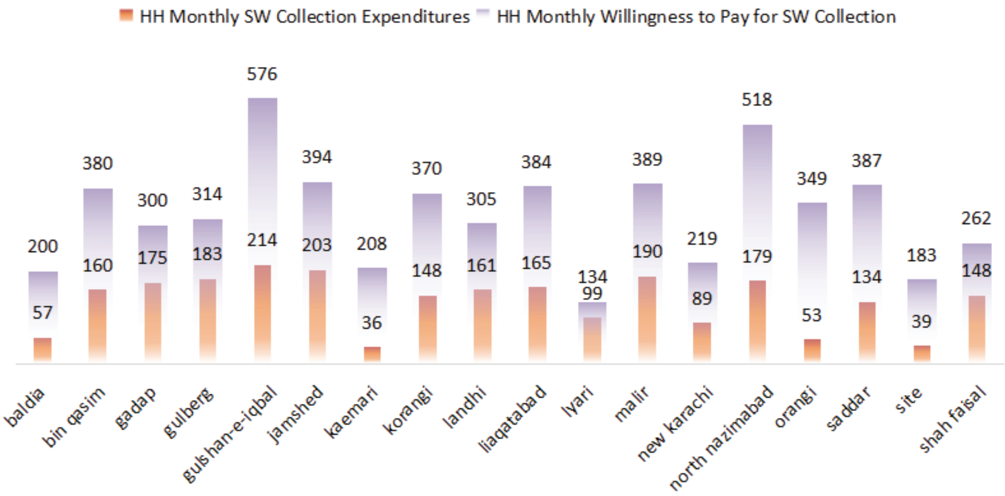
Table 4-20: Descriptive Assessment of Factors Influencing WTP

	# Obs.	Mean	S.D	Minimum	Maximum
Household Willingness to pay	459	467	452	50	5300
Participating in SWM equals 1 otherwise 0	459	0.70	0.46	0	1
Household Per Capita Income	459	19085	21867	1429	340000
Household Headed by Male	459	0.90	0.30	0	1
Dependency Ratio	459	3.89	2.37	1	13
Average Years of Education of Employed Household Members	459	10.43	4.51	0	19
Average Years of Age of Employed Household Members	459	39.40	9.79	17.7	86
Ownership of the house - Own House	459	0.79	0.41	0	1
Index- Knowledge Regarding SW Impacting Environment	459	0.66	0.22	0	1
Bequest - MSW for better Future	459	0.98	0.14	0	1
Index- Satisfaction Score with the current System	459	1.93	0.80	0	3.3
Index - Awareness/ Knowledge regarding SWM	459	0.67	0.16	0	1

Source: Authors' estimations

Figure 4-22 shows the current expenditure household made on SWM and what households were willing to pay for further improving the system. The numbers are disaggregated by town.

Figure 4-22: Current Expenditure on SW Collection and WTP for it.



Source: Authors' estimations

WTP Results

Table 4-21 reports the factors influencing the maximum amount household were willing to pay for making improvements in the current solid waste management condition and their decision to pay for the services (under the current state), which equals 1 if yes and 0 otherwise.

The table shows that among the explanatory variables, household per-capita income, households headed by a male, the average age of the primary contributor, and knowledge regarding SW impacting environment had a significant impact on the households' willingness to pay for the SWM. Except for the average age, the rest showed a positive and significant effect. The table shows that a 1 rupee increase in per-capita income increased the WTP by Rs. 0.002. Similarly, if the household was male-headed, the WTP increased by Rs. 223, and the household's knowledge regarding the environmental impact of solid waste increased the WTP by Rs. 257. However, the average age of the primary contributor, hypothesised to have a positive impact, was found to influence the WTP negatively. The reason could be that as the age of the primary contributor increases, the tendency to save more increases to secure the future after retirement. Overall, an increase in the age of the primary contributor by a year decreased the WTP by Rs. 5.6.

The first stage probit estimates show that an increase in the age and education of the primary contributor increased the probability that the household would pay for the SWM. In terms of the coefficient (the probit coefficients give the change in the z-score for a one-unit change in the predictor), a one-unit increase in the age and the years of education of the primary contributor, increased z-scores by 0.02 and 0.09, respectively. Similarly, a one-unit increase in the satisfaction index increased the z-score by 0.40. In addition, the congestion (rooms per person) also showed a significant impact [with a one-unit increase in the congestion, the z-score increased by 0.44]. Furthermore, the lambda, which measured the presence of selectivity bias, is also significant implying that selectivity bias was present in the model. Therefore, Heckman's two-step approach is justified.

Table 4-21: Factors influencing WTP

Variables	Coefficients	t-stats	p-value
Household Willingness to pay – Rs.			
Household Per Capita Income	0.002	1.97	0.049**

Male Headed Household	223	2.51	0.012*
Average Years of Education of Employed Members	8.5	0.8	0.426
Average Years of Age of Employed Members	-5.6	-1.79	0.073***
Ownership of the house - Own House	-77	-1.24	0.216
Congestion [room per person]	2.8	0.06	0.951
Index- Knowledge regarding SW Impacting Environment	257	2.05	0.04**
Bequest Worth - MSW for Better Future	62	0.35	0.727
Constant	397	1.3	0.195
Participating in MSW equals 1 otherwise 0			
Male Headed Household	-0.18	-0.7	0.485
Dependency Rate	-0.02	-0.67	0.502
congestion [room per person]	0.44	1.93	0.054**
Average Years of Education of Employed Members	0.09	5.7	0.00*
Average Years of Age of Employed Members	0.02	2.5	0.012*
Index- Satisfaction Score with the current System	0.40	4.72	0.00*
Index - Awareness/ Knowledge regarding SW	0.44	1	0.318
Constant	-2.22	-4.48	0.00*
Mills Ratio – Lambda	-311	-1.88	0.06**
Number of observations	459		
Censored observations	136		
Uncensored observations	323		
Wald $chi^2(8)$	26.14		

Significance level: 1% (***), 5% (**), 10% (*)
Source: Authors' estimation

Ability to Pay (ATP) vs. Willingness to Pay (WTP)

The WTP refers to the maximum amount that the households are willing to pay for improvement in solid waste management conditions, while the ATP is the amount households actually can pay. Capturing a household's ATP means checking household affordability. The information is, therefore, useful for policy design. Policies formed without considering who will pay and how much ability they have to pay result in policy failure.

The ATP is usually calculated using the household disposable income or the household expenditure composition. Researchers have followed various techniques to compute the ATP and the suggested ATP for SWM is 1 to 2 per cent of the household's income for low and middle-income countries. In this study, we computed the ATP as 1% of household income (see Wilson et al., 2012). Specifically, the ATP was computed as 1 per cent of the household's income. Table 4-22 compares the household's willingness to pay with the household's ability to pay. The results predict that in all the cases the ATP was much higher than the WTP, suggesting the need for motivational arrangements needed to convince households to pay more to manage solid waste.

Table 4 22: Comparing ATP and WTP

Town	ATP (Rs.)	WTP (Rs.)	Difference
Baldia	705	257	ATP>WTP
Bin Qasim	731	540	ATP>WTP
Gadap	1,374	475	ATP>WTP
Gulberg	1,097	498	ATP>WTP
Gulshan -E- Iqbal	1,738	790	ATP>WTP
Jamshed Town	1,164	597	ATP>WTP
Kaemari	801	244	ATP>WTP
Korangi	720	518	ATP>WTP
Landhi	637	466	ATP>WTP
Liaqatabad	850	549	ATP>WTP
Lyari	683	234	ATP>WTP
Malir	1,367	579	ATP>WTP
New Karachi	623	308	ATP>WTP
North Nazimabad	1,709	705	ATP>WTP
Orangi	748	403	ATP>WTP
Saddar	1,581	521	ATP>WTP
SITE	679	222	ATP>WTP
Shah Faisal	718	409	ATP>WTP
Total	987	467	ATP>WTP

Source: Authors' estimations

SWOT Analysis

This section first develops a framework to understand the role and linkages between various stakeholders at each step of the management process. Identification of the weak and no connectivity at all helps in understanding the leakages in the system.

Generally, in the context of waste generation, a household is regarded as one of the most central units of analysis along with industries and medical units. A strong negative association is found between per capita waste generation and the size of the household (Parizeau et al; 2006 & Ojeda Benitez et al; 2008). The financial position, consumption behaviour, and lifestyle of households influence the waste generation and composition of the waste (Yusof et al; 2002&Tadesse et al 2008). The per capita waste generation decreases as income increases because of the change in lifestyle and types of food consumed (Solomon; 2011). Waste segregation is not common at the household level. In Karachi, households consider themselves as the receiver of service, which they pay to avail. However, they usually do not bother about where the waste goes and how it is disposed of. This opens space for leakages in disposal and recycling/reuse of the waste generated.

With the increase in economic activities and a move towards industrialisation, the ecological damage caused by industrial waste can not be neglected. Unfortunately, industrial waste generation rates are unknown. Industrial waste usually comprises chemical waste, toxic and hazardous materials, and different materials, such as paper, metal, plastic, wood etc. Proper segregation is required to facilitate the efficient disposal of industrial waste. The usual practice in handling industrial waste again comprises both formal and informal ways. Usually, the recyclable material is sorted and segregated on the spot and only the waste that is not of any use is dumped on land or into the sea. Furthermore, medical needs have added a considerable amount of biomedical waste to the waste stream. Empirical studies demonstrate that in Pakistan 2.0kg/per bed/per hospital[3] waste is generated of which 0.5kg can be categorised as bio-medical hazardous waste. Improper handling and disposal of this kind of waste have contaminated the environment and elevated the risk of spreading contagious diseases. For a city having a population of over 20 million, only two incineration units each with a capacity of 1 ton, are installed for the incineration of the hospital, clinical, and medical waste. According to the KMC officials (now responsible for handling medical waste in Karachi after the establishment of SSWMB), two units cater to only 20% of the hospital waste. The plants need to be replaced by new ones.

The whole set of activities related to the collection of solid waste is strongly linked with DMC/local government, private contractors, and informal players. The collection of waste has mainly two aspects, i.e., collection from the source of generation to the large assigned collection point and from that collection site to landfill sites to dispose of. The DMC/local government is mainly accountable for providing waste management services. Due to a lack of attention from the concerned authorities, the management of solid waste is still inefficient. Furthermore, the lack of financial, physical and human resources, institutional inefficiencies, and political interference have made the situation shoddier over time. Local political factors involve excessive political employment or the employment of untrained workers and the misuse of financial resources. Further, Oteng-Ababio (2010) argued that if the public sector fails to deliver an efficient service directly, it may have difficulty in monitoring private contractors as well. When waste is collected by private contractors, it is necessary to monitor the transportation of the collected waste to authorised landfill sites so that it is not dumped illegally to save time and minimise costs. High efficiency requires the presence of good working conditions throughout the process, including legislation, support from authorities, viable contractual arrangements, and effective monitoring. In private arrangements "competition" is key to a successful outcome. Therefore, the tendering process should maintain real competition to ensure good services as well as competitive prices. Since the advent of the SSWMB, the activity of managing SW has been progressively transferred to the private sector. Initially, two Chinese companies were awarded the contract of four of the DMCs (East, West, South, and Malir), while the outsourcing of one district (Central) to a Spanish company is in process. The private companies have been awarded the contracts through a proper tendering process and the requirement of the monitoring process has been fulfilled. However, as the companies have started the work using KMC employees (the SSWMB mostly has KMC employees) – which essentially means maintaining the status quo – very limited desirable results have been achieved. In many UCs the old process continues to exist. The sub-contracts have been awarded based on personal relations.

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[3] https://www.env.go.jp/recycle/3r/en/asia/02_03-2/04.pdf

As the formal sector does not have sufficient resources to provide collection as well as disposal services to all households, informal waste pickers are making a noteworthy contribution to collecting, sorting, disposing, and recycling waste material. Scheinberg et al. (2010) argue that most informal service providers achieve net benefits while formal service providers bear the cost. The prime motivation of informal players to provide waste collection services is not only the fee that can be charged but the income that can be generated by sorting and recycling the waste. The collected waste generally comprises food waste, paper, glass, metal, plastic and silt. Recyclable and reusable waste, such as paper, glass, metal, plastic, etc., are separated by scavengers and waste pickers at community collection points or landfill sites because this kind of waste has economic value.

How informal recycling is performed has significant implications. The informal sector is not well organised and workers are not capable enough of adding value to recyclable material, therefore, they are easily exploited by small and large dealers. The recycled materials are usually sold locally and a chain of intermediate traders is often found between waste pickers and end-users. Though the informal sector brings considerable economic benefits, it usually lacks capital equipment and mostly relies on manpower to supply cheaper secondary recycled material for local industry to replace imported raw material (Wilson et al; 2006). The waste is collected typically through handcarts and donkey pull-carts for primary collection, while open trucks and tractors are used for secondary collection and transport. Without the interest of the government and the formal sector, the segregation of waste is quite difficult due to which all the waste ends up in one container. The scavengers usually sort out the waste at undesignated sites or informal collection points.

Finally, from the assessment done and leakages identified after thorough discussions, the following strengths, weaknesses, opportunities, and threats are identified for each step from generation to disposal.

Table 4-23: SWOT Analysis- Generation

Internal Factor	External Factor
<u>Strength</u> S-1: Households show their willingness to adopt environmentally friendly consumption. S-2: Awareness regarding the negative impact of SW mismanagement on the environment and health. S-3: Average earning of HH from the sale of recyclable waste is around Rs 400 per month.	<u>Opportunities</u> O-1: There exists a wide scope for HH to generate economic benefits from the sale of recyclable waste. O-2: Promoting paper bags or other degradable materials in daily transactions would contribute potentially to controlling SW generation. O-3: Individuals are concerned regarding waste management.
<u>Weakness</u> W-1: Generation of waste in the form of high-micron polythene bags causes blockages in the drainage system. W-2: Statistics for industrial waste generation are not available for evaluation and monitoring.	<u>Threats</u> T-1: Growing population & uncontrolled migration influx T-2: Increasing demand for health services especially after the emergence of the covid19 pandemic is raising bio-medical waste.

Table 4-24: SWOT Analysis - Collection

Internal Factor	External Factor
Strength S-1: Public-Private partnerships through tendering for improving collection and controlling system informality. S-2: High ATP than WTP of HH in all towns in Karachi. S-3: Financial support for SWM nationally and internationally.	Opportunities O-1: under the umbrella of public-private partnership the government may utilise the informal network for efficient waste collection. O-2: Fundraising opportunities are available as HHs are willing to pay additionally for improved SWM system, O-3: profitable recyclable waste - if collected properly
Weakness W-1: Sub-contracting based on personal relationships or under political influence W-2: Lack of physical resources W-3: Waste is not collected daily but rather weekly or fortnightly. W-4: Only 25% of vehicles are functional. W-5: Poor monitoring system. W-6: Emergence of informal transfer stations. W-7: Untrained worker for collecting waste.	Threats T-1: Lack of interest in managing SW by stakeholders. T-2: Political influence in managing SW. T-3: Delay in waste collection exaggerates various health and environmental concerns. T-4: Non-availability of standard procedure for collection.

Table 4-25: SWOT Analysis – Disposal/Recycling

Internal Factor	External Factor
Strength S-1: Individuals agreed to segregate waste by type. S-2: Increasing industries for recycling, especially the informal ones, is contributing towards tackling and generating revenue from solid waste.	Opportunities O-1: Segregated waste would expedite the recycling process as it can be directly sent to relevant recyclers. O-2: Around 20% of plastic waste collected is resalable while only around 12% is currently sold. Further, through on spot sorting about 8kg plastic, 10 kg paper, 8 kg cardboard and 4 kg iron/steel collected daily are resalable and sold by the worker while the worker claims that around 20% of the remaining waste is still resalable. O-3: Boosting industries' recycling of food waste into animal feed could also be a potential revenue source.

Weakness	Threats
W-1: Lack of coordination and connections between KMCs and informal pickers W-2: Informal dumping points: dumping of waste at nearby vicinity, streets, parks etc. W-3: Despite acknowledging the impact of SW on health and the environment, individuals behave reluctantly while disposing of their waste properly or in an environment-friendly manner. W-4: About 60% of total waste is food waste which is directly disposed of because the industry for converting food waste into animal food is in its primitive stage. W-5: Untrained worker for collecting waste. W-5: Improper disposal practices deteriorate the prevailing ecology and give birth to many biological diseases. W-6: Low-capacity landfill sites in relation to the waste generated.	T-1: Households don't bother where and how the waste is disposed of after collection from their houses. T-2: Lack of interest in managing SW by stakeholders. T-3: Lack of implementation of environmental legislation. T-4: Non-availability of standard procedure for disposal.

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

Tackling the solid waste problem in a megacity such as Karachi which has a population of around 16.5 million and generates a daily waste of almost 0.28 to 0.61 kg/per capita with 2.5% annual growth, requires an effective policy framework and efficient implementation. A holistic understanding of the institutional capacities (technical, financial, human, and physical resources), actors involved in managing solid waste, household socioeconomic conditions, political issues, and how they are linked to the stakeholders under various phases of the SWM system given the ground realities is crucial for such policy framework. Identification of the stakeholders and their interests is important in coordinating their participation and involvement in various waste management activities. Therefore, it is essential to access the role, interests, and power structure of various stakeholders in the process of waste management. This report is unique as it provides an in-depth assessment of all the stakeholders involved in solid waste management from generation to disposal. The study draws the following conclusions and policy measures:

- The analysis highlighted that issues have been exacerbated by unclear duties, overlapping functions, and inadequate coordination among the numerous institutions responsible for solid waste management. The functions are largely divided between the KMC and the SSWAMB, resulting in a lack of coordinated planning and integration. There is a need to resolve the issue by clearly assigning the responsibilities; there should be only one authority responsible for the SWM.

- In addition, public awareness, financial needs, institutional capacity, regulation enforcement, and the establishment of a proper sanitary landfill are principal measures needed to ensure a sustainable solid waste management system.

- The assessment predicts high profitability from recovering recyclable materials, which is mainly enjoyed by private contractors and informal workers. Given the profitability, the study recommends that the problem of SWM can be dealt with by adopting policies for improved municipal solid waste services characterised by regular collection, timely transportation, careful disposal (especially hazardous medical waste), and proper separation of recyclable waste in achieving sustainable development.

- Households are concerned with the improved solid waste system and are ready to make efforts for it. However, for those who are reluctant to adopt sustainable waste management strategies motivational aspects are needed.

- Finally, elected local governments have ineffective processes and capacities, and they lack the authority to carry out numerous municipal responsibilities. A variety of services and functions that the city performs, including master planning, building control, water and sewerage services and solid waste management are all under the control of the provincial government. DMCs are in dire economic straits, relying almost completely on provincial government payments to satisfy their budgetary demands, the bulk of which is consumed for salaries and pensions, leaving relatively little for much-needed infrastructure management and development.

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ANNEXURE

Annex-A1-1

S.No	Title	Author	Key Findings
For Developing Nations			
1	A Literature Review on Solid Waste Management: Characteristics, Techniques, Environmental Impacts and Health Effects in Aligarh City", Uttar Pradesh, India.	Priyadarshi et al (2019)	➢ Priyadarshi et al (2019) performed a scenario analysis for Aligarh city, India by conducting a door-to-door survey in the residential areas of Aligarh. ➢ The major information collected by the survey was comprised of the generation and sources of solid waste, the amount of waste generated, the technique with which the waste is usually dispose-off and the prevailing health conditions. ➢ The finding revealed that regardless of all struggles being made by the local officials using their inadequate resources still the situation of solid waste management is not satisfactory. Usually, the waste is dumped on open areas on the periphery of the city without considering any scientific methods. ➢ At every level from the collection, and transportation to disposal there were problems in the prevailing practices of solid waste management. Therefore, the mismanagement of solid waste is a matter of serious concern for individual health and the sustainable environment of Aligarh city.
2	Sustainable solid waste management in developing countries: a study of institutional strengthening for solid waste management in Johannesburg, South Africa	Kubanza, N. S & M. D. Simatele (2019)	➢ The research used both primary and secondary data to analyze the impact of solid waste on environmental well-being and human health in Johannesburg, South Africa. ➢ It was found that the health of individuals and the urban ecology is inversely related to the extent of mismanaged solid waste in the region. This in turn becomes a barrier to economic growth by reducing productivity and well-being. ➢ It concludes that the ineffective SWM is the result of the incapability of the institutions to enforce and implement policies/ regulations and also the reluctance of the private agents and community to duly recognise the issue of SW and their participation in urban development.

3	Waste Mismanagement in Developing Countries: A Review of Global Issues	Ferronato and Torretta (2019)	➢ They conclude that dumping and burning waste openly is majorly visible implemented final waste disposal treatment in developing countries. ➢ The study also evaluates the impacts on health attributable to the scavenging of waste activities in informal sectors of cities, especially in developing countries. The key factors influencing the environment include interacting directly with hazardous waste collection along with contamination of water, air and gas. ➢ This multi-sourced pollution not only impacts the environment and health but also endangers the sustainable development of cities in particular and countries as a whole. This emphasised the need to integrate policies regarding SWM in the city and national policy frameworks to improve SDGs indicators as solid waste has its impact on all three pillars of sustainability: planet, people and profit. ➢ The study suggested that future policies for municipal waste management be based on collecting and treating waste on an ad hoc basis.
4	Solid waste management in India: an assessment of resource recovery and environmental impact	Ahluwalia and Patel (2018)	➢ This study investigates the environmental and financial sustainability of solid waste management in Indian cities. ➢ It assesses the rapidly increasing volume of solid waste along with its changing composition and concluded that the existing system is mainly operating to collect and transport largely mixed un-segregated waste. ➢ Resource recovery from the waste and safe disposal of the residual waste in scientifically designed landfills are grossly neglected. ➢ In the absence of segregation of waste recycling is also not performed properly. Landfill Sites are used for open dumping because too much waste dumping without resource recovery generates leachate and methane gas. ➢ Although, Rules have now been introduced to achieve sustainable solid waste management the enforcement of the rules is still a big challenge because of the lack of resources and capacity to manage the system efficiently.

5	A review of solid waste management practice in Dhaka City, Bangladesh.	Yasmin&Rahman (2017)	➢ As per their results, uncollected waste produces a serious drainage predicament in a city, especially in the rainy season. ➢ The open disposal and dumping of garbage are unhealthy for the environment and health and therefore there is much need to adopt modern technology and equipment. They emphasise the role of Public and private partnerships in this regard.
6	A comparative study of municipal solid waste management in India and Japan.	Niyati, M. (2015)	➢ Niyati performed a comparative study on the regulations and practices of SWM in Japan and India. Results revealed that Rapid urbanisation and industrialisation especially in low-income countries have been recognised as the core source of rising SW generation trends creating a mass mess in urban settings. ➢ Japan attained sustainability in managing its solid waste because of its well-organised, efficiently planned and implemented SWM system. In most developing countries, disposal of waste is commonly associated with open dumping despite having laws in place discouraging such acts. ➢ Furthermore, most of these legislative policy frameworks lack the push toward promoting waste management in an environmentally sound manner. Thus, widening the scope of such frameworks in this regard would aid in tackling solid waste management effectively. ➢ Japanese SWM model is not suited for developing countries like India because of its much different waste composition and prevailing large informal recycling sector. ➢ Moreover, it would be relatively expensive for such economies to adopt commonly used incineration technologies practised in Japan. Thus, it was suggested that a human-rich country like India may raise its recycling rate by engaging its abundant resources in the informal sector and innovating on technological and regulatory grounds.

7	Factors Influencing Solid-W or Influencing Solid-Waste Management in the Waste Management in the Developing eloping World	McAllister, J. (2015)	➢ This study is found as a comprehensive review regarding solid waste management practices in developing countries and mentions that culture, knowledge, infrastructure, social provisions, technology, and lack of policies are found as the key constraints to influence solid waste systems. ➢ The study suggests that to achieve a sustainable solid waste management system in developing nations financial resources, physical capital proper public awareness and other necessities that are currently lacking need to be provided. ➢ Furthermore, as sustainable SWM practices call for some behavioural changes therefore community participation and awareness programmes need to be conducted.
8	Assessment of municipal solid waste management system in a developing country	Ahsan et al (2014)	➢ Bangladesh analyses the current practices for managing municipal waste and indicate that the concerned authority is unable to manage huge generation of waste because of fewer economic and human resource and a lack of infrastructure and technological capabilities. ➢ Support is required from all stakeholders for the door-to-door collection of waste along with proper campaigns related to awareness and motivation of sustainable collection and disposal of solid waste. ➢ Further, they highlight that efficiency of waste transportation is required to be improved with the help of the private sector. Because there is no single solution, they suggest integrated solid waste management techniques to improve the solid waste management system in Bangladesh.

9	Solid waste management in Kenya: a case study of public technical training institutions	Gakungu, N. K., Gitau, A. N., Njoroge, B. N. K., &Kimani, M. W. (2012)	➢ This study examined the generation, collection and disposal of solid waste using the data of 73% of the technical training institutions in Kenya that are engaged in producing 23 tons of waste per week. ➢ The research quantifies the solid waste generated into its different components and evaluates the attitudes of those responsible for its generation and management. ➢ It concludes that the unsafe disposal of SW by these institutions has influenced the economy negatively and caused pollution to rise substantially, thus, impacting the standard of living in the regions adversely. 82% of the waste consists of vegetables and food waste along with plastics, papers, ash, metals and glass as the other waste types. ➢ The study also estimated the cost for planning and managing the SW to range from Ksh 0.13 to 0.59 /week/student while per capita waste generation ranged from 0.28kg/week/student to 0.71kg/week/student. ➢ The study suggests that Boards of Management should incorporate waste management in their institutional planning to ensure the collection and disposal of SW in a planned manner and to allocate appropriate financial and human resources for its remedy.
10	Disposal of solid waste in Istanbul and along the Black Sea coast of Turkey	Berkun et al (2005)	➢ Istanbul is having great progress in its existing practices to manage solid waste by establishing transfer stations, sanitary landfills and methane recovery systems, but on the Black Sea coast in Turkey, the problems are still unmanageable. ➢ The factors that are responsible for such differences include the complex topography, feeble administrative structures and the low level of income in these local areas.

11	Integrated solid waste management: Engineering principles and management issues	Tchobanoglous et al (1993)	➢ The elevated growth rate of the population and rising economic activities combined with the lack of training in contemporary solid waste management practices cause difficulties in the efforts to improve solid waste management services in the urban areas of developing countries.

	Title	Author	Findings
For Pakistan			
12	Knowledge, Perception and Attitude of common People towards Solid Waste Management-A case study of Lahore, Pakistan	Haider.et.al (2015)	➢ Discussed the SWM system relate to the respondents' view about perception, knowledge and attitude for the location of low middle and high-income levels by the sample of 300 households collected for the city of Lahore ➢ The finding of the result shows that SWM practices have been improved but are still unsatisfactory ➢ The three income levels contributed about 564kg/day of solid waste, among which low-income areas contributed171kg/day, middle-income areas 194kg/day and higher income areas 199kg/day and the quantity of waste increased as the number of family members increased ➢ Composition of solid waste includes fruits and vegetables 65.2%, plastic 20.2%, paper 10.9%, glass 0.3%, textile 3.3% and others 0.1% respectively. ➢ The finding of the study also reveals the trend of reuse material and waste collection vary from high to low income

13	Impacts of solid waste management in Pakistan: a case study of Rawalpindi city	Nisar et.al (2008)	➢ Solid waste management is considered a major environmental issue, especially for larger cities. ➢ Highlighted the impact of solid waste management in Rawalpindi city by an increase in urbanisation, horizon of industries and growing standard of living in urban areas leaving a drastic impact in case of solid waste management ➢ Research findings show it is revealed two major problems due to poor solid waste management respectively communicable diseases and an unhygienic environment ➢ Lack of efficient management and legislation, existing solid waste management systems, high waste generation rate and high growth rate are not making the system properly grow. ➢ Because unplanned annexation of the city, extreme weather conditions, lack of public awareness/community involvement, improper resources including improper equipment and lack of funds caused the failure of SWM
14	Alternative approaches for solid waste management a case study in Faisalabad	Yasin et.al (2017)	➢ Identify the solid waste management alternative approaches of recycling, composting and incineration for Faisalabad city that are producing 1,300 to 1,600 tons per day varying by the time ➢ The waste generated amount is near 54% while disposal of facility available only for 43% exist ➢ Manageable criteria for SWM reduce the problem of pollution while making the positive outcome of fertiliser and energy ➢ The recycling process is applied to all the plastic and rubbers used for extra growth of running while an incineration system is applied to generate the energy and another part could use for electricity generation.

15	Solid waste management practices under public and private sectors in Lahore	Ashraf et al (2016)	➢ The study explored the comparison between public-private practices of solid waste management in Lahore ➢ The study indicates lacking some key indicators, such as solid waste storage capacity, administrative structure, sweeping, monitoring system and waste collection process ➢ The overall condition of SWM has not been satisfied that also point out by the government of Pakistan due to the irregularities in the legislative system with poor institution performance making it worst. ➢ The study concludes that with public resources private system contributes through material recovery, sanitary landfills and the informal sector support
16	Municipal solid waste management in Lahore City District, Pakistan Country report Waste Management	Batool and Ch (2009)	➢ This study analyses the determinants of total and per-capita generation of waste for Data Ganj Bakshs Town (DGBT) which is the urban area of Lahore. ➢ The composition of those determinants consists of transportation, disposal in open dumps and storage problems, and cost of the current management system by improving the used IWM-2 model. ➢ Findings show that around 0.8% kg per capita /per day of waste generated in (DGBT), mostly the non-organic waste generation of the total waste that consists of around 91% while organic waste consists of 67.02%
17	Waste Generation Rate and Composition Analysis of Solid Waste in Gujranwala City	Ilyas.et.al(2017)	➢ This study aims to find out the quantity of waste produced and what the contribution is in Gujranwala city of Lahore. ➢ A sample of 776 was collected through the survey by the integration of residential and commercial areas while household sources were divided into rural low medium and high-income levels. ➢ The output shows for these four levels of average waste generations rate found in

			in the range of 0.3 per capita per day in low to high-income areas near about 0.4 per capita per day ➢ The finding shows more than 80% of waste consists of organic waste, moreover to the analysis specific gravity for waste calculated from high income is 275kg /m3 for middle accounted 285 kg/m3 while for low income is 283kg/m3 meanwhile for rural areas is 256kg/m3.
18	Comparison of MSW management practices in Pakistan and China	Korai et al. (2019)	➢ Stated the comparison of Municipal Solid waste (MSW) management in between Pakistan and China ➢ In Pakistan been observed that unsanitary disposal MSW realised the growing concern due to the lack of efficient management plan ➢ Moreover, shortage of electricity and environmental issues create more complexity and alarming situation for MSW ➢ Karachi has, a total quantity of waste generation of around 0.57Kg/Capita/day while the total quantity rate is 4.76 MT/Y while further goes respectively. ➢ Lahore 0.75 Kg/C/D with quantity rate 2.8MT/Year. ➢ Faisalabad 0.45Kg/C/D and quantity spread 2.8MT/Y ➢ Rawalpindi 0.21Kg/C/D and quantity 0.13MT/Y ➢ Hyderabad 0.8Kg/C/D and 0.8 ➢ Islamabad expresses around 0.5Kg/C/D and 0.1MT/Y. ➢ Comparison discloses Pakistan and China ➢ MSW collection efficiency 60% and >95% Total MSW 30mill tons and in China 203mill, dominant landfill slide >90% while in China shows 60%.
19	Hospital waste management in Pakistan	Khattak (2009)	➢ This study explores the situation in Pakistan regarding the health care waste management system.

			➢ Finding reveals on the daily basis around four to two thousand kg from various hospitals generating near about 2.0kg of waste/bed /per day produce in that 0.1 to 0.5 declared high-risk waste. ➢ Moreover, also declare around 75% to 95% are coming from non-risk waste collecting by health care, household and administrative functions.
20	Framework for integration of informal waste management sector with the formal sector in Pakistan	Masood and Barlow (2013)	➢ Discussed that in developing countries for the mutual benefit informal waste management networks collaborates with formal for that a proposed integrated framework system for Lahore city try to identify the points of intervention among these sectors ➢ Interventions are divided into four categories that are formal SWMS, Material and value chain, society as a whole and organisation and empowerment of the informal recyclers.
21	Willingness to Pay for Solid Waste Management Services: A Case Study of Islamabad	Anjum (2013)	➢ As SWM has always been a crucial problem that has to face mostly the developing countries where the larger part of the budget consumes for that purpose ➢ The study conducted for the Islamabad SWM consists of the generation collection and disposal of waste ➢ Used contingent valuation survey approach for 100 respondents ➢ Finding shows by the application of logistic regression that reveals 65.4 per cent of the total respondents are willing to pay ➢ However, multiple regression reveals a monthly mean willingness to pay of Rs 289.15 shows ➢ Results also elaborate on the findings that willingness to pay is affected by age, education and income and environmental awareness ➢ Higher education and income produce a higher willingness to pay

22	An assessment of the current municipal solid waste management system in Lahore, Pakistan	Masood et al (2014)	➢ In that study, the review of SWM regards to Lahore city has focused ➢ The study covers the UN-Habitat city profile approach ➢ Analyzes the current SWM system based on waste collection and transportation ➢ Although collection coverage is near about 68%, however, there is no controlled and semi-controlled disposal of the facility has seen in Lahore, meanwhile, no official recycling process is active in the city ➢ Although 27% of the recycling process undergoes by the informal sector ➢ Lahore is not making more efficient progress with respect to governance features ➢ The study suggested that more awareness should be provided by the consumer side and to make the recycling process more effective there should be the integration of the informal sector for financial sustainability ➢ Lahore Waste Management has 58 officials and 10,000 field workers for waste collection and disposal by the figure LWMC(2011) ➢ Summary of the Lahore on UN- Habit is like that public health waste collection is around 68%, environmental dispose near 8%, resource management (3R) reduce, reuse and recycle 35%, Governance strategies are too low while financial sustainability is near 68% ➢ Lack of planning and public-private coordination is barriers to improving the SWM
23	A Study of Solid Waste Management in Karachi City	Sabir et al (2016)	➢ The study is qualitative and mainly focused on the problem issues and challenges to cope with the SWM in Karachi. ➢ For the survey, selected 20 respondents included household and responsible municipal committee officials for the SWM.

			➢ Findings show citizens are not satisfied with the current system of SWM, municipal has the responsibility to tackle the entire situation that is not handled properly. ➢ Meanwhile, it has also been observed that municipal committees are facing the problems of lack of funding and ineffectiveness for that purpose. ➢ Illegal dumping without any awareness produces the largest problem in the city. ➢ Hazardous waste dumping in society creates multiple types of diseases in the city. ➢ Machinery and equipment are too old to support the system ➢ There is a need to be required to control the per-day collection of SW in growing urban areas. ➢ Management should adopt some immediate actions, strategies, planning and design to streamline the current situation to control. ➢ The study also suggested that there is also some sort of need to educate the citizens with respect to reducing the quantity of SW and further the recycling process.
24	Urban Solid Waste Management in Karachi, Pakistan	Mahmood& Khan (2019)	➢ The study evaluates the importance of the Solid Waste Management system (SWM) in Urban Karachi. ➢ Multiple factors have contributed to the vast growth of garbage in Karachi. Overpopulation and migration are some of those factors. ➢ People living in Katchi Abadis deprived of solid waste disposal facilities; hence, they dumped solid waste in natural drains, streets or open plots. ➢ The city produces various categories of solid waste which are household municipal waste, institutional waste, restaurant

			waste, street sweepings, landscaping waste, agricultural waste, animal slaughterhouse waste, fish market waste, vegetable market waste, sewage sludge, and tires. ➢ A landfill site to informal picker to garbage transfer system is not enough to sustain the severity of Karachi
25	A Study of Solid Waste Management in Karachi City	Sabir et al (2016)	➢ The study aims to analyse the condition of solid waste management in Karachi city. ➢ Observations show on the daily basis about 12000 tons of SW for six districts are generated in the city. ➢ Findings show that citizens on an equal basis break the laws and violate the restriction in the sense dump the wastages in front of houses open areas and on roads. ➢ As it declared by the different statistics that 60% waste collected in the city while 40% reaming as it is on roads. ➢ There is a need to require (3R) that are reduce, reuse and recycle process
26	Urban Solid Waste Management in Karachi, Pakistan	Hajra et al (2019)	➢ This study evaluates the importance of solid waste management in the urban city of Karachi ➢ For the study of Karachi different models has adopted by different cities for the SWM. ➢ Shed the lights on different master plans from 1992 to 2020. Before 1974 around 2,000 tons SW was produced per day and now in 2019, it reached near about 12,000 tons per day. ➢ A highly dense populated city with vast, growth of garbage producing various categories of garbage like household municipal waste, commercial waste, Institutional waste, restaurants, streets, hospitals, Industrial, landscaping, agriculture, animal, slaughter etc. ➢ The government made Karachi 2020 Plan although the increasing population with rising waste produced an alarming situation for the city to control.

			➢ Studies suggested that there should be a link between the government and the masses, people have aware of dropdown waste places. The landowner, board and membership should be developed. ➢ Educational institutes can be helpful in that they can motivate their students to the garbage collection and the recycling process awareness programs such as convert agriculture waste to the use of livestock food.
27	Baseline Study for Solid Waste Management - Karachi	ESCAP/IUCN/UN HABITANT (2013)	➢ The main purpose of the study is to find out waste storage methods at the household level in Karachi. ➢ The study also discusses the social and cultural habits of people with respect to hygiene and cleaning and the role they have for manage the waste and segregating waste. ➢ The study found that the average household solid waste generation for the city of Karachi is estimated to be 0.44 kg/cap/day ranging from 0.19 to 0.84 kg/cap/day. ➢ In fruit and vegetable market 1.795 kg/shop/day and 11.77 kg/shop/day waste generated respectively. ➢ Moreover, the study shows that waste generated by household, vegetable and fruit markets shows organic fraction (food waste) has the highest proportion ranging from 36.1 to 93% (weight/weight). ➢ The study also found that after plastic and paper waste the metal waste contribution remained highest. ➢ It is suggested that a decentralised system should be adopted in Karachi for the SWM because a centralised system creates problems.
28	Exploring E-Waste Resources Recovery in Household Solid Waste Recycling	Siddiqi et al., (2020)	➢ This paper strives to contribute to the issue of Household SW management that matters to everyone's business, specifically to developing nations.

			➢ The HSW management system of the world's 12th largest city and 24th most polluted city, Karachi, was studied to generate possible economic gains by recycling HSWs. ➢ In this regard, the authors surveyed dumping sites for sample collection. The sample was segregated physically to determine the content type (organic, metals, and many others). Afterwards, chemical analysis on AAS (Atomic Absorption Spectrophotometry) of debris and soil from a landfill site was performed. ➢ HSW is classified and quantified into major classes of household materials. The concentrations of e-waste [Cu], industrial development indicator [Fe], and the main component of lead-acid storage batteries [Pb] are quantified as 199.5, 428.5, and 108.5 ppm, respectively. ➢ The annual generation of the aforementioned metals as waste recovery is articulated as 1.2 _ 106, 2.6 _ 106 and 6.5 _ 105 kg, respectively. ➢ Significantly, this study concluded that a results-based metal recovery worth 6.1 million USD is discarded every year in HSW management practices.
29	Solid Waste Management A study of Karachi's Garbage Crises Turning the City of Light into City of Trash	KCCI Research & Development Department (2018)	➢ This report attempts to shed some light on the sanitation crisis and analyze the dynamics of the waste management system of Karachi. It also highlights the recommendations to overcome the problems related to waste management in one of the main urban agglomerations of Pakistan, 'Karachi'. ➢ Solid waste generation in Karachi hovers between 12,000 to 15,000 TPD and is expected to be doubled by the end of 2020 of which only up to 10,000 TPD of solid waste gets collected. ➢ Unfortunately, Karachi has been ranked among the least livable cities in the world

			due to improper management of civic facilities which are already inadequate where rapid urbanisation has aggravated the challenges. According to the EIU livability index 2017, Karachi has been ranked 136th out of 140th among the world's least livable cities of the world due to failing on various indicators like environment, health, livability, education and safety. ➢ For long waste management was the core responsibility of the Karachi and District Municipal Corporations. A few years back, a part of this responsibility was shifted to Sindh Solid Waste Management Board (SSWMB). Since then, the waste collection situation has improved to some extent but it is still much below par. To get the work done, SSWMB outsourced the garbage collection system to Chinese Sanitation Companies and imported some machinery and equipment for the job. ➢ However, this setup was ~12 times costlier for the Sindh government than the spending of the municipal corporation for the work. ➢ The unattended organic waste triggers the growth of flies and other harmful pests and bacteria which cause a host of diseases. Even hazardous hospital waste does not get properly treated due to only two obsolete incineration plants. ➢ Solid waste collection in Karachi comprises straightforward steps where garbage is initially collected from household residents through door-to-door service and finally dumped at allocated sites without any treatment or segregation. ➢ To overcome the challenges and the abysmal state of Solid Waste Management in Karachi, a systematic approach is required to minimise waste generation and at the same time put the waste to best use through recycling or converting it into energy.

			➢ The study recommends that all garbage lifting authorities including KMC and DMCs can make joint efforts in promoting a clean healthy environment which we can preferably term 'Naya Karachi' (New Karachi). ➢ It is, therefore inevitable for Karachi to not only improve the municipal solid waste management while adopting the global best practices but the citizens of Karachi should start using basic learning techniques right from their homes. ➢ A clean, healthy and safe Karachi will transform this city into a major tourist attraction and a preferred investment destination.

Annex-A3-1

Questionnaire for the Survey of Contractors (2021)

(The information collected is strictly confidential and will be used only for educational purposes)
Applied Economics Research Centre (AERC), University of Karachi

- Name of the Contractor/Organisation ______________________
- Employer - Public (UC/KMC/SSWMB) or Private ______________________
- Hiring Process/ Basis:
  (Tender/ Informal/Personal Relation/Experience) ______________________
- Formal Agreement 1. Yes 2. No
- Agreement Period (if Formal) ______________________
- Area of work (Town/UC) ______________________
- WARD No. ______________________
- Do you have contract of other areas/UC as well ______________________
- How many areas/UC you covered ______________________

For the UC/Area under Survey

- Number of Household Covered ______________________
- Number of Employees /Informal/Contractual ______________________
- Number of (owned) Vehicles (Engage in this Ward) ______________________
- Type of Vehicle (s) (owned) ______________________
- Total Cost of Garbage Collection (per month) ______________________
- Fee Collection per household/per month ______________________
- Who Take the Fee Himself/Hired Worker/UC/KMC
- Income of Contractor ______________________
- Wages to Employee ______________________
- Are you aware of Waste dumping Points 1. Yes 2. No
- Number of Waste dumping Points Formal ______ Informal _______
- Who collect waste From these Points ______________________
- Collection Times per week From these Points ______________________
- Did involve in segregation/selling/Recycling 1. Yes 2. No
- (If Yes) Amount segregated/Sell per day:
  Plastic: ______________________
  Paper: ______________________
  Cardboard: ______________________
  Glass: ______________________
  Steel/Iron: ______________________
  Wood: ______________________
  Other Specify: ______________________
  Other Specify: ______________________
- Rate at which Sell
  Plastic: ______________________
  Paper: ______________________
  Cardboard: ______________________
  Glass: ______________________
  Steel/Iron: ______________________
  Wood: ______________________

Other Specify: ____________
Other Specify: ____________

- Where do you sell the collected material ____________

- Garbage Leftover 1. Yes 2. No
  If Yes: Why ____________

- If Yes: What do you suggest for the leftover:
  - Manpower needed ____________
  - Number and Type of vehicle ____________
  - Other Suggestion ____________

- Problems/Hindrances faced in operation (if any) ____________
- Monitoring Mechanism adopted (if any) ____________

Annex-A3-2

Questionnaire for the Survey of Informal Players (2021)

(The information collected is strictly confidential and will be used only for educational purposes)

Applied Economics Research Centre (AERC), University of Karachi

Informal Players/Rag Pickers/ Scavengers

- Name of the respondent ____________
- Age of the respondent ____________
- Gender of the respondent ____________
- Do you live with your Parents 1. Yes 2. No
- If No; to whom you live (relationship code) ____________
- Where do you live? ____________
- Permanent District of Residence (parents) ____________
- # Family member's ____________
- Do you combine Education and work ____________
- Education (if any) ____________
- How long you are involved in SWM/rag picking ____________
- Name of the contractor/Employer (if any) ____________
- Distance of Area of work from place of residence ____________
- Areas of work (Town/UC/WARD) ____________
- Frequency of visit to the collection area (per day) ____________
- Dumping points in your Area (name & no.) ____________
- Type & amount of wastes collected: (Pls. mention Units)
  - Plastic ____________
  - Paper: ____________
  - Cardboard: ____________
  - Glass: ____________
  - Steel/Iron: ____________
  - Wood: ____________

	Other Specify:	____________
	Other Specify:	____________
• Segregation done		1. Yes 2. No
• Amount Sell per day	Plastic:	____________
	Paper:	____________
	Cardboard:	____________
	Glass:	____________
	Steel/Iron:	____________
	Wood:	____________
	Other Specify:	____________
	Other Specify:	____________
• Rate at which Sell	Plastic:	____________
	Paper:	____________
	Cardboard:	____________
	Glass:	____________
	Steel/Iron:	____________
	Wood:	____________
	Other Specify:	____________
	Other Specify:	____________
• Where do you sell the collected material		____________
		____________
• If involved in door-to-door collections		
o Number of Household Waste collected per day		____________
o Amount of Waste Collected per day		____________
o Waste Segregated		1. Yes 2. No
o Waste dumping Points (Formal)		____________
o Waste dumping Points (in Formal)		____________
o Who collect waste From these Points		____________
o Collection Times per week From these Points		____________
o Fee Charge from Household (monthly)		____________
o Total Fee collected		____________
o Fee Amount Share by Contractor		____________
o Fee Amount Kept by himself		____________
• Occupational hazard if any		1. Yes 2. No
• Involvement in:		
o None		1. Yes 2. No
o Pickpocketing		1. Yes 2. No
o Gambling		1. Yes 2. No
o Theft		1. Yes 2. No
o Smoking		1. Yes 2. No
o Drugs		1. Yes 2. No
o Gutka/Pan		1. Yes 2. No
o Others/Specify		1. Yes 2. No
• Income (if hired)		____________
Any other Source		____________
• # Earner in the House		____________
• Occupation of the earners		____________
		____________
		____________

- Family income
  1. Below 5,000
  2. 5,000 – 10,000
  3. 10,001 – 15,000
  4. 15,001 - 20,000
  5. 20,001 - higher

Annex-A3-3

Questionnaire for the Survey of Household (2021)

CONFIDENTIAL

Prospects for the Development of Solid Waste Management System: A Case Study of Metropolitan City Karachi
RASTA ID #: 01----

QUESTIONNAIRE FOR HOUSEHOLD INFORMATION

I.	Name of the Head of the Household (HOH)	____________
II.	Name of the respondent	____________
III.	Respondent's relationship with the HOH	____________
IV.	Town	____________
V.	Address	____________
		____________
VIII.	Name of Enumerator	____________
IX.	Name of Supervisor	____________
X.	Date of Interview	____________
XI.	Time of Interview	____________

SECTION -1: HOUSEHOLD COMPOSITION AND DEMOGRAPHIC INFORMATION								SECTION -2: CURRENT EDUCATION STATUS			
R. No.	Name of household members who usually live here. Do not list guests, visitors, etc.	What is the relationship to the head of the household?	Gender	Age in Years	Mother Tongue	Current marital status?	How long has been living in this city?	Can read with understanding in any language.	Can write in any language with understanding?	Is, currently enrolled in an educational institute?	What was the highest grade, completed? (See codes below)
		1. Head of HH 2. Spouse 3. Son/Daughter 4. Father/Mother 5. Brother/Sister 6. Grandchild 7. Nephew/Niece 8. Son/Daughter-in-law 9.Brother/Sister-in- law 10. Father/Mother-in-law 11. Others	1. Male 2. Female		1. Urdu 2. Sindhi 3.Punjabi 4. Pashto 5.Balochi 6.Gujrati 7.English 8. Siraiki 9. Others	1.Unmarried 2. Married 3. Widow/ Widower 4. Divorced 5. Others	1. Sincebirth 2. Less than 1 3. 1-4 4. 5-9 5. 10 years & Over	1=Yes 2=No	1=Yes 2=No	1=Yes 2=No	
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2.1	2.2	2.3	2.4
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											

Codes for Section-2.4

00=Below Class 1	03=Class 3	06=Class 6	09=Class 9	12=Intermediate	15=Class 15/ M.A/ M.Sc. Part I	18=B.Ed./M.Ed.	21=Degree in Law	24=PhD.
01=Class 1	04=Class 4	07=Class 7	10=Class 10 /O-Level	13=B.A/ B.Sc./B.com Part I	16=Class 16/Masters	19=Degree in Medicine (MBBS/BDS/Pharm-D etc)	22=Degree in Accountancy	25=Others(Specify…)
02=Class 2	05=Class 5	08=Class 8	11=First Year	14=B.A/B. Sc./B.com II	17=Polytechnic diploma/Diploma	20=Degree in Agriculture	23=MS/M.Phil.	

SECTION -3 (A): EMPLOYMENT								
R.No.	What were the principal activities during last month?	Reasons of Unemployment (Specify if any)	What was employment status? (Read all the options to the respondent)	What was the nature of work (Occupation) that did?	Which industry is your primary job in?	What kind of employment ?	At main work, what is the periodicity of payment?	How much net money did earn on the main work last month?
	1. Employed (If Employed Go to 3.3) 2. Unemployed 3. Not in LF (Skip Section 3-A)	After reasoning Skip Section 3A	1. Regular paid employee with a fixed wage 2. Casual paid employee 3. Paid worker by piece rate or work performed 4. Employer 5. Own account worker/ Sole Proprietor 6. Unpaid family worker 7. Other (Specify if Any)			1. Public 2. Private 3. Semi Govt. 4. Other (Specify)	1. Daily 2. Weekly 3. Fortnightly 4. Monthly 5. Other periodicity 6. Piece rate basis for service performed 7. Other (Specify)	Rs.
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8
1.								
2.								
3.								
4.								
5.								
6.								
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10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								

SECTION -3(B): EMPLOYMENT (OTHER SOURCES)											
R. No.	Does any member of the household earn income from other source s?	What is that source or form of earnings or benefits?					Amount in Rs. from these sources during last month.				
	1. Yes 2. No (Skip Section 3-B)	1. Rental 2. Subsidiary work 3. Pension 4. Bonus 5. Remittances 6. Interest Income 7. Profit 8. Shares 9. Others					Rs.				
	3.9	3.10					3.11				
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											
11.											
12.											

SECTION -4(A): HOUSING CHARACTERISTICS		
1. What is your present occupancy status? 1. Owner occupied 4. Subsidised rent 2. On rent 5. Pagri 3. Rent free 6. Other (Specify)	2. What is the Nature of the plot? 1. Residential 2. Residential/Commercial 3. Residential/Industrial	3. What is the total area of the plot? (sq.yds)
4. What is the dwelling type? 1. Independent house/compound 2. Apartment/Flat 3. Part of the large unit/ Portion 4. Other (Please specify)	5. What is the area of a single residential unit? (sq.yds)	6. How many rooms are there in this residential unit?
7. Which main material is used for the Floor? 1. Ceramic tiles/Marbles/Chips 2. Cement 3. Non-Cement 4. Other (Please explain)	8. Which main material is used for the roof? 1. RCC/RBC 2. Cement sheets 3. Metal/Tin/Girders/T-Iron 4. Other (Please explain)	9. Which main material is used for walls? 1. Cement 2. Raw bricks/mud 3. Plywood/Cardboard 4. Stone 5. Other (Please explain)
10. What is the main fuel used for cooking? 1. Gas 2. LPG 3. Kerosene Oil 4. Electricity 5. Other (Please explain)	11. What is the main fuel used for heating? 1. Solar Energy 2.Electricity 3. LPG 4. Gas 5. Bio Gas 6. Crop residue 7. Kerosene Oil 8. Charcoal\Coal 9. Dung Cake 10. No Facility 11. Other (Please explain)	12. What is the main fuel used for lighting? 1. Electricity 2. Solar Energy 3. Gas 4. Kerosene Oil\Diesel\Petrol 5. Candle 6. Other(Please explain)

SECTION -4(B): HOUSING CHARACTERISTICS		
13. What is the main source of drinking water for members of your household? 1. Piped water 2. Borehole 3. Dug well 4. Water from spring 5. Rainwater 6. Tanker truck 7. Cart with small tank 8. Bottled/R.O. Plant Water 9. Other (specify) (river/dam/lake/pond/stream/canal/irrigationchannel)	14. Who installed the water delivery system? 1. Government 2. Private 3. Others(specify)	15. Is sufficient water available for drinking when needed? 1. Yes 2. No 3. Don't Know 4. Others(specify)
16. Do you do something to make water safer to drink? 1. Yes 2. No 3. Don't Know	17. What do you actually do to make water safer to drink? 1. Boil 2. Add chlorine/tablet 3. Strain it through a cloth 4. Water filters 5. Solar Disinfection 6. Let it stand and settle 7. Others(specify)	18. Do you normally pay for water used by your dwelling? 1. Yes 2. No For code 2 go to Q.20
19. How much do you normally pay for one month 's water supply? 1. Private (Pay) 2. Public (Pay) (Rs.)	20. Are you willing to pay for an improved water supply system? 1. Yes 2. No 3. Don't Know	21. What type of toilet is used by your household? 1. No Toilet 2. Flush connected to the public sewerage 3. Flush connected to septic tank 4. Flush connected to the pit 5. Flush connected to open drain 6. Dry raised latrine 7. Dry pit latrine 8. Composting toilet 9. Others(specify)
22. Is your house connected to a drainage/sewerage system? 1. Yes, to covered drains 2. Yes, to Under Ground drains 3. Yes, to open drain 4. No, no system 5. Other(please explain)		

SECTION -5: HOUSEHOLD EXPENDITURE		
Did household members consume any of the following items?		
(Cross the None box if the item was not consumed)	Paid (in Rupees)	
	Monthly	Yearly
Food & Beverages		
Tobacco & chewing products		
Clothing & Footwear		
House Rent		
Property tax		
Electricity Charges		
Gas Charges		
Water Charges (Bill)		
Furniture, Furnishing, Floor covering, Household equipment		
Health Expenditure		
Transport		
Communication		
Recreation & Culture		
Education Expenditure		
Loan Payments		
Remittances Out		
Miscellaneous (All other)		

SECTION -6: HEALTH				
R No.	Does any member of your family suffer from any disease?	If Yes, What type of the following disease?	How frequently do they suffer?	Who did you consult first?
	1. Yes 2. No (Skip Section 6)	1. Chikungunya 2. Malaria 3. Dengue 4. Diarrhea 5. ENT Problems 6. Allergies 7. Typhoid 8. Hepatitis 9. Covid-19 Corona 10. Others(specify)	1. Monthly 2. Twice a month 3. Twice in a year 4. Others(specify)	1. Govt. dispensary/Hospital/Doctor 2. Basic Health Unit 3. Hakeem/Herbalist 4. Homeopathic 5. Private consultant 6. Self-medication 7. Others(specify)
	6.1	6.2	6.3	6.4
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				

SECTION -7(A): SOLID WASTE MANAGEMENT (GENERATION & DISPOSAL)		
1. Which type of waste is usually generated? 1. Kitchen waste 2. Paper 3. Plastic 5. Other(Please specify)	2. Can you roughly identify the percentage composition of 1. Food waste ....% 2. Paper...........% 3. Plastic........% 4. Other (Please specify)	3. Do you usually separate waste by category before disposal? 1. Yes 2. No If Yes, Skip Q.4
4. Would you do so, if you are told by your collection service 1. Yes 2. No	5. How often do you dispose of your household waste? 1. Every day 2. Once every two days 3. Once every three days 4. Other (Please specify)	6. Generally, when do you dispose of your waste 1. No definite time 2. Between 6 am to 6 pm 3. After 6 pm 4. Other (Please specify)
7. What is the Location of your waste bin? 1. Kitchen 2. Backyard 3. Outside main door/Next to the door 4. Other Specify	8. Is your waste bin covered? 1. Yes 2. No	9. You dispose of your household waste in? 1. Polythene /plastic packet 2. Paper bags 3. Any other container
10. Do you wash your Waste bin? 1. Yes 2. No If No skip Q. 11	11. How often the waste bin is washed? 1. Daily 2. Weekly 3. Monthly	12. Who disposes of your household waste? 1. Servant 2. Family member 3. Wastes are collected by the city municipality from the house 4. Wastes are collected by a locally recruited person from the house 5. Other (please specify)
13. Does the person wash his hand after disposing of waste? 1. Yes 2. No	14. Where is the household waste disposed of? 1. In the community dustbin 2. By the side of the road as there is no dustbin 3. In space near the house 4. Inside the house 5. Don't know	15. What are the problems you are facing with disposing of your waste? 1. No dustbin in the area 2. Dustbin is quite far away 3. Dustbin is not in the right place 4. Dustbin is not in the way of 5. It is smelly near the dustbin 6.No one is at home to dispose of the waste

SECTION -7(B): SOLID WASTE MANAGEMENT (COLLECTION, EXPENDITURE AND INCOME GENERATION)		
1. Who collects waste from household s? 1. City municipality(Public) 2. Private contractor 3. Others Specify	2. How often does the waste being collected? 1. Everyday 2. Once in two days 3. Once in three days 4. Irregularly 5. Don't know	3. When do you prefer for your waste to be collected? 1. Morning 2. Noon 3. Afternoon 4. Evening
4. How much are you paying monthly for the collection of waste? (Rs.) 1. From household 2. From the neighbourhood 3. From the community bin 4. Others Specify	5. How do you evaluate the state of solid waste collection in your house area? 1. Good 2. Fair 3. Not Good 4. Don't know	6. How much are you willing to pay monthly for the improvement of the SW collection system? (Rs .)
7. Have you ever heard about the importance of recycling? 1. Yes 2. No If No, Skip Q.8	8. If yes, do you agree to SW recycling? 1. Yes 2.No	9. If the SW recycling program is set up, would you be willing to separate ma terial into separate bags for collection purpose s? 1. Yes 2. No 3. Don' know
10. Did the househo ld generate any income from selling waste? 1. Yes 2. No If No Skip Q. 11, Q. 12	11. What type of waste is usually sold for income generation? 1. Paper 2. Metal 3. Plastic 4. Other (Specify)	12. How much income is generated from each waste type? 1. Paper 2. Metal 3. Plastic 4. Other (Specify)

SECTION-7(C) SOLID WASTE MANAGEMENT (ENVIRONMENT)		
1. The current waste disposal system is polluting the environment. Do you agree? 1. Yes 2. No If No go to Q. 3	2. Which of the following problems (generated from improper waste disposal) are responsible for polluting the local environment? 1. Wastes being disposed of in the drain and blocking the drain. 2. Wastes being disposed in the sewerage line and blocking the line. 3. Wastes being disposed of on the road and spreading odour. 4. Uncollected waste from the drain or dustbin spreading odour. 5. Mosquitoes/flies from the dumped wastes 6. Deterioration of the local environment and beauty by the improper disposal of waste here & there. 7. Other (Specify)	3. Do people dump their waste alongside the garbage bins instead of putting it inside them? 1. Yes 2. No If No go to Q. 5
4. Any particular reason………………. 1. Difficult to put the waste inside the bin due to the height of the bin 2. Difficult to put the waste inside the bin due to waste and litter spread around the bin 3. Stray animals (dogs, mice and birds etc. 4. Any other reason ………………………..	5. Do you consider that environmental degradation has a negative effect on your family? 1. Yes 2.No	6. Do you know that from kitchen and vegetable wastes, organic fertiliser can be made which is good for the environment, does not degrade the fertility of land like other chemical fertilisers, and is very much useful for plants and lands? 1. Yes 2.No
7. Would you like to use this organic fertiliser in your garden or the plants' tub? 1. Yes 2. No	8. Do you have any idea about Community -Based Organisations (CBO)? 1. Yes 2. No	9. Community-based Organisations (CBO)s can improve the local waste removal system and help to provide a better environment. Do you agree…? 1. Yes 2.No
10. Do you know how your service provider disposes of your collected waste? 1. Yes 2. No	11. Are you concerned about the disposal methods of the service provider? 1. Yes 2. No	12. Do you think that leaving a better environment for future generations is something? 1. Yes 2.No

Annex-A3-4

List of Selected Public Sector Official Interview Summaries

First Meeting
Public Sector Official Interview
KMC

- The function of KMC is to deal only with medical waste after the emergence of SWMB.
- They Collect 20% of the medical waste which is around 4 to 5 tons/per day only from private registered hospitals.
- The estimated generation is approximately 1.44 kg per bed in hospitals.
- There was no scientific way of disposing of waste observed before 2006 while after 2006 KMC installed two insulation plants for disposing of waste scientifically.
- The capacity of two insulation plants is about 220 units. Individually each insulation plant insulates 2 tons per hour with gaps on average i.e 5 tons per day.
- He highlighted some administrative issues and problems that are.
    - Limited capacity for collection
    - No record of proper generation
    - The insulation plant functioning at full capacity, but it is not enough
    - No uniform policy for hospitals has been developed for their plants and records.
    - Big hospitals do not provide access to the record
- Small private hospitals are not registered and they work informally although they hire private contractors to collect their waste they have no record of waste disposed of.

Suggestions

- A Uniform policy should be adopted
- Everybody should be under one umbrella whether it be KMC, SWMB or EPA

Second Meeting
Public Sector Officials Interview
SSWMB

- The KII emphasised the problems before 1999 and discussed the previous system of Nazim's and Mayer's performance devoted to Karachi.
- He elaborated outsource financing and disclosed its pros and cons. He informed me regarding the current collaboration of SSWMB with a Chinese Company and a Spanish company.
- Recently SSWMB completed a survey with the collaboration World Bank and pointed out 20 key performance indicators (KPI).
- The core issues that are relevant in describing the city's condition are;
    - Ownership and stakeholders
      (Until the city has a centralised authority that owns the city instead of decentralised ones, the process of criticizing and politicizing will continue).
    - Behavioural response of the persons
      (Individuals are unaware of the seriousness of the issue thus they do not behave in the manner they should. There is a need to change the individual mindset on an immediate basis from the grass root level).
- While mentioning an SWM survey conducted in different districts of Karachi he mentioned that more or less similar situations were found concerning the localities and garbage dumping situations either in front of houses or nearer empty places along the roadsides.
- The Major dumping of garbage is done into two landfill sites [Jam Chakro and Goandpass] that Sindh Solid Waste Management designated.

- Talking about the statistics in the previous studies mentioning that the generation of waste in Karachi is about 12000 tons daily, he rectified this figure to be approximately 9000 tons per day instead.
- He pointed out different collection sources like; door-to-door collection from households by UCs, Industrial and hospital hazardous waste etc.
- No discussion was made regarding the cost of collection and cost of generation.
- He discussed assessing the management capacities and agreed that lack of labour efficiencies, poorly equipped systems, and inadequate household cooperation are the core obstacles in SWM.
- He said they are trying to enhance the efficiency of the SSWMB. To improve the system and to have a check and balance on the employees, they have developed a Command and Control System on a per-day basis in Karachi. Further, daily workers such as sweepers, collectors, trolley loaders, dumpers etc., remained on record by the time of entrance and exit. Snapshots of workers are also identified if they are involved in any causality or misshape during the workplace.

Third Meeting

Public Sector Official Interview

SSWMB

- The KII focused on the ground realities of SWM collection issues in Karachi that the SWM teams faces during the work.
- To him increasing children's awareness regarding how and where to dump waste is of crucial importance in shaping the behaviour of society in general.
- The garbage bins at the collection points are inadequate at various places; garbage has been dumped in the open air alongside the streets.
- According to him the waste generation per day per person is around 0.6.
- He highlighted the lack of resources as the major institutional issue.
- He also mentioned that there are only two-land fill sites namely Jam Chakro and Goand-pass where the garbage is dumped.
- They also launched awareness campaigns regarding proper waste handling.
- Further, he highlighted that the Afghan mafia in Karachi has strong support. The mafia is circulating day and night and segregates the waste. Some of them sold the segregated waste to street vendors and the rest sold the waste to the primary collectors.
- Politically influenced contracting is making SWM problematic.
- Around 1800 to 1900 tons of daily waste is generated and we collect almost all of it.
- The uncooperative behaviour of restaurants/shop managers or owners is also contributing to making collection difficult as they usually remove the waste bins placed in front of their businesses.
- In general, Afghanis usually sort and segregate on spot thus the waste collected afterwards is usually of no or very low resale potential.
- According to him, they struggled relatively much more in controlling the informally working Afghan mafia in the East district.
- He further mentioned that industrial waste does not appear on roads because of its relatively higher economic value and thus it is not creating many on-ground problems.
- He also mentioned complaints regarding Afghan ragpickers' involvement in stealing vehicle batteries and other such activities.

Suggestions

Provide awareness regarding proper waste disposal from grass root level especially by educating children. Spread awareness using various platforms such as mosques, social media, advertisements etc.

Mechanisation is to be adopted rather than manual sweeping.

Fourth Meeting
Public Sector Officials Interview
KMC

- KMC is now responsible for dealing with the medical waste and cleaning of Nalas in Karachi after handing over the remaining responsibilities to SSWMB. The activities in which KMC is involved are as follows
  - Transportation is provided to industry and hospitals through a private contractor (only local contractors)
  - Private contractors charge fees from the industry and hospitals
  - The fee is divided into two parts 75% to KMC, and 25% to contractors
  - The contractor monitors Installation plants as well
  - Eid -ul-Azha waste management
- Talking about the generation issues KMC officials pointed out that
  - The population is not defined properly as migrants are not included, especially those who work daily from Karachi to Hyderabad and Hub
  - Without proper population count, the generation is around 12000 tons per day but If the popula tion is properly documented, the generation will go on around 25000 tons per day
- The other issues that he raised regarding proper waste management include:
  - Lack of proper system to manage garbage
  - Landfill sites are not enough and properly managed.
  - Front-end collection, if not provided by SWMB/KMC –leakages will be there, and hence there will be informalities in the system
  - 40% of the waste is dumped in Nalas
  - 10% remained laid down on streets
  - The composition of waste is not known
  - Informal dumping sites emerged all over the city
  - Formal transfer stations are limited from where they are shifting to the landfill site

Fifth Meeting
Public Sector Official Interview
Karachi Cantonment Board (PAF Base Faisal)

- The area of responsibility and rubbish outsourcing seen.
- For the collection of garbage, registered known private contractors are available.
- The proper accountability is handled by the Faisal base, while tender criteria entirely depend upon the competition.
- The collection of garbage charged by each household is around Rs 425, and the timing of collection in the morning and evening varies as per the convenience of the household.
- Approximately 120 to 130 tons of garbage is generated daily.
- It is the right time to avoid outsourcing because subcontracting has its leakages, and we have to pay an extra amount in form of taxes.
- There is a significant difference between KMC and the Cantonment board concerning accountability and responsibility at all levels of work. Therefore, the sound monitoring system of the cantonment board makes it different from the others shown by their outcome.

Annex-A4-1

Historical understanding of SWM in Karachi

Acts/Ordinance/System	Major Highlights
KMC Rules 1947 abandoned on 1960	
Basic Democracies Act 1959 dismantled in 1971	
Granted Metropolitan Corporation status in 1976 -disbanded by the Government of Sindh on 1986	Combines Landhi Korangi Municipal Committee, Drigh Malir, Baldia Township, and North Karachi in KMC
A two-tier federated system was implemented in 1986	Administrator was appointed
Sindh Local Government (Fourth Amendment) Ordinance, 1987 - abolished in 1992	Established the four Zonal Municipal Committees (district-wise), namely South, East, West and Central
A two-tier federated system was implemented in 1992 and abolished in 1994	An administrator was appointed, Zonal Municipal Committees amalgamated into KMC, District Municipal office Malir was established
The unified KMC continue till mid-1996, the two-tiered federated system was restored - till 2001	Been given the authority to levy taxes and collect Fees
The Sindh Local Government Ordinance 2001 added a third tier continue till 2011	District/City District Governments, Talukas / Town Municipal Administrations, & Union Councils. Karachi Metropolitan Corporation was replaced by the City District Government Karachi under the devolution
Sindh Local Government Ordinance 1979 revived in 2011	
Enactment of the Sindh Local Government Act 2013	The KMC re-emerged in place of the City District Government Karachi in 2013
Sindh Solid Waste Management Board was established in 2014 under the Sindh Solid Waste Management Act	the Board is expected to gradually take over the solid waste management function from the Councils and other bodies

CHOICE MODELLING OF PUBLIC TRANSPORT TO DESIGN TRANSPORT POLICIES FOR URBAN MOBILITY IN PAKISTAN

Ajaz Ahmad and David Palma

ABSTRACT

Public transport is vital for socioeconomic development as it allows citizens to access opportunities, including markets, social interaction, education, and other services, which enables them to rise out of poverty and overcome social exclusion (GOP, 2018). However, Pakistan lacks a decent and affordable public transport system for its citizens. This issue is particularly serious in urban areas due to greater population density, expansion in urbanisation, cities' economic potential, generation of greater economic activity and subsequent need for mobility, and commuting on regular basis. Using choice modelling approach and primary surveys, this study investigated commuters' preferences for different attributes or features of public transport and their willingness to pay for the fare in three main cities of Pakistan (Islamabad, Lahore and Karachi).

Results revealed that Karachi is in dire need of a better public transport system. Since commuters in Karachi are currently used to long trips and dislike multiple transfers (change of public transport mode within a journey), the new system should focus on reduced access and waiting times. Access and waiting time are more onerous than in-vehicle travel time in Lahore, whereas commuters in Islamabad disliked in-vehicle travel time more. Furthermore, Islamabad displays greater sensitivity to the provision of additional services such as air conditioning, Wi-Fi, and reserved ladies' seats while travelling. Lastly, Lahore demonstrates more suitability for a carpool system as commuters place a greater value on its adoption.

1. INTRODUCTION

Public transport is vital for socioeconomic development as it allows citizens to access opportunities, including, markets, social interaction, education, and other services, enabling them to rise out of poverty and overcome social exclusion (GOP, 2018). However, Pakistan lacks a decent and affordable public transport system for its citizens. This issue is particularly serious in urban areas due to the expansion in urbanisation, cities' economic potential, generation of greater economic activity and subsequent need for mobility, and commuting. Despite the rapidly growing population and economic, social, and environmental benefits of public transport, investment in this sector has been largely neglected. Pakistan has a population of around 210 million, roughly 36% of which resides in cities which is expected to reach 50% by 2050 (GOP, 2017). Considering that a good public transport system is fundamental to the sustainable urban development of Pakistan, there is a need to transform Pakistani public transport into a more modern, sustainable, and effective one (GOP, 2018).

The existing public transport options in Pakistani cities are limited, disorganised, inappropriate, and inefficient, which have serious implications for citizens' mobility, productivity, and social well-being (Adeel et al., 2016). Furthermore, public transport in urban areas is generally slow, unsafe, and inconvenient due to inappropriate modes of transport managed by individuals in an unregulated environment (GOP, 2018). This puts commuters' safety at risk in addition to discomfort, waste of their precious time, and low labour productivity. Similarly, there are fewer routes that do not cover the main areas of the cities, impeding commuters' equal access to public transport (Adeel et al., 2016). This discourages commuters to use whatever available public transport options are and results in a distaste for public transport. In addition to the hassle and tediousness that people endure, the economic cost of a lack of affordable and efficient public transport system is untenably high.

While few mass transit systems have been installed in Pakistani cities, they are not socially optimal due to expensive infrastructures and limited coverage (Qureshi & Huapu, 2007; Imran, 2009; Masood et al., 2011). Thus, there is greater use of car and taxi services, which has not only increased the cost of mobility but also resulted in road congestion and pollution and increased gender and class inequality. A lack of a decent and affordable public transport system deters labour force participation and effectual use of time and human resources, which have serious implications for individual workers, businesses, and overall society. The private sector has rushed in to fill the gap with ride-hailing services, which are relatively comfortable and efficient, but these services are unaffordable for low-income groups and again operate in a largely unregulated environment.

There is a lack of a coherent institutional framework for public transport in Pakistan (GOP, 2018) that can properly engage and facilitate the key stakeholders to design and implement an inclusive, affordable, and efficient public transport system. Therefore, there is a need to use more novel approaches such as the use of a market-based mechanism to incentivise the private sector to invest in bus rapid transit systems to make cities more inclusive, diverse, competitive, commuter-friendly, and livable. Using a stated-preference survey and discrete choice modelling approach, this research aims to investigate the citizens' preferences and their willingness to pay (WTP)[1] for the key attributes of the public transport system in three major cities of Pakistan (Karachi, Lahore and Islamabad). The results of this research are expected to provide input to policymakers in designing economically efficient and socially optimal practical solutions to the problem of public transport in the three selected cities. This could be achieved using economic incentive schemes which are based on the idea of the 'user-pays principle' and is a market-based mechanism to transform urban mobility in Pakistan.ys principle' and is a market-based mechanism to transform urban mobility in Pakistan.

Research objectives

This research has three specific objectives.

- To investigate the commuters' preferences of key attributes of a public transport system in major Pakistani cities to establish the optimal trade-offs between key attributes.
- To estimate commuters' monetary valuation, i.e., willingness to pay, for different attributes of public transport, identifying the most relevant aspects of the public transport system that influence their choices.

[1] The term willingness to pay (WTP) in choice modelling literature refers to the price or cost parameter which usually is also an attribute in an experiment. In public transport literature, WTP is commuters' readiness to pay for a fare to commute in a public transport mode and it means the same in the present research.

- To make some policy recommendations on the design and optimal characteristics of a transport service in Pakistani cities for the relevant authorities and stakeholders.

In what follows is the description of the process of research that has been carried out so far to achieve the above-stated research objectives.

2. LITERATURE REVIEW

Citizens' choices of the attributes of public transport have been studied extensively in the choice modelling literature. Since the seminal work by McFadden (1974), discrete choice models (Train, 2009) have been used in many areas, such as transport (McFadden 1974), health (de Bekker Grob et al. 2010), food choices (Palma et al. 2017), tourism (Geoffrey & Louviere, 2000), and education (Holdsworth & Nind 2006). Choice models are used to understand and predict individual choices with regard to public transport (e.g., whether individuals will travel by public or private modes of transport), and to measure the monetary valuation of different features of public transport. One noteworthy application of the latter is the calculation of willingness-to-pay (WTP) for attributes of an alternative. For example, in the case of transport, it is possible to calculate the WTP for a reduction in travel time, a value that is known as the subjective value of time (SVT).

In the case of travel mode studies, the most essential attributes to include are travel time and cost (Batley et al., 2019). Traditional work on the subject focused on the impact of fare, access, waiting and travel time on mode choice (McFadden, 1974) finds, for example, that access and waiting time are more onerous to individuals than on-vehicle travel time. More recent work has focused on the impact of perception and subjective factors on mode choice (Hensher et al., 2013), such as crowding (Li & Hensher, 2011; Varghese & Adhvaryu, 2016), transfers between buses or different modes (Navarrete & Ortúzar, 2013), deliberate planning and car habit (Nordfjærn et al., 2014), information availability (Molin & Timmermans, 2006), environmental friendliness (Khoon & Ong, 2015) and security (Fan et al., 2016; Allen et al., 2019), among others (Gruyter et al 2019). Another aspect capturing attention among academics and practitioners in recent times is the use of emerging transport modes, such as smart modes (Choudhury, 2018), adaptive transport services (Morsche et al., 2019), mobility as a service (Ho et al., 2008), and ride-pooling services (König & Grippenkoven 2020).

In the case of developing countries (specific to the Asian context), a few studies have been conducted that investigate spatial transferability of mode choice (Santoso & Tsunokawa, 2005), methodological approaches of transferability analysis of work trip mode choice (Santoso & Tsunokawa, 2010), the psychological factors influencing the transportation mode choice in six Asian countries that included Japan, Thailand, China, Vietnam, Indonesia, and the Philippines (Tan Van et al., 2014). Similarly, Le Loo et al. (2015) investigated the users' perception of transport mode use and travel behaviour in a case study of Johor Bahru, Malaysia. TUAN. Vu (2015) also explored patterns of travel behaviour and mode choice in the context of Vietnam. Munshi (2016) studied the relationship between the built environment and mode choice in the Indian context and found that there is a tendency to pre-select residential location choices to enable the use of a particular mode.

While there are a few studies on public transport in Pakistan, we could not find any choice-modelling studies on the attributes of public transport that could help to design policies. Using binary logit and count models Adeel et al. (2016) studied the choice between private and public transport modes as well as activity participation in the Rawalpindi-Islamabad metropolitan area. They found poor accessibility and the high cost of public transport to be an important deterrent to activity participation, especially in the case of women. Women are more affected because public transport is perceived as unsafe and it requires walking long distances to access it. This leads women to prefer private modes, but they are more expensive and, therefore, out of reach for most women, who lack personal income. The analysis of gender bias in transportation and activity participation in Pakistan by Adeel et al. (2017) highlighted that women travel mostly by walking and have, therefore, limited mobility, especially as their travelling is often socially constrained.

Ullah et al. (2019) studied the acceptance of car-sharing systems among the residents of Peshawar by asking survey participants to choose a car-sharing scheme, their car, regular taxi, or bus to commute. Alternatives were only described based on their travel time and cost, and no pivoting (customisation based on respondents' characteristics) was performed. The research showed a high willingness to accept car sharing schemes, especially among women and higher income individuals, and when travelling with other family members or friends. However, the authors did not report a subjective value of time (SVT), which is a gap in this research.

A study by Ali et al. (2020) investigated parents' preferences for travel mode for their children, for example, when picking up or dropping them off at schools in Lahore. The authors used a multinomial logit model to study respondents' preferences and described alternatives based on their travel time and cost. They found a generalised dislike for public transport due to its low accessibility and a perceived lack of safety. Higher-income respondents preferred using their private vehicles, and most participants perceived ride-sharing services (such as Uber or Careem) as a potential replacement for private cars if new laws ensure appropriate policy and safety. However, the scope of this research is limited as it focused on school children's pick-and-drop service.

A study by Memon et al. (2021) investigated the mode choice modelling to shift car travellers towards the park and ride services in the city centre of Karachi. They developed a mode choice model and implemented it on the data that were collected by a self-administered structured questionnaire using the logistic regression model. The study showed that roughly more than 70% of the survey participants were willing to adopt the park-and-ride services to avoid mental stress and to protect the environment.

The present research seeks to improve over previous studies mainly in three ways. First, this study employs discrete choice modelling using experimental designs, which maximises the amount of information from each respondent in addition to increasing realism. Second, the survey for this research is administered in multiple cities to model the citizens' choices of public transport attributes, allowing for comparison of choices across the cities, and improving the representativeness of the results. Third, the present research incorporates a larger number of public transport attributes than previous studies, enabling a more comprehensive analysis of commuters' choices. This also allows the calculation of the willingness to pay (WTP) for a range of public transport attributes to make policy recommendations for potential new services. Since this research calculates commuters' WTP values indirectly (i.e., respondents are not explicitly asked for a figure, instead WTP is derived from their choices) strategic biases are avoided (e.g., respondents declaring a lower WTP hoping to influence the fare of a future service). Finally, we measure acceptance and WTP for female-friendly public transport services, to identify the potential to implement such systems in Karachi, Lahore, and Islamabad.

Since choice modelling research involves the selection of the attributes of the good or service that is being investigated and the creation of experimental designs to deploy in the survey in addition to a questionnaire, the next section describes the process of attribute selection and refinement and creation of the experimental design.

3. MATERIAL AND METHODS

The following sections present the description of the choice modelling methodology deployed in this research.

Background information collection

A comprehensive process was followed to collect the background information relevant to the design of the present research. The background information collection process started from the National Transport Research Center (NTRC), which is the research wing of the Ministry of Communication, Pakistan. NTRC provided an overview of the prevailing transport system in the mega cities of Pakistan. The deputy chief of research kindly agreed to comment on the public transport system. The deputy chief elaborated on the overall public transportation in the whole country, and also discussed the coordination between provincial transport departments and the federal government. This was followed by a visit to the district administration office in Islamabad, where a meeting was arranged with the secretary of transport, Islamabad Transport Authority. The transport secretary explained the public transport routes, transport modes, and fare structure. These two meetings augmented and in some cases updated the secondary information that was collected from various sources regarding public transport in Islamabad.

The sectary, Punjab Transport Authority office, was contacted to gather information on public transport routes, modes, and fare structures in the mega cities of Punjab. Furthermore, since Punjab Mass Transit Authority (PMTA) is covering most of the public transport provided by the government, the PMTA office was also visited. PMTA provided published documents and data regarding fares and routes covered by the Metro bus, Speedo, and Orange train line in Lahore. The gathered information and meetings with officials revealed that Punjab Mass-transit Authority (PMA) is a regulatory body set up by the Government of Punjab to plan, construct, operate, and maintain mass transit systems in the major cities of Punjab. As such, PMA runs the entire Lahore Metro-bus Service (MBS) along with all of its connecting feeder buses. Lahore Metro Bus Service has become the primary mode of transport now for many locals after it became operational in February 2013. Hence, PMA was also contacted to gather the required information.

In the end, information about public transport in Karachi was gathered. For this purpose, initially, the information was gathered from the Sindh Transport Authority and Secretary Transport Office. Additionally, various key informants were also contacted. To collect the background information regarding public transport in the three selected cities, a list of questions was used. This list included the questions which are relevant to this research and could help in gathering the required information. Three lists of questions (one from each city) along with the reported answers are attached in the Appendix-A of this report. It is also important to mention here that in addition to the secondary sources, we also interviewed several commuters in three cities to gather the information that was either not available from secondary sources or we felt the need to double or cross-check it.

The next section elucidates the experimental designs used in this research.

Attribute selection and refinement

The first step in designing a choice modelling study after identifying the research problem and research questions is to identify the relevant attributes. The selection of attributes that matter to the study population in a given context is a crucial issue and must involve an extensive enquiry to select the attributes that influence individual choices (Hensher et al., 2005). The initial selection of attributes presented in the research proposal was made using a review of literature, i.e., relevant choice modelling studies on public transport, and information from other secondary sources in the Pakistani context. However, to finalise the attributes and attribute levels, we needed to collect additional primary as well as secondary information. This was also required to minimise the unobserved sources of influence on respondents' choice behaviour. Attribute levels and alternatives were identified and refined using the relevant background information.

The selected attributes were measurable and respondents could easily decipher their levels in terms of quantitative scales. Table 1 shows the final attribute table used in the pilots and the final survey. Below is the description of the process of background information collection that was used to collect the information to refine the attribute tables.

Table 1: Attribute table for citizens' preferences for public transport

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5
Mode	Van	Minibus	Bus	Metro bus	Car pooling
Access time in minutes (includes walking time)	5	10	15	20	30
Waiting time in minutes	5	10	15	20	30
Travel time in minutes (i.e., in a vehicle)	20	30	45	60	90
Transfers[2] (or change of mode)	0	1	2	3	-
AC	No	Yes	-	-	-
Wi-Fi	No	Yes	-	-	-
Reserved ladies seats	No	Yes	-	-	-

[2] A transfer in public transport means that a commuter pays for a single-trip fare to continue the trip on another bus or train. However, the transfer in the context of present research is essentially a change in the public transport mode in a journey by paying additional fare.

Service provider/management	Individuals	Private companies	Government	-	-
Fare (PKR)	15	20	25	30	40

Experimental design

The data-generation process for a choice modelling study relies on experimental design. Experimental design is created in design software and is used to construct the choice situations from attributes and attribute levels to present to the respondents. The design has some statistical properties such as design type, design efficiency, and choice of labelled and unlabelled design. The experimental designs deployed in this research were created using Ngene software which gave the output (as per specifications of attributes, attribute levels, and alternatives) in the form of code, which was used to generate the choice situations. For the present research, the design code from Ngene was copied into a Microsoft Excel spreadsheet to create the choice situations. The choice situations were incorporated in the primary surveys along with the questionnaire in the form of choice cards which were choice situations with visuals that helped respondents to comprehend the choices. The choice cards presented hypothetical alternatives from which respondents then made the choices. Examples of choice cards are attached in Appendix B. The experimental design is created using priors which are tentative values for the parameters to be estimated through the experiment. However, since the values of these parameters were unknown before performing the experiment, at first a pilot survey was used to obtain the priors. An efficient design was adopted in the pilot as well as the final surveys.

The actual levels used in each choice scenario were defined using a D-efficient design (Rose & Bliemer 2009). This kind of design guarantees a low variance in the model parameters estimated with the collected data, meaning that it maximises the information contained in the choices of each respondent. However, it requires assumptions about the value of the parameters. But as their values are not known at the beginning of the study, the analyst must make educated guesses at the stage of the pilot. In the final data collection, it is possible to use the results from the pilot to estimate preliminary values for the parameters. Therefore, for the pilot, we assumed small values in magnitude (0.01), with a positive sign if higher amounts of the attributes benefit the individual (AC, Wi-Fi, and reserved seats for ladies), or negative if they decrease the benefit of the individual (access, waiting and travel time, transfers, and fare). The D-efficient experimental design used in the pilot is shown in the appendix. While the whole design contained 60 choice scenarios, each individual faced only four of them.

Along with the experimental design, we used a questionnaire; its development is discussed in the following section.

Questionnaire

As is done in a choice modelling study, the survey instrument for the present research included a questionnaire in addition to the experimental design. The questionnaire was drafted using the relevant literature from Pakistan and elsewhere on public transport in general and commuters' choices in particular in addition to the secondary information gathered from different transport departments. The draft questionnaire was shared with experts for comments. The questionnaire was composed of 22 questions divided into five sections. Below is a short description of the objective and questions in each section of the questionnaire.

- Socio-demographics: Seven questions recording the city of residence, sex, age, level of education, household size, and income (total and hourly) of the respondent.
- Travel habits: Ten questions recording frequency of travel and public transport use as well as their expenditure on transport.
- Description of the current trip: Respondents were asked to describe the trip they were currently making in terms of their access, waiting and travel time as well as their mode transfers.
- Perception of quality of the public transport system: Respondents were asked to rate the overall current performance of the public transport system as well as on nine specific aspects (access, frequency, safety, etc.).

- Car-pooling: Respondents were asked if they were aware, had ever used, and would be willing to use a car-pooling system. A carpooling system, as explained to participants, is a system through which private individuals can contact each other and share rides in private cars.

The data collected during the first pilot revealed that respondents had trouble recalling their hourly wage, and describing their current trip with the requested level of detail. Their evaluation of most aspects of public transport was highly correlated as well, indicating that the level of detail was probably too high for the respondents' attention span. Based on these results, we decided to simplify and reduce the size of the travel questionnaire in the second pilot.

The questionnaire for the second pilot was shortened and simplified. The question about hourly wage was removed. The question asking to describe the current journey was simplified to only ask about the main mode used during the trip and its total length. The evaluation of public transport was simplified to just three aspects, i.e., overall, coverage, and frequency for all public transport, and reliability, comfort and safety for each mode in particular. Appendix C presents both questionnaires, the first questionnaire was used in the first pilot survey. The second questionnaire in Appendix C is the final questionnaire that was used to collect the data. After the development of the survey instrument, we conducted the pilots in the three cities using the stratified random sampling technique. The next section discusses the modelling approaches used in this research.

Modelling approaches

To study the behaviour of respondents, we tested multinomial (McFadden 1973) and mixed logit (McFadden & Train 2000) models. The estimated models are based on the random utility theory, which states that respondents receive a different amount of utility (i.e., benefit) from each alternative, and they choose the alternative that provides them with the most utility. The utility is assumed to be determined by a set of observable explanatory variables (the alternative's attributes and the individual's characteristics) as well as some unobservable factors represented by a random error (e.g., unobservable attributes or restrictions faced by the decision maker). In particular, we defined the utility of each alternative as follows.

$$U_{jtn} = ASC_j + \beta_{AT}AT_{jt} + \beta_{WT}WT_{jt} + \beta_{TT}(TT_{jt}) + \beta_{AC}AC_{jt} + \beta_{WF}WF_{jt} + (\beta_{LSM}(1 - female) + \beta_{LSF}female_n)LS_{jt} + \beta_{FA}FA_{jt} + \varepsilon_{jtn} \quad (1)$$

Where U_{jtn} is the utility of alternative j for individual n in choice scenario t. The alternative specific constant (ASC_j) is a parameter to be estimated representing how attractive each alternative *j* is if all other observable attributes are kept the same (ceteris paribus). For example, imagine a scenario where for a given trip all modes take the same time, cost the same, and are equal in all other attributes. If the ASC for alternative metro-bus is bigger than the ASC for alternative van, then respondents would prefer the metro-bus, despite all of its attributes being the same as the van. In other words, ASC parameters capture the effects of unobserved attributes associated with each alternative.

Attributes AT_{jt}, WT_{jt} and TT_{jt} represent the access, waiting, and travel times of alternative $_j$ in choice scenario t in minutes, respectively. Attributes AC_{jt}, WFjt and LS_{jt} are dummy variables taking the value one (1) if alternative *j* in choice scenario t include air conditioning, free Wi-Fi, and reserved ladies' seats, respectively and they take the value zero (0) otherwise. The variable $female_n$ takes the value one (1) if respondent n is a woman, and zero (0) if not. FA_{jt} is the fare (or cost) of travelling by mode *j* in choice scenario *t*.

All β parameters must be estimated and they represent the weight of each corresponding attribute in the utility as perceived by the decision maker. The weight of the ladies' seat attribute was further disaggregated into the utility it provides to men (β_{LSM}) and women (β_{LSF}). Finally, ε_{jtn} is a standard Gumbel random error term, representing all factors influencing the choice that is not perceived by the modeller.

Most basic multinomial logit models assume homogenous preferences, i.e., that everyone in the sample has the same preferences. But such an assumption is not realistic. There are several ways to introduce heterogeneity in preferences. A simple way is to introduce systematic preference variations. This method consists of adding specific parameters for subsamples in the data, for example, using different parameters for male and female respondents. That is what we did when modelling the preferences for ladies' seats using β_{LS} and β_{LSF}.

Another way to introduce heterogeneity in preferences is by assuming β parameters to follow a probabilistic distribution. This implies that all respondents have potentially different preferences, and we only know how these preferences are distributed, but not their precise value. This also implies that we now must calculate the mean and standard deviation of each random β parameter. Logit models with random parameters are called mixed logit models (McFadden & Train 2000). Even though we tested this kind of model, they did not increase fit significantly over the regular MNL models. Furthermore, they led to different specifications for datasets from different cities, making between-city comparisons more difficult. Therefore, we selected a traditional multinomial (MNL) model as the best approach.

The utility function does not have any meaningful unit, in the sense that its origin is arbitrary. To see this more clearly, consider adding a constant to the utility of all alternatives. This would not change the decisions made by the individual, as the order of the alternatives, and the difference between them would remain intact. This has two implications. First, for attributes with multiple levels, the effect of one level must be set to zero (normalised), just as it is done in linear regression with dummy variables. This also means that one of the ASCs must be set to zero for the model to be identified.

The second consequence of utility not having any meaningful unit is that the value of the β parameters is hard to interpret. For example, in Equation (1), an increase of one minute of waiting time leads to a change of β_{WT} units of utility. But as the utility does not have any meaningful unit, neither does β_{WT}.

An easier way to interpret results from the model estimation is by focusing on its implied willingness to pay (WTP). The WTP is the marginal rate of substitution between an attribute included in the utility function and its its price (fare) is also included in the utility. This represents how much money an individual is willing to trade in exchange for acquiring the specified attribute while keeping the same level of utility. In other words, the WTP amount represents how much money the individual is willing to pay for that attribute. Formally, the calculation is as follows.

$$WTP_k = \frac{\frac{\partial U}{\partial x_k}}{\frac{\partial U}{\partial fare}} \tag{2}$$

A positive WTP (WTP>0) implies that an individual likes the attribute k under consideration and would be willing to pay an increased fare if that attribute was present while maintaining their utility level. We expect attributes like air conditioning, Wi-Fi and reserved ladies' seats to have a positive WTP. A negative WTP (WTP<0) implies that the individual dislikes the attribute k under consideration and would have to be compensated with a lower fare if that attribute was present or increased to maintain their level of utility. We expect access, waiting time, and travel time to have a negative WTP.

Another way to compare preferences across models estimated with different datasets is through their average marginal effects (AME). They represent the average change in the probability of choosing an alternative in the sample due to a change in attributes. They are calculated using Equation (3) if the attribute under consideration is continuous (e.g., travel time), and Equation (4) if the attribute is categorical or a dummy variable (e.g., the presence of an AC) (Wooldridge 2002).

$$AME_{jk} = \frac{1}{N}\sum_{n}\sum_{t}\hat{P}_{jn}(x_{kjnt} + \delta_k) - \hat{P}_{jn}(x_{kjnt}) \tag{3}$$

$$AME_{jk} = \frac{1}{N}\sum_{n}\hat{P}_{jn}(x_{kjn} = 1) - \hat{P}_{jn}(x_{kjn} = 0) \tag{4}$$

In the equations above P_{jn} represents the forecasted probability of individual n selecting alternative (i.e., mode) *j*, which is a function, among other things, of the value of attribute *k* of alternative *j* for individual n and choice scenario t (x_{kjnt}). δk is a small disturbance, e.g., an increase of 10 minutes in the travel time. Note that in the formula only the k^{th} attribute of the alternative under consideration (*j*) changes its value. All other attributes for all other alternatives remain at the values observed by the respondents during the data collection stage.

AMEs are expressed as percentage point changes in probabilities, and can, therefore, be directly compared across models, even if they were estimated using different datasets.

All models were estimated using the software Apollo (Hess & Palma 2019).

4. RESULTS

The results description starts from the discussion of sample characteristics, which is followed by the presentation and discussion of the empirical results of the models estimated using data from final surveys carried out in Islamabad, Lahore, and Karachi. Below is the description of sample characteristics.

Sample characteristics

Table 2 presents the main socio-demographic characteristics of the respondents across the three cities under consideration, namely Islamabad, Lahore, and Karachi. Around 520 individuals answered the survey in each city. In all cases, men were a majority, with women representing only 23%, 30%, and 37% of the sample in Islamabad, Lahore, and Karachi, respectively. In terms of the samples' age composition, Islamabad and Lahore were similar, with over 50% of the sample being between 20 and 29 years old. On the other hand, in Karachi, only 27% of the sample was between 20 and 29 years old. The level of education was higher in Lahore with an average of 12.3 years of formal education, followed by Islamabad with an average of 11.6 years, and finally Karachi with only 8.2 years.

Table 2 Sociodemographic characteristics of survey participants (Values are %age of the total)

<table>
<tr><th></th><th></th><th colspan="3">Islamabad</th><th colspan="3">Lahore</th><th colspan="3">Karachi</th></tr>
<tr><th></th><th></th><th>♂</th><th>♀</th><th>Total</th><th>♂</th><th>♀</th><th>Total</th><th>♂</th><th>♀</th><th>Total</th></tr>
<tr><td>Respondent age</td><td>10-19</td><td>11</td><td>11</td><td>11</td><td>18</td><td>26</td><td>20</td><td>10</td><td>13</td><td>11</td></tr>
<tr><td>(Years)</td><td>20-29</td><td>50</td><td>67</td><td>54</td><td>54</td><td>59</td><td>56</td><td>27</td><td>27</td><td>27</td></tr>
<tr><td></td><td>30-39</td><td>18</td><td>10</td><td>16</td><td>15</td><td>11</td><td>14</td><td>19</td><td>27</td><td>22</td></tr>
<tr><td></td><td>40-49</td><td>10</td><td>6</td><td>9</td><td>5</td><td>1</td><td>4</td><td>20</td><td>18</td><td>19</td></tr>
<tr><td></td><td>50-59</td><td>6</td><td>6</td><td>6</td><td>5</td><td>2</td><td>4</td><td>14</td><td>9</td><td>13</td></tr>
<tr><td></td><td>60-69</td><td>2</td><td>0</td><td>2</td><td>3</td><td>0</td><td>2</td><td>6</td><td>5</td><td>6</td></tr>
<tr><td></td><td>>70</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>3</td><td>1</td><td>2</td></tr>
<tr><td>Education</td><td>None</td><td>2</td><td>1</td><td>2</td><td>2</td><td>3</td><td>2</td><td>24</td><td>31</td><td>27</td></tr>
<tr><td>(Years of schooling)</td><td>1-5</td><td>8</td><td>2</td><td>7</td><td>3</td><td>3</td><td>3</td><td>9</td><td>5</td><td>7</td></tr>
<tr><td></td><td>6-11</td><td>42</td><td>13</td><td>35</td><td>26</td><td>17</td><td>23</td><td>36</td><td>21</td><td>31</td></tr>
<tr><td></td><td>12</td><td>20</td><td>15</td><td>19</td><td>25</td><td>25</td><td>25</td><td>12</td><td>15</td><td>13</td></tr>
<tr><td></td><td>> 12</td><td>28</td><td>68</td><td>37</td><td>44</td><td>54</td><td>47</td><td>19</td><td>28</td><td>22</td></tr>
<tr><td>Household size</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>2</td><td>1</td></tr>
<tr><td>(Number of members)</td><td>2</td><td>3</td><td>3</td><td>3</td><td>1</td><td>3</td><td>2</td><td>6</td><td>2</td><td>4</td></tr>
<tr><td></td><td>3-4</td><td>18</td><td>17</td><td>18</td><td>16</td><td>14</td><td>15</td><td>21</td><td>26</td><td>23</td></tr>
<tr><td></td><td>5-8</td><td>67</td><td>71</td><td>68</td><td>68</td><td>72</td><td>69</td><td>53</td><td>60</td><td>56</td></tr>
<tr><td></td><td>> 8</td><td>12</td><td>9</td><td>11</td><td>15</td><td>11</td><td>14</td><td>21</td><td>10</td><td>17</td></tr>
<tr><td>Household monthly income</td><td>0</td><td rowspan="3">74</td><td rowspan="3">59</td><td rowspan="3">0</td><td>9</td><td>25</td><td>14</td><td>7</td><td>7</td><td>7</td></tr>
<tr><td>(PKR)</td><td>0.1-24</td><td>33</td><td>35</td><td>34</td><td>27</td><td>30</td><td>28</td></tr>
<tr><td></td><td>25-49</td><td>36</td><td>33</td><td>35</td><td>45</td><td>40</td><td>43</td></tr>
<tr><td></td><td>50-99</td><td>21</td><td>36</td><td>24</td><td>18</td><td>6</td><td>14</td><td>13</td><td>17</td><td>14</td></tr>
<tr><td></td><td>100-149</td><td rowspan="2">4</td><td rowspan="2">5</td><td rowspan="2">5</td><td rowspan="2">3</td><td rowspan="2">1</td><td rowspan="2">3</td><td>6</td><td>5</td><td>6</td></tr>
<tr><td></td><td>150-200</td><td>2</td><td>1</td><td>1</td></tr>
</table>

	200-399	1	0	1	1	0	0	0	0	0
	> 400	0	1	0	0	0	0	0	0	0
Total (respondents)		408	123	531	360	155	515	326	194	520

Different income thresholds were used in different cities, making it harder to compare them. When collecting data in Islamabad, the bands were not detailed enough for the low-income range. The low-income bands were further disaggregated in Lahore and Karachi. Due to this change, it is only possible to compare the income level of Lahore and Karachi, but not Islamabad. Respondents from Karachi averaged a monthly household income of Rs. 39,900, while respondents from Lahore averaged only Rs. 33,000 per month.

Empirical results

Empirical results include models estimated using the data on commuters' preferences for public transport modes and their attributes from the three cities. While public transport modes vary across the three cities, their attributes, and, hence, most of the model parameters were similar in the three surveys. This means that most of the explanatory variables in the models were the same across the three datasets. The utility function assumed for model estimation is presented below.

$$U_j = \beta_{0j} + \beta_{AT}AT_j + \beta_{WT}WT_j + \beta_{TTj}TT_j + \beta_{nTra}nTra_j + \beta_{AC}AC_j + \beta_{Wf}Wf_j + \beta_{LS}LS_j + \beta_F Fare_j + \varepsilon_j$$

Where j enumerates alternatives (i.e., transport modes); AT, WT, and TT are the access, waiting and in-vehicle travel times, respectively; nTra is the number of transfers between different vehicles of the same mode (e.g., changing from one bus to another); AC, Wf, and LS are dummy variables taking the value 1 if the mode has air conditioning, Wi-Fi (i.e., wireless internet access), and reserved seats for women available, respectively, and zero otherwise. Fare is the fare of travelling using the given mode that commuters have to pay, and ε is a Gumbel random error term. All β coefficients are parameters to be estimated.

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According to the random utility modelling, respondents will choose the alternative that provides them with the highest utility. In the utility described above, the β coefficients represent the marginal impact of attributes in the utility. We expect $\beta>0$ for desirable attributes (for example, the presence of AC, Wi-Fi and ladies' seats), and $\beta<0$ for undesirable attributes (e.g., fare, transfers, access, waiting, and travel time). If $\beta = 0$ (or not significantly different from zero), it means that the corresponding attribute has no impact on respondents' perceived utility. A bigger magnitude of β does not necessarily imply a bigger effect of the corresponding attribute on the utility, as the net effect is also influenced by the magnitude of the attribute (i.e., β*x, where x is the value of the attribute). The average marginal effects of attributes are presented and discussed later on.

The β_0 parameter is an intercept, also called an alternative specific constant (ASC). Their objective is twofold: (i) to capture the average effect of attributes not explicitly included in the utility function (e.g., inherent preference for a given mode), and (ii) to reproduce the observed market share of the alternatives in the sample. The second is a property of MNL models, where the inclusion of intercepts for all alternatives (except for one that takes the role of the base) guarantees that the model perfectly reproduces the observed market shares in the sample.

Table 3 presents the coefficients of the models estimated for each city, as well as their t-ratios and each model's main fit indices. Results reveal that all parameters were significant (i.e., a t-ratio bigger in absolute value than 1.96) in the Islamabad model, except for the alternative specific constants (ASC), which are only there to reproduce the observed market share and do not have a clear interpretation. In Lahore, access, waiting and travel times, and transfers were significant. However, among the additional services, only AC turned out to be significant. Karachi is the only sample where not all times were significant. Nevertheless, access and waiting time were significant, as was travel time for van, mini-bus and Qingqi. The presence of AC was also significantly valued, as are ladies' reserved seats among women. The effect of the fare was highly significant in all models.

Besides the level of significance, the log-likelihood function value is also an indicator of model fit and the smallest value is achieved for Islamabad, followed by Lahore and Karachi. Since all three cities have a similar number of observations, this fact suggests that the model fit is best for the Islamabad data compared to Lahore and Karachi. This phenomenon has multiple explanations. For example, (i) data indicates that commuters' preferences in Islamabad and Lahore are more homogenous as compared to Karachi; (ii) Islamabad and Lahore residents could be more familiar with the transport modes offered as alternatives, due to a relatively better public transport system in these cities as compared to Karachi; (iii) respondents from Karachi are more heterogeneous in terms of preferences and characteristics; or (iv) it could be a combination of the above reasons.

Despite the differing fit of the models across cities, all models achieved acceptable levels of significance, and all of the measured effects point in the expected direction. For example, all access, waiting, and travel time parameters were negative as were transfer and fare parameters, while air conditioner, Wi-Fi and reserved ladies' seats had positive coefficients. This means that respondents disliked walking and waiting for longer, as they also disliked travelling for longer, transferring more times, and paying more. On the other hand, they liked the presence of AC, Wi-Fi, and reserved ladies' seats.

Table 3 - Parameter values and main fit indices for models

		Islamabad		Lahore		Karachi	
		Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
Alternative	Do not travel			0.0000	(base)	0.0000	(base)
Specific	Van	-0.3480	-1.52	5.4827	12.64	5.0772	12.17
Constants	Mini-bus	-0.0648	-0.28	6.3515	21.73	5.3098	12.65
	Bus	-0.2059	-1.12	6.4624	23.52	4.8382	10.78
	Metro-bus	0.0000	(base)	6.9846	24.84	-	-
	Qingqi	-	-	-	-	5.3468	12.50
	Car-pool	-0.0265	-0.12	6.3166	21.09	5.1105	12.29
	Orange line			6.8542	24.25		
Time	Access time (AT)	-0.0215	-6.94	-0.0461	-13.26	-0.0175	-3.57
	Waiting time (WT)	-0.0151	-5.15	-0.0604	-15.24	-0.0075	-2.71
	Van (TT)	-0.0336	-9.45	-0.0275	-4.63	-0.0064	-1.82
	Mini-bus (TT)	-0.0389	-10.68	-0.0402	-9.22	-0.0073	-2.08
	Bus(TT)	-0.0350	-11.69	-0.0348	-9.76	-0.0022	-0.50
	Metro-bus (TT)	-0.0363	-10.74	-0.0322	-10.11		
	Qingqi (TT)	-	-	-	-	-0.0261	-2.54
	Car-pool (TT)	-0.0372	-10.28	-0.0373	-6.50	-0.0084	-1.15
	Metro			-0.0412	-9.19		
Transfers		-0.2490	-10.38	-0.2509	-8.33	-0.2981	-8.46
Services	Air Cond.	0.8081	13.01	0.1375	2.11	0.1116	1.89
	Wifi	0.7192	12.19	0.0370	0.65	0.0816	1.23
Ladies' seats	Male	0.9007	11.58	0.0876	1.38	0.0987	1.25
	Female	1.5728	8.87	0.0768	0.75	0.1913	2.04
Fare		-0.0302	-8.84	-0.0444	-10.52	-0.0075	-4.39
Fit	Likelihood		-2252.7		-2874.0		-3263.0
	Number of individuals		530		515		520
	Number of observations		2120		2060		2080
	Number of parameters		17		20		18
	Rho2		0.3398		0.283		0.1245
	Adjusted Rho2		0.3348		0.278		0.1196

Even though all models across cities share the same formulation, they do not share the same scale, and, therefore, the magnitude of their parameters cannot be compared directly. Furthermore, in line with a custom in choice modelling literature, willingness to pay (WTP) for a fare for each attribute was computed. The WTP represents the amount of money that individuals are willing to exchange for an attribute. In the case of an undesirable attribute, it represents the monetary compensation the user requires for enduring that undesirable attribute or the reduction in price necessary to avoid a reduction in the probability of choosing that alternative. For example, in the case of travel time, the WTP for one minute of travel time represents the extra amount of money a user is willing to pay in the fare to reduce their travel time by one minute. These values not only help the meaningful interpretation of the results, but they also facilitate the comparison of the results across cities. Note that the Metro-bus in Islamabad and the Metro-bus and Orange line in Lahore are public-funded transport modes with a flat fare. A flat fare is a fare usually for one journey that remains the same no matter how far one travels. Similarly, since these two travel modes are public-funded and it is very often that such projects provide subsidised services, especially in developing countries, as politicians use these projects for political gains. Hence, the WTP for a fare derived for Metro-bus and the Orange line may not reflect the true market value of the service by these two modes. It is however necessary to include to alternatives of public transport.

Willingness to pay (WTP) for each attribute is presented in Table 4. WTP was not calculated for the alternative specific constants as their interpretation is complex and unclear. WTP estimates for all attributes in each city include a 95% confidence interval (CI) around the mean WTP value. If a CI crosses zero it means that the WTP is not significantly different from zero.

WTP estimates show that the value of time for most uses was lower than the minimum wage (approximately 83 Rs/hour, assuming 45 work hours per week). This is in accordance with other studies on the value of travel time savings, where the estimated values for trips with multiple purposes were just below the minimum wage (Department for Transport, 2015; Wardman et al., 2016).

Unlike most of the empirical evidence, the value of access (AT) and waiting time (WT) in Islamabad was smaller than the in-vehicle time (TT). This means that commuters placed a greater negative value on in-vehicle time. Most plausibly, this is due to the relatively shorter trips in Islamabad. Furthermore, data in Islamabad was collected during July and August 2021, matching a peak of Covid-19 cases in Pakistan.[3] As people might have been more scared of contracting Covid-19 during data collection in Islamabad, and, hence, they penalised in-vehicle travel time more strongly due to the increased probability of getting infected. However, data from Lahore and Karachi were collected later in the year, during a dip in the number of Covid-19 cases.

Higher in-vehicle values of time for a given mode indicate that individuals were willing to pay more to reduce the travel time in that mode. In other words, a high value of time could mean that passengers find that mode less comfortable and are, therefore, willing to pay more to reduce their time on it. Moreover, this also means that commuters of that mode are richer and are, therefore, willing to pay more to reduce their travel time in general.

The most onerous mode was a mini-bus for commuters in Islamabad and Lahore. However, in Karachi, it was the Qingqi, which was followed by a mini-bus. Qingqi, however, had a very large value of travel time, probably because this mode was used only for short trips. Furthermore, its confidence interval is very wide, pointing to the value being measured with little accuracy. Therefore, the value of travel time by Qingqi should be considered with caution. A similar situation happens with the value of access time in Karachi.

Transfers (changing from one vehicle to another of the same mode) are particularly onerous for Karachi residents. This is probably due to the fact Karachi lacks a well-developed and interconnected public transport system in addition to already longer trips. As transport systems grow and are centrally planned, the number of transfers tends to increase because the transport systems are often structured around the feeder and main (or "trunk") services, making transfers more common. Less developed and organic transport systems tend to offer more point-to-point services that are less efficient, but require fewer transfers.

It is important to explain that transfers in the context of this research are not the same as they are in the public transport systems in the developed world where a commuter pays the fare at the start of the journey and one

[3] https://ourworldindata.org/coronavirus/country/pakistan

transport mode feeds to and/or connects with the other transport mode. We use the term ‘transfers’ as there is no other clear substitute for this. Furthermore, we follow the convention and nomenclature of the choice modelling in public transport.

Air conditioning and Wi-Fi were more valued in Islamabad, followed by Karachi and finally Lahore. The presence of reserved seats for women was only significantly valued in Islamabad, by both men and women, but women valued it 66% higher than men. It is not clear why commuters in Lahore and Karachi do not seem to value this service. One intriguing interpretation could be the less liberated and more conservative society of Islamabad due to their rural and tribal origins as compared to Lahore and Karachi, which are more industrialised and old metropolitans.

Table 4 - Willingness to pay with a 95% confidence interval

		Islamabad			Lahore			Karachi		
		Lower	Mean	Upper	Lower	Mean	Upper	Lower	Mean	Upper
Time	Access	-27.0	-42.7	-58.4	-47.8	-62.3	-76.9	-38.5	-139.8	-241.2
(Rs/H)	Waiting	-16.5	-30.0	-43.4	-63.0	-81.6	-100.1	-7.8	-59.9	-112.1
	Van	-45.5	-66.9	-88.3	-20.4	-37.2	-54.1	6.5	-50.7	-108.0
	Mini-bus	-55.2	-77.4	-99.7	-38.6	-54.3	-70.0	4.8	-58.5	-121.9
	Bus	-50.7	-69.5	-88.3	-33.9	-47.0	-60.0	50.9	-17.5	-85.9
	Metro-bus	-50.9	-72.3	-93.7	-31.5	-43.5	-55.4	-	-	-
	Qingqi							-6.6	-208.2	-409.8
	Car-pool	-51.9	-73.9	-95.9	-32.5	-50.4	-68.4	49.4	-67.4	-184.3
	Orange line				-39.8	-55.7	-71.5	-	-	-
Transfers		-5.9	-8.3	-10.6	-4.0	-5.6	-7.3	-20.6	-39.7	-58.7
Services	Air Cond.	33.5	26.8	20.1	0.2	3.1	6.0	32.0	14.9	-2.2
	Wifi	30.2	23.8	17.5	3.3	0.8	-1.7	29.2	10.9	-7.5
Ladies’ seats	Male	37.9	29.9	21.9	4.8	2.0	-0.8	34.2	13.1	-8.0
	Female	69.0	52.1	35.3	6.3	1.7	-2.8	52.7	25.5	-1.7

Finally, to identify the attributes with the biggest impact on the choice of a travel mode, Table 4 presents the average marginal effects (AME) of changes in attributes into the probability of choosing that alternative, as well as its 95% confidence interval. For example, keeping other things constant, increasing the access time of a van by 10 minutes in Islamabad generated an average decrease of about 2% in the probability of choosing a van. This means that the further the van stop is from an individual’s home, the less likely they are to use the van, and this probability will decay, on average, by 2% per additional 10 minutes of walking.

In Islamabad, we observed that the impact of access time was very similar across all modes. This is because all modes share the same coefficient, and the alternative specific constants were small and not significant in the model for this city. The same thing happens in the case of waiting time. However, as expected, the effect of an increase in in-vehicle time (TT) varies between modes, i.e., -3.16% for van and -3.90% for car-pool. On the other hand, this effect is always bigger than the effect of increasing access or waiting time. Increasing the number of transfers (from one vehicle to another vehicle for the subsequent journeys) by one has an equivalent effect on choice probabilities of mode as increasing access time by 10 minutes.

Reserved ladies’ seats in a public transport mode are the attribute with the largest AME, especially among women. This is followed by the two onboard services, i.e., air conditioning and Wi-Fi. This means that amenities in public transport carry significant value for commuters in the studied Pakistani cities. Changes in access, waiting and travel times would have to be bigger than 10 minutes to surpass the effects of ladies’ seats, air conditioning, or Wi-Fi. But achieving travel time reductions bigger than 10 minutes in congested cities is not an easy task.

In Lahore, we observed that access, waiting and travel time had different impacts on different modes. This is so because, even though all modes had the same access and waiting time coefficient, their alternative specific constants were significantly different, leading to different results. For example, the probability of choosing a van in Lahore (5% on average across the whole sample) was much lower than choosing the Metro bus (25%), so even if the attributes of a van change for the worse, their average effect cannot be very big, as the probability cannot decrease by more than 5% before reaching 0%. On the other hand, the probability of the Metro bus has much more room to decrease.

Orange line and Metro bus are the modes more negatively affected by increases in access and waiting time, meaning that commuters are discouraged to use those modes if they need to walk long distances to reach them or have to wait for too long at bus stops or metro stations. Van, on the other hand, is the mode least affected by access and waiting times. This is probably because Metro and Metro bus modes are generally more efficient than a van or a mini-bus. The effect of travel time follows the same trend, but with a less onerous effect, indicating that waiting and access time are valued more negatively than in-vehicle time. This implies that reducing access and waiting time for public transport could increase commuters' welfare, and thereby incentivise and enhance their use of public transport modes. On average, the effect of one additional transfer in a trip is slightly less onerous than a 10 minutes increase in travel time. This and the above finding together suggest that transfers are painful, but this discomfort could be reduced if the waiting and access time are lesser, which could be achieved by designing more comprehensive and inclusive routes and timeliness of public transport.

Onboard services had little to no effect on the mode choice among the commuters in Lahore as the air conditioning was the only service which increased the probability of choosing a mode by nearly 1%. It is plausible to say that commuters in Lahore already had these amenities on the Metro bus and Orange line, hence, they placed less value on these.

The impact of access, waiting and travel time in mode decisions for commuters in Karachi was much lower than in Lahore and more similar to Islamabad (except for travel time). While increasing access time by 10 minutes had an average effect across modes in Karachi of -2.6%, the same value reached -4.4% in Lahore, and -2.2% in Islamabad. Results are similar for waiting time. The effect of travel time, on the other hand, was significantly lower in Karachi (average -1.4%) as compared to both Islamabad (-3.7%) and Lahore (-3.6%). The obvious interpretation of this is that Karachi has very limited public transport options, hence, commuters pay less attention to the travel time as their priority is to have a public transport mode. Furthermore, it is a big city and travel is usually more time-consuming in most of the modes, including private taxis, resulting in commuters' lack of attention to longer travel times.

As discussed before, transfers had a significantly greater effect on commuters in Karachi than those in Islamabad and Lahore. This suggests that transfers are more painful in Karachi, and, hence, contribute to commuters' disutility from public transport. This, however, is expected in Karachi as the city has a very poor public transport system and changing the mode within a journey could be very annoying and time-consuming. This finding spells out a clear policy implication that transfers should be made easy and less time-consuming for commuters in Karachi so that their transits are less painful. This could be achieved by efficient route design and better coverage of the main areas of the city.

Finally, concerning onboard services in Karachi, the only service that had a significant impact on commuters' choice was the presence of reserved ladies' seats in the metro bus and Qingqi among women.

Table 5 Average Marginal Effects (AME) of attributes on the probability of choosing each mode (%)

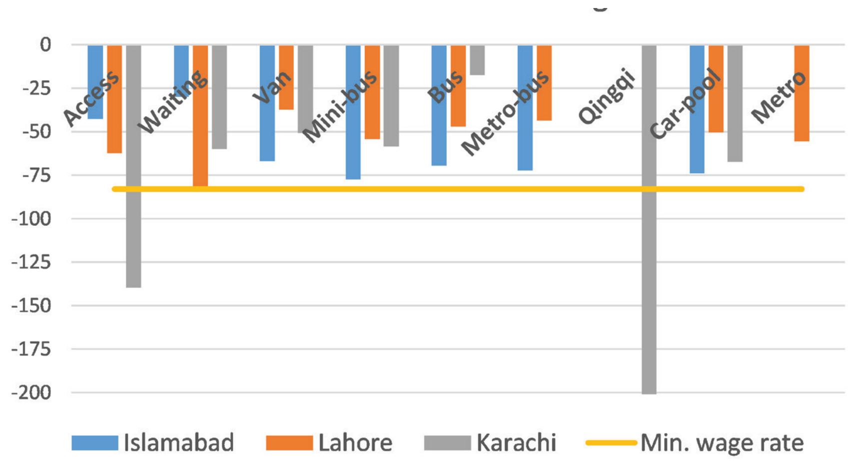
		Islamabad			Lahore			Karachi		
		Lower	Mean	Upper	Lower	Mean	Upper	Lower	Mean	Upper
Access time	Van	-2.51	-2.02	-1.42	-1.94	-1.53	-1.24	-4.17	-2.84	-1.15
(+10 min)	Mini-bus	-2.73	-2.20	-1.50	-4.14	-3.53	-2.91	-4.75	-3.07	-1.25
	Bus	-2.85	-2.23	-1.55	-5.16	-4.50	-3.74	-3.82	-2.54	-1.01
	Metro-bus	-2.86	-2.29	-1.58	-7.02	-6.06	-5.17	-	-	-
	Qingqi	-	-	-	-	-	-	-3.74	-2.55	-1.00
	Car-pool	-2.92	-2.31	-1.60	-5.14	-4.51	-3.77	-2.86	-1.87	-0.77
	Orange line				-7.09	-6.15	-5.12	-	-	-
Waiting	Van	-2.04	-1.46	-0.96	-2.41	-1.94	-1.54	-2.14	-1.27	-0.46
Time	Mini-bus	-2.17	-1.59	-1.06	-5.04	-4.52	-3.96	-2.30	-1.37	-0.50
(+10 min)	Bus	-2.22	-1.60	-1.09	-6.51	-5.81	-5.21	-1.92	-1.13	-0.41
	Metro-bus	-2.22	-1.64	-1.10	-8.53	-7.88	-7.09	-1.42	-0.84	-0.29
	Qingqi	-	-	-	-	-	-	-1.89	-1.14	-0.41
	Car-pool	-2.30	-1.66	-1.13	-6.50	-5.79	-4.98	-	-	-
	Orange line	-	-	-	-8.81	-7.99	-7.14	-	-	-
Travel	Van	-3.66	-3.16	-2.60	-1.47	-0.98	-0.60	-2.03	-1.18	-0.02
Time	Mini-bus	-4.42	-3.88	-3.40	-3.68	-3.20	-2.56	-2.56	-1.37	-0.21
(+10 min)	Bus	-4.01	-3.58	-3.13	-4.03	-3.49	-2.89	-1.59	-0.34	0.91
	Metro-bus	-4.28	-3.87	-3.35	-5.07	-4.41	-3.53	-4.48	-2.69	-0.36
	Qingqi	-	-	-	-	-	-	-3.19	-1.25	0.65
	Car-pool	-4.48	-3.90	-3.26	-4.95	-3.83	-2.82	-	-	-
	Orange line	-	-	-	-6.89	-5.70	-4.58	-		
Transfers	Van	-2.80	-2.37	-1.97	-1.27	-0.91	-0.64	-5.71	-4.65	-3.45
(+1)	Mini-bus	-3.01	-2.59	-2.14	-2.50	-2.03	-1.46	-6.15	-5.01	-3.78
	Bus	-3.10	-2.61	-2.16	-3.24	-2.57	-1.88	-4.97	-4.12	-3.08
	Metro-bus	-3.16	-2.69	-2.29	-4.22	-3.41	-2.61	-3.71	-3.02	-2.25
	Qingqi							-5.13	-4.14	-2.99
	Car-pool	-3.20	-2.72	-2.25	-3.38	-2.60	-1.85			
	Orange line				-4.22	-3.47	-2.52			
Air	Van	3.55	4.31	5.23	0.01	0.28	0.58	-0.01	0.64	1.23
Conditioning	Mini-bus	3.25	3.96	4.64	0.02	0.60	1.16	-0.02	1.00	1.93
	Bus	3.98	4.66	5.42	0.03	0.69	1.38	-0.01	0.59	1.17
	Metro-bus	3.12	3.77	4.35	0.04	0.89	1.74	-0.02	1.27	2.52
	Qingqi							-0.01	0.61	1.17
	Car-pool	3.54	4.18	4.87	0.03	0.85	1.72			
	Orange line				0.00	0.00	0.00			
Wifi	Van	3.07	3.71	4.25	-0.13	0.06	0.25	-0.51	0.86	2.48
	Mini-bus	2.77	3.38	3.86	-0.28	0.13	0.56	-0.51	0.94	2.82
	Bus	3.20	3.77	4.32	-0.34	0.16	0.64	-0.36	0.65	1.89
	Metro-bus	3.22	3.78	4.27	-0.41	0.19	0.79	-0.51	0.94	2.62
	Qingqi							-0.73	1.25	3.70
	Car-pool	3.45	4.14	5.00	-0.38	0.18	0.75			
	Orange line				-0.41	0.19	0.76			
Ladies' seats	Van	3.97	4.50	5.40	-0.09	0.19	0.57	-0.76	0.43	1.98
	Mini-bus	4.04	4.64	5.51	-0.17	0.36	0.99	-0.96	0.35	1.97
(male)	Bus	4.57	5.27	6.10	-0.22	0.48	1.34	-0.57	0.71	2.29

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study presents meaningful results and interesting insights into commuters' preferences in Islamabad, Lahore, and Karachi. Findings from Islamabad and Lahore are more intuitive than those from Karachi. This is somewhat expected considering the greater heterogeneity in socioeconomic, cultural, ethnic, and geographical aspects. In addition to extremely inefficient and thin public transport infrastructure in the city could have contributed to more heterogeneous and less focused responses from travellers in Karachi. This is also most likely due to similarities in socioeconomic and cultural factors, and improved public transport systems in Islamabad and Lahore. For example, the transport modes offered as alternatives are similar and relatively better in these cities as compared to Karachi.

All time parameters (access, waiting, and travel time), transfers, and fare were negative across three models in the three cities, just as expected because these are undesirable attributes. On the other hand, since air conditioning, Wi-Fi, and reserved ladies' seats are desirable attributes, these had positive parameters for three cities, though not all of them were significant in all cities. This implies that, in general, availability and access to public transport are considered more crucial than the other amenities, which makes theoretical sense.

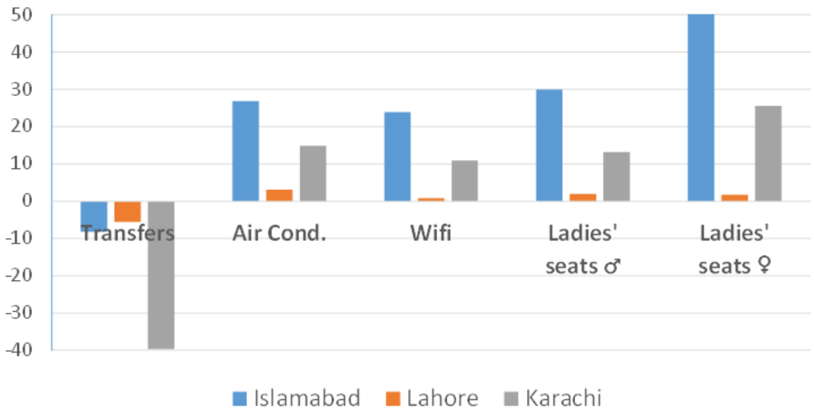
Figure 1 - Summary of WTP for access, waiting and travel time



Willingness to pay (WTP) estimates, summarised in Figure 1, show that most commuters valued their time less than the minimum wage rate of 83 Rs/hour (assuming 45 work hours per week). This is in line with other studies, where the estimated value of travel-time-savings for trips with multiple purposes was just below the minimum wage (Department for Transport, 2015; Wardman et al., 2016). Furthermore, the value of access and waiting time in Islamabad was smaller than the in-vehicle time, indicating that commuters in Islamabad place a greater negative value on in-vehicle time. This could be due to relatively shorter trips in Islamabad, as they are not used to longer trips. It could also have resulted from the fact data in Islamabad was collected during the time that coincided with a peak of active Covid-19 cases in Pakistan. The fear of getting infected may have caused individuals to more strongly dislike the in-vehicle travel time due to a higher chance of getting infected (which matches the results as WTP for in-vehicle time is higher in Islamabad than in other cities). By contrast, travellers' dislike for walking and waiting might have decreased, as the chances of being infected during those times were lower.

Mini-bus was the mode with the highest WTP for in-vehicle time reduction in Islamabad and Lahore, and the third highest in Karachi (surpassed only by Qingqi and car-pool). This points to the mini-bus being one of the least preferred modes because travellers were willing to pay more to reduce their time on it. The situation for Qingqi was somewhat different, as its high value of in-vehicle travel time can be explained because this mode is only used for relatively short trips (i.e., the "last mile" or "last leg" of a trip), and, therefore, users would require a big fare discount to be willing to make longer trips in the mode.

Figure 2 - Willingness to pay for transfers and additional services

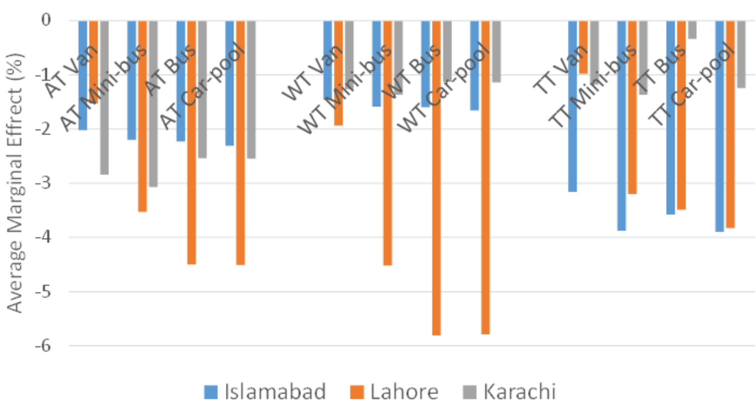


As far as car-pooling is concerned, Lahore displayed the lowest WTP for in-vehicle travel time reduction, which was at a similar level to buses' WTP. This makes Lahore the most promising city to implement a wide car-pool system. The fare could be higher for the bus as this mode would imply reduced access and waiting time, as well as a reduced number of transfers. The fare could be further increased for cars with air conditioning.

Access time and transfers were highly disliked by travellers in Karachi, with a WTP of -140 Rs/hour for the first, and -40 Rs/transfer for the second. This is probably due to Karachi lacking a well-developed and interconnected public transport system, in addition to already longer trips. Today, travellers in Karachi are likely to make long trips in a single vehicle. While comfortable for the user, this is inefficient from a system perspective. Throughout the world, centrally organised and efficient public transport systems work with a trunk and feeder system, where small buses take travellers from residential areas to the city's main roads, where the travellers transfer to bigger buses that take them to the main centres of activities. Travellers in Karachi are likely to oppose such a structure, so if such a model is to be implemented, it should be introduced in phases to reduce travellers' opposition to it.

Results indicate that the presence of reserved seats for women was only significantly valued in Islamabad by both men and women, but women valued it 66% higher than men. The average valuation of all additional services in Lahore was low, with air conditioning being the only additional service reaching a valuation significantly different from zero at only 3 Rs. The lack of a significant valuation of reserved seats for women might be due to a higher perception of safety in Lahore as compared to the other cities. Valuation in Karachi, on the other hand, was much higher than in Lahore, but also more heterogeneous, so none of the additional services (AC, Wi-Fi, reserved ladies' seats) reached a valuation significantly different from zero. There could be, however, segments of users that would value these services.

Figure 3 - Average Marginal Effects of a 10 minutes increase in access, waiting and travel time across common modes present in all cities

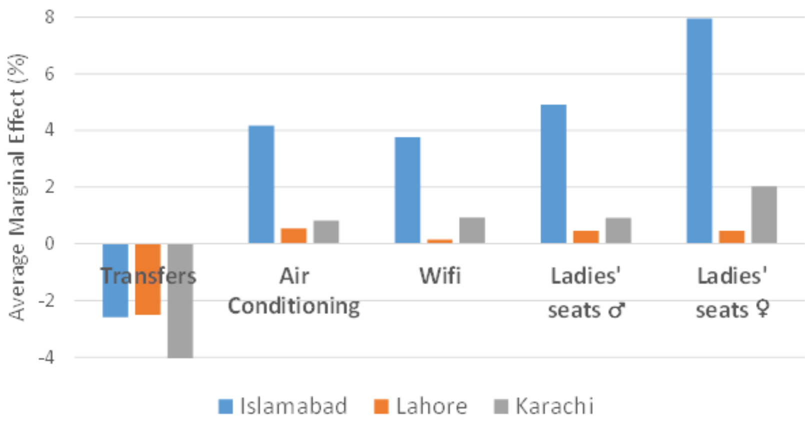


The average marginal effects (AME) allow for easy identification of the attributes that most strongly influence the decision of what transport mode to use. A summary of AMEs is presented in Figure 3 and Figure 4. Clearly, access and waiting times were much more important for travellers in Lahore than in Islamabad and Karachi. This is what is normally observed in cities with a developed transport system. On the other hand, the impact of access, waiting and travel times on mode decisions for travellers in Karachi were much lower, suggesting that they placed less value on time parameters as their priority was to have a working public transport mode. Furthermore, the van was the mode least sensitive to changes in travel time in all three cities, except for the bus in Karachi.

As discussed before, transfers had a significantly greater effect on commuters in Karachi than those in Islamabad and Lahore (Figure 4), which means that transfers are more painful in Karachi. This is expected in Karachi as the city has a very poor public transport system and changing the mode within a journey could be very annoying and time-consuming. This finding spells out a clear policy implication, that is, transfers should be made easy and less time-consuming for commuters in Karachi so that their transits are less painful. This could be achieved by efficient route design and better coverage of the main areas of the city.

The largest AME was due to the presence of reserved ladies' seats in Islamabad, which increased the probability of choosing a mode by 6% on average. This is a relatively easy change to implement, so it is highly recommended to implement it in Islamabad. Some users in Karachi might also value this service, though its effect would be lower, leading to only an expected 2% increase in the probability to use the mode. Onboard services had little to no effect on the mode choice among travellers in Lahore, i.e., they placed less value on onboard services. This is perhaps because they already have these amenities on the Metro bus and the Orange line.

Figure 4 - Average Marginal Effects of transfers and additional services



Findings (not shown in Figure 3) also revealed that Metro and Metro bus in Lahore were more negatively affected by increases in access and waiting time. This means that commuters were discouraged to use these modes if they needed to walk long distances to reach them or had to wait for too long at bus stops or metro stations. Van, on the other hand, was the mode least affected by access and waiting times. This means commuters expect Metro and the Metro bus to be more efficient than van or mini-bus. The effect of travel time follows the same trend, but with a less onerous effect, indicating that waiting and access times were valued more negatively than in-vehicle time. This implies that reducing access and waiting time for public transport could increase commuters' welfare, and thereby incentivise and enhance their use of public transport modes. On average, the effect of one additional transfer in a trip was slightly less onerous than a 10 minutes increase in travel time. This and the findings above together suggest that transfers are painful, but this discomfort could be reduced if the waiting and access times are lesser, which could be achieved by designing more comprehensive and inclusive routes and timeliness of public transport.

In summary, key results indicate that:

- Karachi needs a better public transport system. Travellers are currently used to long trips. But implementing a better system would not be easy as it would probably imply more complex trips with multiple transfers, something that travellers dislike in Karachi. Therefore, the new system should focus on reduced access and waiting times, as well as providing reserved ladies' seats if possible.

- Results from Lahore show a behaviour typical of big cities with a more developed transport system, where access and waiting time are more onerous than in-vehicle travel time. Carpool systems could be implemented in the city to reduce the use of the car as this city is the one that is most likely to adopt such a system.

- Islamabad displays the biggest sensitivity to the provision of additional services while travelling. Adding air conditioning, Wi-Fi, and specially reserved ladies' seats in public transport could have a significant impact in increasing its use in this city.

Policy Implications

The findings of this research have interesting policy implications. Some of the main policy implications are outlined below.

- The sample of the study reveals that roughly 30% of interviewed commuters were women, indicating that the provision of a good public transport service could enhance women's access to economic opportunities as well as basic services such as health and education. This could improve their socioeconomic conditions and their participation in the labour force which is already very low. Similarly, data show that a large fraction of the respondents are young (at least 50% of the sample is below 40 years of age) and educated (at least 50% have a college degree), indicating that the most productive workforce uses the public transport and any improvements in public transport has a clear advantage in terms of increase in their output, and their contribution in economic growth and social development.

- The findings of this research indicate that commuters in all three cities prefer bus or metro-bus over van as a mode of public transport. This suggests that commuters want appropriate and safe public transport modes such as a bus transit system and its provision might improve the use of public transport. This will not only make public transport more efficient, but it might help reduce the use of cars and the subsequent road congestion and pollution.

- Since the costs of additional services such as reserved ladies' seats and Wi-Fi is negligible, their provision in public transport modes could attract young commuters, including women, to use public transport more often.

- Commuters' disutility from access time of public transport is understood considering the harsh weather conditions and the lack of walkable cities. Hence, this has a clear policy implication for the design of the cities as well as public transport routes to create an ease of access for commuters to use public transport. Designing a good feeder-trunk system could also help reduce the periphery areas' commuters' access time for public transport.

- Almost all commuters expressed their dislike for transfers (changes in the public transport mode within a journey) due to their discomfort and increased overall travel time. In this regard, transport planners need to focus on improving the timeliness and ease of connections during the journey. This would require comprehensive planning of the routes and their connections in addition to creating options in case of delays or disruptions.

- The findings of this research indicate that commuters are willing to use and pay an additional fare for the car-pool system, however, Pakistani public transport departments have yet to implement it. In the age of ride-hailing services such as Uber and the frequent use of mobile applications, introducing a car-pool system is a cheaper option from the public transport authorities' point of view. However, this can take out a significant fraction of cars from the roads.

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APPENDIX - A

Background information (Islamabad)

- What are the existing modes of transport in the three selected cities? For example, in Islamabad, these are vans, minibuses, and the metro mainly. But there might be others in the documents.
  Islamabad: Wagon (80%), Minibus (5%), Metro Bus (10%), Suzuki pickup (3%) Qinchi (<1%)

- For ***each mode in each city***:
  - Is it public or privately funded?
    Metro bus is public-funded and all other modes are privately funded
  - Does it have pre-defined routes? If so, who sets the routes (transport department or private operator)?
    Transport Authority issues the permit for routes)
  - What is their market share? Market competition for share and incentive to compete or other relevant information.
    The market share for privately-funded transport is more than 80%.
  - What is the fare system? Is it a flat fare per trip or does it change by distance? Is there a special fare for students or the elderly?
    The fare system is distance based and the provincial transport authority (mainly the secretary of public transport in every province) sets it. For Punjab (including Lahore and Islamabad), the fare varies after
  - What is their average fare per kilometre? The answer to this question must have a lot of information beyond fare and it is very crucial to collect all of this from relevant departments.

Mode	Distance (Km)	Fare (PKR)
Van & Minibus	4	15
	8	20
	14	24
	22	28
	30	35
Metro Bus	No dependence (Track length is 22.5 Km)	30
Suzuki Pickup	4	12
	8	16
	12	20
	16	24

Qinqqi	It is used as a taxi and there is no fixed fare per km distance (usually bargain fare between commuter and the Qingqi driver)

For example, there might be some subsidy in the case of Metrobus or there is a difference in set fare and market fare (which is actually paid by commuters). Similarly, information on how the fare is regulated is also very important.

Mode	Subsidies
Van	No
Minibus	No
Metro	1.9 Billion RS/ Year
Suzuki Pickup	N0
Qinqchi	NO

- What is the average access time in minutes (including walking time at the beginning and end of the trip) for each mode of public transport? Knowing an approximate variation range (min and max) would also be useful.

Mode	Average Access Time Islamabad (from commuters of Bharakahu, F8 Kachahri (metro) and Aabpara wagon station)
Van	15 mins
Minibus	20 mins
Metro	10 mins
Suzuki Pickup	15 mins

- What are the average waiting time (at a stop) and travel time in minutes for each mode of public transport? For example, the average travel time for a trip for each mode of public transport I have collected information from Islamabad commuters from three spots (from commuters of Bharakahu, F8 Kachahri (metro) and Aabpara wagon station) regarding their waiting and travel times; average times are below:

Mode	Waiting Time (Peak)	Waiting Time (off-Peak)	Travel Time (Peak)	Travel Time (off - Peak)
Minibus	20 mins	15 mins	30-35 mins	25-30 mins
Wagon	15 mins	10 mins	Up to 60 mins	30-45 mins

Metrobus	5-7 mins	10 mins	Around 50 mins	Around 50 mins
Suzuki Pickup	15 mins	12 mins	40 mins	30 mins
Qingqi	N/A	N/A	N/A	N/A

What is the average number of transfers for a trip for each mode of public transport in each city? This could be different for different modes of public transport as well as across the centre (CBD) and periphery areas. Knowing an approximate variation range (min and max) would also be useful.

- Transfers within the same mode **(in overall survey (0/12) commuters transfer to the same mode**
- Transfers across the different modes **(2/12) but Metro commuters that live away from Saddar or approaching the metro station from Aabpara use wagons and their dominant mode was a metro bus). Moreover, their average numbe r of transfers is 1.**

What is the coverage of each mode of public transport in each city? There will be a lot of information around this question as coverage is a serious problem in Pakistani public transport.

In the case of Islamabad according to ITA

Mode	Coverage (%)
Wagons	80
Minibus	5
Metro	10
Suzuki Pickup	3
Qingqi	<1

How female-friendly are existing modes of public transport? What has been done in this regard? For example, there was some discussion on **Pink Buses.**

Which modes are more or less comfortable for females?

Female security and comfort as security and comfort is more subjective as different people define 'what is safe and secure?' and 'what is comfortable?' differently.

Mode	Teasing	Staring	Touching	Groping	Reserve seats	Door-to-door access
Wagon	Very few	Quiet often	Rarely	Few	Front two	No
Minibus	Rarely	Quiet often	Rarely	Yes	No	No

Metro bus	Rarely	Very few	No	Yes	Yes	Yes
Suzuki Pickup	Rarely	Quiet often	Quiet often	Yes	No	No
Qingqi	N/A	N/A	N/A	N/A	N/A	N/A

Gather as much information as you can about **AC and Wifi** in public transport. Urgency, benefits, incentive, etc.

Mode	AC	Wi-Fi
Wagons	NO	NO
Minibus	NO	NO
Metro bus	Yes	NO
Suzuki Pickup	No	NO
Qingqi	No	No

- Origin-destination information. Transport departments may have information on the number of trips from and to different areas of the city during the morning peak or other times. This is usually expressed as matrices, for example:

Origin \ Destination	City centre	Neighbourhood 1	Neighbourhood 2
City centre	100	50	50
Neighbourhood 1	500	80	150
Neighbourhood 2	800	200	300

- If available, we need to get this information, including the definition of each area (e.g., what exactly "city centre" means).
  The city centre in the case of Islamabad is considered the Blue Area (commercial hub).

- They may have similar matrices for other data, for example, the average travel time by origin-destination pair, the average fare for a given mode, etc.
  This data is unavailable from secondary sources.

After collecting all possible information from secondary sources, you should validate it against data provided by commuters. The idea is to ask a small sample of commuters about their trips, record their answers, and later compare them to the information gathered from the authorities. Does it match? The things to ask commuters:

- Origin and destination of the trip
  The origin and destination varied for each commuter surveyed. For example, the metro bus trip originated from the F-8 Kachahri stop and ended at the Saddar Metro bus stop (destination).

- Description of the trip: how many legs? Mode, fare, access, waiting and travel time of each leg.
  (10/12) commuters are using a single mode.

- Purpose of the trip
  (11/12) were doing work trips (going to offices and jobs).

- How often the trip is made
  5 Days a week.

- What other alternative ways to travel the person could have used? Not very interested in other possible routes using the same modes, but in other modes that could be used, e.g., driving and taking a taxi instead of public transport, or the metro instead of the bus.
  Taxi/Uber and Careem are alternative options.

A lot of this and other relevant information is available in origin-destination surveys which you will have to access and acquire. Also, provincial governments (especially the Punjab Government) have their master plans and data-sets on transport.

Background information (Lahore)

What are the existing modes of transport in the **three selected cities**? For example, in Islamabad, these are vans, minibuses and the metro mainly. But there might be others in the documents.

Lahore: wagon (30%), Buses (metro, Feeder by LTC & speedo) (40%), orange Metro Train system (10%), Qingqi (15%), Suzuki pickup (<1%)

For each mode in each city:

- Is it public or privately funded?
  Metro buses, feeder buses, speedo and orange Metro train system are Public Funded & all other modes are privately funded

- Does it have pre-defined routes? If so, who sets the routes (transport department or private operator)?
  Yes, Routes are pre-defined and it is set by Regional Transport departments e.g. (Punjab Mass transit Authority (PMTA) & Lahore Transport Company (LTC))

- What is their market share? Market competition for share and incentive to compete or other relevant information.
  Market share for privately funded transport is around 50% in Lahore according to the official source of PMTA.

- What is the fare system? Is it a flat fare per trip or does it change by distance? Is there a special fare for students or the elderly?
  The fare system is distance based and the provincial Transport Authority (Mainly the secretary of public transport in every province) sets it.

- What is their average fare per kilometre? The answer to this question must have a lot of information beyond fare and it is very crucial to collect all of this from relevant departments.

Mode	Distance (Km)	Fare (PKR)
Wagons	4	15
	8	20
	14	24
	22	28
	30	35
Metro Bus	No dependence (Track length is 27Km)	30
Speedo	25 RS up to the metro station and then charge 10 Rs. on the metro	25
Feeder Buses (LTC)	4	20
	8	25
	14	30
	22	35
	38	40
Orange Metro Line	No dependence (Track length is 27Km)	40
Qinchi (taxi)	It is used as a taxi and there is no fixed fare per km distance (usually bargain fare b/w commuter and Qinchi driver)	
Qingqi (Share ride)	1-4	20
	4-8	25
	8-12	30
	12-15	40
Suzuki Pickup	It is not used in Lahore but to keep the uniform design of the study we keep it here as per instructions.	

For example, there might be some subsidy in the case of Metrobus or there is a difference in set fare and market fare (which is actually paid by commuters). Similarly, information on how the fare is regulated is also very important.

Mode	Subsidies
Wagon	No
Metro Bus	Rs 1.9 Billion
Feeder Buses (pink buses and Speedo)	Rs 4.25 billion
Orange Metro Line	Rs 4.5 billion
Qingqi	No
Suzuki Pickup	No

Sources: https://www.dawn.com/news/1614258

- What is the average access time in minutes (including walking time at the beginning and end of the trip) for each mode of public transport? Knowing an approximate variation range (min and max) would also be useful.

Mode	Average Access Time Lahore (Mazang, Chuburji & Johar town)
Wagon	10 mins
Metro bus	10 mins
Feeder buses	10 mins
Speedo	15 mins
Orange Metro Line	10 mins
Qingqi	5 mins
Suzuki Pickup	It is not used in these areas but to keep the uniform design of the study we keep it here as per instructions.

What are the average waiting time (at a stop) and travel time in minutes for each mode of public transport? For example, the average travel time for a trip for each mode of public transport in each city. Knowing an approximate variation range (min and max) would also be useful.

I have collected information from Lahore 15 commuters on three spots (Mazang, Chuburji & Johar town) regarding their waiting and travel times and the average times are below:

Mode	Waiting Time (Peak)	Waiting Time (off-Peak)	Travel Time (Peak)	Travel Time (off-Peak)
Minibus	20 mins	15 mins	30-35 mins	25-30 mins
Wagon	15 mins	10 mins	Up to 60 mins	30-45 mins
Metrobus	5-7 mins	10 mins	Around 50 mins	Around 50 mins
Metro train	10 mins	10 mins	45 mins	45 mins
Speedo	10 mins	5-7 mins	35 mins	25 mins
Feeder Buses	5 mins	10 mins	75 mins	60 mins
Qingqi	5 mins	10 mins	30 mins	20 mins

- What is the average number of transfers for a trip for each mode of public transport in each city? This could be different for different modes of public transport as well as across the centre (CBD) and periphery areas. Knowing an approximate variation range (min and max) would also be useful.

- Transfers within the same mode **(in the overall survey (3/15) commuters transferred to the same mode and the dominant mode in the journey was a bus) and the average number of transfers is 1.**
- Transfers across the different modes **(2/15) yes especially for the areas like Mazang, which is the hub for transportation Metro commuters do shift to the metro orange line train) in this case, the dominant mode is (the Metro train) and the average number of transfers is 1.**
- **In the areas away from the Chaurbarji commuters use the Qingqi after using the metro bus (2/15), in this case, the dominant mode is (the Metro bus) and the average number of transfers is 1.**

- What is the coverage of each mode of public transport in each city? There will be a lot of information around this question as coverage is a serious problem in Pakistani public transport.

Mode	**Coverage (%)**
Wagons	30
Speedo	5
Metro bus	10
Metro train	10
Feeder Buses	20
Qingqi	15
Sukuzi Pickup	<1

- How female-friendly are existing modes of public transport? What has been done in this regard? For example, there was some discussion on **Pink Buses.**

Which modes are more or less comfortable for females?

Female security and comfort as security and comfort is more subjective as different people define 'what is safe and secure?' and 'what is comfortable?' differently.

Mode	Teasing	Staring	Touching	Groping	Reserve seats	Door-to-door access
Wagon	Very few	Quiet often	Rarely	few	Front two	No
Metro bus	Rarely	Very few	No	Yes	Yes	Yes
Speedo	Rarely	Very few	No	Yes	Yes	Yes
Metro train	Rarely	Very few	No	Yes	Yes	Yes
Feeder Buses	Rarely	Very few	No	Yes	Yes	Yes
Qingqi	Rarely	Quiet often	Rarely	yes	No	No
Suzuki Pickup	N/A	N/A	N/A	N/A	N/A	N/A

- Gather as much information as you can about AC and Wifi in public transport. Urgency, benefits, incentive etc.

Mode	AC	Wi-Fi
Wagons	NO	NO
Speedo	yes	NO
Metro bus	Yes	NO
Metro train	Yes	NO
Feeder Buses	Yes	NO
Qingqi	NO	NO
Suzuki Pickup	NO	NO

- Service providers: individual transporters, private companies, government.

Mode	Regulating Authority
Wagons	Privately funded
Speedo	Public Funded (PMTA)
Metro bus	Public Funded (PMTA)
Metro train	Public Funded (PMTA)
Feeder Buses	Public Funded by (LTC)
Qingqi	Privately funded

- Conduct and professionalism of the staff/service quality (bad, fair, good) (information from 15 commuters in the areas of Mazang, Chauburji & Johar town)

Mode	The behaviour of Conductor/ Employees
Wagons	(10/15) Bad and (4/15) Fair (1/15) good.
Speedo	(11/15) good (4/15) Fair
Metrobus	(10/15) good (3/15) Fair (2/15) Bad
Metro train	(12/15) good (3/15) Fair
Feeder Buses	(9/15) good (4/15) Fair (2/15) Bad
Qingqi	Bad (12/15) and (3/15) Fair
Suzuki Pickup	It is not used in these areas but to keep the uniform design of the study we keep it here as per instructions.

Origin-destination information. Transport departments may have information on the number of trips from and to different areas of the city during the morning peak or other times. This is usually expressed as matrices, for example:

Origin \ Destination	City centre	Neighbourhood 1	Neighbourhood 2
City centre	100	50	50
Neighbourhood 1	500	80	150
Neighbourhood 2	800	200	300

- If available, we need to get this information, including the definition of each area (e.g. what exactly "City centre" means).

  City centre means the hub of commercial area.

- They may have similar matrices for other data, for example, the average travel time by origin-destination pair, the average fare for a given mode, etc.

  This data is unavailable with secondary sources.

After collecting all possible information from secondary sources, you should validate it against data provided by commuters. The idea is to ask a small sample of commuters about their trips, record their answers, and later compare them to the information gathered from the authorities. Does it match? The things to ask commuters:

- Origin and destination of the trip

The origin and destination varied for each commuter surveyed. For example, most of the metro bus trips originated from the Mazang stop and ended at the Gajumata metro-bus stop (destination). Similarly, most of the orange line commuters from trips originating from Chaurbhji end at Dera Gujran.

- Description of the trip: how many legs? Mode, fare, access, waiting and travel time of each leg.

There is a mix of one and two modes in the case of Lahore mostly, in our survey commuters (8/15) used single mode (7/15) uses more than one mode.

- Purpose of the trip

(14/15) were doing work trips (going to offices and jobs).

- How often the trip is made

5 Days a week.

- What other alternative ways to travel the person could have used? Not very interested in other possible routes using the same modes, but in other modes that could be used, e.g. driving and taking a taxi instead of public transport, or the metro instead of the bus.

Taxi/Uber and Careem are alternative options.

A lot of this and other relevant information is available in origin-destination surveys which you will have to access and acquire. Also, provincial governments (especially the Punjab Government) have their master plans and datasets on transport.

Background information (KARACHI)

What are the existing modes of transport in the three selected cities? For example, in Islamabad, these are vans, minibuses and the metro mainly. But there might be others in the documents.

Karachi: Minibus & buses (75-80%), Qingqi (20-25%).

For **each mode in each city:**

- Is it public or privately funded?
  All modes are privately funded.

- Does it have pre-defined routes? If so, who sets the routes (transport department or private operator)?
  Yes, Routes are pre-defined and it is set by Sindh Transport Authority.

- What is their market share? Market competition for share and incentive to compete or other relevant information.
  The market share for privately-funded transport is 100% in Karachi.

- What is the fare system? Is it a flat fare per trip or does it change by distance? Is there a special fare for students or the elderly?
  The fare system is distance based and the provincial transport authority (mainly the secretary of public transport in every province) sets it.

- What is their average fare per kilometre? The answer to this question must have a lot of information beyond fare and it is very crucial to collect all of this from relevant departments.

Mode	Distance (Km)	Fare (PKR)
Mini-buses	5	15
	10	20
	15	23
	20	30
	30	35
Qingqi (booking)	5-15	100-150
Qingqi (share ride)	1-4	20
	4-8	25
	8-12	30
	12-15	40

For example, there might be some subsidy in the case of Metrobus or there is a difference in set fare and market fare (which is actually paid by commuters). Similarly, information on how the fare is regulated is also very important.

There is no subsides public transport mode available in Karachi

- What is the average access time in minutes (including walking time at the beginning and end of the trip) for each mode of public transport? Knowing an approximate variation range (min and max) would also be useful.

Mode	Average Access Time KARACHI (from the commute rs North Nazimabad, Baldia and L yari)
Minibus	15-20 mins
Qingqi	5-10 mins

- What are the average waiting time (at a stop) and travel time in minutes for each mode of public transport? For example, the average travel time for a trip for each mode of public transport in each city. Knowing an approximate variation range (min and max) would also be useful.

I have collected information from Karachi commuters on three spots (from 15 commuters from the areas of north Nazimabad, Baldiya, and Lyari) regarding their waiting and travel times and the average times are below:

Mode	Waiting Time (Peak)	Waiting Time (off-Peak)	Travel Time (Peak)	Travel Time (off-Peak)
Minibus & Bus	20 mins	30 mins	60-70 mins	40-60 mins
Qingqi	5 mins	15 mins	50 mins	40 mins

- What is the average number of transfers for a trip for each mode of public transport in each city? This could be different for different modes of public transport as well as across the centre (CBD) and periphery areas. Knowing an approximate variation range (min and max) would also be useful.

- Transfers within the same mode **(4/15) use Minibuses and the dominant mode is a minibus. Moreover, their average number of transfers is 1.**

- Transfers across the different modes **(3/15) use Qingqi for last-mile travel after using a minibus) the dominant mode is a minibus. Moreover, their average number of transfers is 1.**

- What is the coverage of each mode of public transport in each city? There will be a lot of information around this question as coverage is a serious problem in Pakistani public transport.

Mode	Coverage (%)
Minibuses & Buses	75-80
Qingqi	15-20

- How female-friendly are existing modes of public transport? What has been done in this regard? For example, there was some discussion on Pink Buses.

Which modes are more or less comfortable for females?

Female security and comfort as security and comfort is more subjective as different people define 'what is safe and secure?' and 'what is comfortable?' differently.

Mode	Teasing	Staring	Touching	Groping	Reserve seats	Door-to-door access
Minibus	Rarely	Quiet often	Rarely	Yes	No	No
Qingqi	Rarely	Quiet often	Rarely	Yes	No	No

- Gather as much information as you can about AC and Wifi in public transport. Urgency, benefits, incentive etc.

Mode	AC	Wi-Fi
Minibus	NO	NO
Qingi	NO	NO

- Service providers: individual transporters, private companies, government.

Mode	Funding
Minibus	Privately funded
Qingqi	Privately funded

- Conduct and professionalism of the staff/service quality (bad, fair, good) (information from commuters)

Mode	The behaviour of Conductor/ Employees
Minibus	(13/15) Bad and (2/15) Fair
Qingqi	(10/15) Bad and (5/15) Fair

Origin-destination information. Transport departments may have information on the number of trips from and to different areas of the city during the morning peak or other times. This is usually expressed as matrices, for example:

Origin \ Destination	City centre	Neighbourhood 1	Neighbourhood 2
City centre	100	50	50
Neighbourhood 1	500	80	150
Neighbourhood 2	800	200	300

- If available, we need to get this information, including the definition of each area (e.g. what exactly "City centre" means).

  The city centre is mainly (a commercial hub), like Saddar in Karachi.

- They may have similar matrices for other data, for example, the average travel time by origin-destination origin-destination pair, the average fare for a given mode, etc.

  This data is unavailable from secondary sources.

After collecting all possible information from secondary sources, you should validate it against data provided by commuters. The idea is to ask a small sample of commuters about their trips, record their answers, and later compare them to the information gathered from the authorities. Does it match? The things to ask commuters:

- Origin and destination of a trip

The origin and destination varied for each commuter surveyed. For example, most of the minibus trips originated from Lyari and ended in Shershah (destination). Similarly, most of the orange line commuters from the trip originated from Baldiya ends at Aziz Nagar and Saddar areas.

- Description of the trip: how many legs? Mode, fare, access, waiting and travel time of each leg.
- **(8/15) commuters are using a single mode that is a minibus and (7/15) using more than one mode.**
- Purpose of the trip

  (12/15) were doing work trips (going to offices and jobs).

- How often the trip is made

  5 and 6 Days a week.

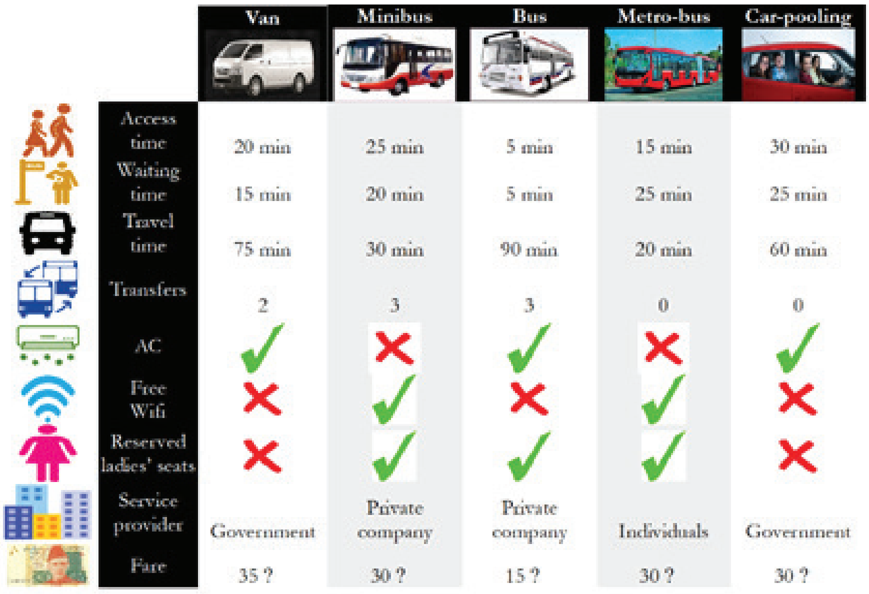
- What other alternative ways to travel the person could have used? Not very interested in other possible routes using the same modes, but in other modes that could be used, e.g. driving and taking a taxi instead of public transport, or the metro instead of the bus.

  Taxi/Uber and Careem are alternative options.

A lot of this and other relevant information is available in origin-destination surveys which you will have to access and acquire. Also, provincial governments (especially the Punjab Government) have their master plans and datasets on transport.

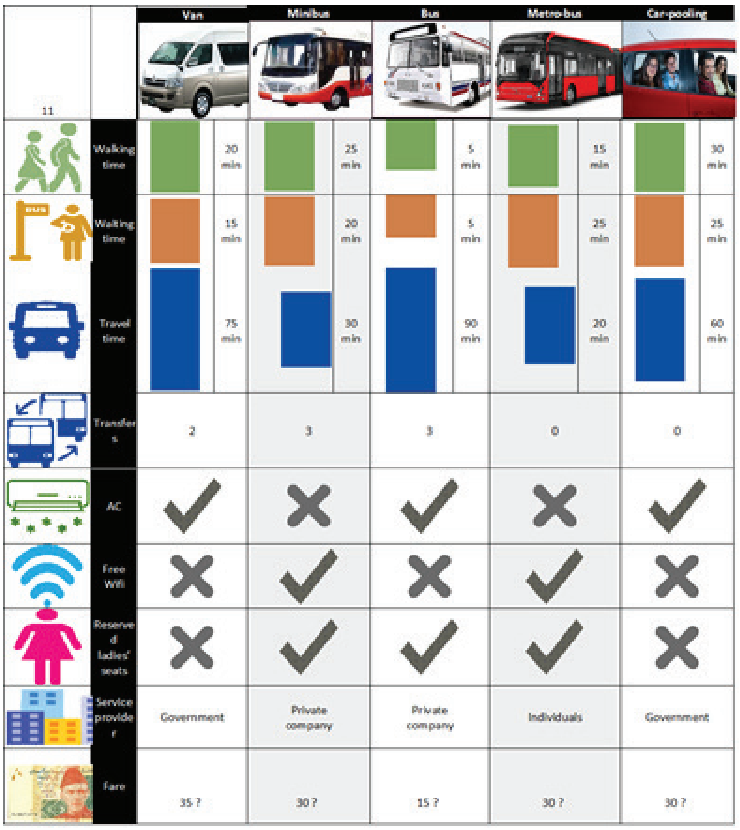
Appendix – B

Example of choice cards used in 2nd pilot and final survey



	Van	Minibus	Bus	Metro-bus	Car-pooling
Access time	20 min	25 min	5 min	15 min	30 min
Waiting time	15 min	20 min	5 min	25 min	25 min
Travel time	75 min	30 min	90 min	20 min	60 min
Transfers	2	3	3	0	0
AC	✓	✗	✓	✗	✓
Free Wifi	✗	✓	✗	✓	✗
Reserved ladies' seats	✗	✓	✓	✓	✗
Service provider	Government	Private company	Private company	Individuals	Government
Fare	35 ?	30 ?	15 ?	30 ?	30 ?

Example of choice cards used in 2nd pilot and final survey



11	Van	Minibus	Bus	Metro-bus	Car-pooling
Walking time	20 min	25 min	5 min	15 min	30 min
Waiting time	15 min	20 min	5 min	25 min	25 min
Travel time	75 min	30 min	90 min	20 min	60 min
Transfers	2	3	3	0	0
AC	✓	✗	✓	✗	✓
Free Wifi	✗	✓	✗	✓	✗
Reserved ladies' seats	✗	✓	✓	✓	✗
Service provider	Government	Private company	Private company	Individuals	Government
Fare	35 ?	30 ?	15 ?	30 ?	30 ?

APPENDIX – III

Public transport questionnaire for Islamabad and Lahore

- Survey site (1) Islamabad (2) Lahore (3) Karachi
- Gender (1) male (2) female
- Respondent age (years) _____
- Respondent education (Number of years of schooling) _____
- Household size ___________
- Monthly household income (Rs) (1)= up to 49,999 (2)=50, 000 – 99,999 (3)= 100,000 – 199,999 (4)=200,000 – 399,999, (5)= 400000+
- The number of days in a week do you use public transport? _______
- The number of days in a week you commute? _______
- What is your average commuting cost (including Careem/taxi/rickshaw) per day (Rs) _______
- What would be your daily average commuting cost (Rs) if there is reliable public transport _______
- How many days per week do you use Careem/taxi/rickshaw because of the lack of public transport? ___
- How much did you pay for Careem/taxi/rikshaw in the last week? ________________
- Per day number of hours you could save if public transport is reliable and efficient ___________
- Public transport in your area is managed by (1) individuals (2) private companies (3) the government (4) don't know
- In your opinion, which of the above three would provide better public transport? ______
- Have you ever quit a job or did not take one because of the lack of public transport? (1) yes (2) no
- What are your per-hour wages (rough idea) (Rs) __________
- Please describe your current journey:

	Single journey	1st transfer	2nd transfer
Access time (minutes) For how long did you walk to get to the *[mode]* stop?			
Waiting time (minutes) How long *did/do* you expect to wait in *that/this* stop?			
Mode (van, minibus, bus, metro bus, other) What mode *did/will* you use in that stop?			
Travel time (minutes) For how long *did/will* you ride the *[mode]*			
Walk to next destination (minutes) After alighting, for how long *did/will* you walk?			

- Using a scale from 1 to 5, where 1 means "very unsatisfied" and 5 means "very satisfied", please state your level of satisfaction with the following ***features of the public transport***:

Features of the public transport	1	2	3	4	5
Overall service					
Ease of access to public transport					
Frequency (i.e. how often they come by)					
Timeliness (i.e. you will arrive on time and there will be no extended delay in your journey)					
Comfort while on the public transport					
Safety and security while on the public transport					
Coverage of public transport in your city					
Ladies reserved seats					
The level of respect & cordiality from staff and other passengers toward you					
The level of respect & cordiality from staff and other passengers toward women					

- Are you aware of the car-pooling system? (1) yes (2) no
- Have you ever used it? (1) yes (2) no
- Would you be willing to subscribe to a car-pooling system? (1) yes (2) no

APPENDIX – IV

Public transport questionnaire for Karachi

- Survey site: (1) Islamabad (2) Lahore (3) Karachi
- Gender: (1) male (2) female
- Respondent age: _____ (years)
- Respondent education: _____ (Number of years of schooling)
- Household size: _____ (people)
- Monthly household income (Rs):
  (1)up to 49,999 (2)50,000 – 99,999 (3)100,000 – 199,999 (4)200,000 – 399,999 (5)400,000+
- The number of days in a week do you use public transport?: _______
- The number of days in a week you commute?: _______
- What is your average commuting cost (including Careem/taxi/rikshaw) per day?: _______ (Rs)
- What would be your daily average commuting cost if there is reliable public transport?: ______(Rs)
- How many days per week do you use Careem/taxi/rikshaw because of the lack of public transport?: _____ (days)

- How much did you pay for Careem/taxi/rikshaw in the last week?: ___
- Per day number of hours you could save if public transport is reliable and efficient? _____ (Hours)
- Public transport in your area is managed by: (1)individuals (2)private companies (3) the government (4)don't know
- In your opinion, which of the above three would provide better public transport?: ______
- Have you ever quit a job or did not take one because of the lack of public transport?: (1)yes (2)no
- Please describe your current (or latest) journey:
- Main mode (the one you travelled by the furthest):
  (1)Van (2)Mini-bus (3)Bus (4)Metro-bus (5)Rickshaw (6)Qinchi (7) Car (8) Other:________
  Total length of trip: Access_____ (minutes) Waiting _____ (minutes) Travel________ (minutes)
- Using a scale from 1 to 5, where 1 means "very unsatisfied" and 5 means "very satisfied", please state your level of satisfaction with the following ***features of public transport (PT) in your city:***

Features of the public transport	Mark (1-5)
Overall	
Coverage PT is easily accessible from your origin and destination	
Frequency PT vehicles come by often	

- Using the same scale from 1 to 5, where 1 means "very unsatisfied" and 5 means "very satisfied", please state your level of satisfaction with the following features of EACH public transport mode:

Features of each public transport mode	Van	Minibus	Bus	Metro bus
Reliability/ Timeliness You will arrive on time with no extended delay				
Comfort You feel comfortable while travelling in the mode				
Safety You feel safe and secure while travelling in the mode				

- Are you aware of the car-pooling system?: (1)yes (2)no
- Have you ever used it?: (1)yes (2)no
- Would you be willing to subscribe to a car-pooling system?: (1)yes (2)no

APPENDIX – V

Pilot surveys

A pilot survey is a pre-condition for the primary data collection as it is used to test and improve the survey instrument/questionnaire with actual respondents. However, piloting a choice modelling survey is extremely crucial and a requirement without which it is impossible to design and conduct a choice modelling survey. As stated above, piloting a choice modelling survey is necessary to collect the priors which are required to create the experimental design. This is in addition to testing the survey instrument itself which is also more complex for a choice modelling survey as it involves the experimental design, description of choice scenarios, visuals and survey questions. Two pilot surveys have been administered in the present research.

After collecting 90 responses, 30 in each city under study, we estimated a simple choice model using the collected data. Results are shown in Table 2 below. This model was not satisfactory, as the coefficients for access and waiting time, as well as the coefficient for travel time for Van and Metro-bus, were positive. A positive coefficient means that respondents prefer higher values of those attributes. In other words, this model implied that the longer a trip took, the most appealing it was for respondents. This contradicts the basic theory in transport studies and economics, which states that time is a scarce resource, and therefore individuals prefer to spend less rather than more time on unproductive and displeasing activities such as travelling.

Table 2: Parameter estimates using data from pilot 1

MNL			
		Estimates	t-ratio
Alternative specific constants	Van	-1.2175	-2.22
	Mini-bus	-0.1195	-0.24
	Bus	-0.1971	-0.39
	Metro-bus	0.0000	(fixed)
	Carpool	-0.8706	-1.49
Time (minutes)	Access	0.0018	0.30
	Waiting	0.0067	0.92
	Van	0.0124	2.05
	Mini-bus	-0.0056	-1.09
	Bus	-0.0069	-0.99
	Metro-bus	0.0002	0.04
	Carpool	-0.0157	-1.90
Transfers		-0.4922	-6.69
Perks	AC	1.0748	6.56
	Wifi	0.5913	4.17
	Ladies' seats	0.6523	4.66
	x female	0.5797	1.40
Operator	Individuals	0.0000	(fixed)
	Private	0.0786	0.47
	Government	0.3223	2.07
Fare		-0.0892	-10.80
Fit	LL	-398.55	
	Rho2		0.31
	No. of parameters		19
	Observations		360
	Respondents		90

After examining these results, we hypothesised that respondents were not paying enough attention to access, waiting and travel times due to the visual design of the survey. We believe that the colourful tick and x marks were preventing participants from paying attention to the numeric time attributes. Therefore, we decided to present the time attributes visually in a second pilot. Additionally, we decided to change the order of the survey in the second pilot, presenting the choice experiment first, and the travel questionnaire second, to avoid the respondent being fatigued by the time they answered the choice exercise.

Table 3: Parameter estimates using data from pilot 2

MNL			
		Estimate	t-ratio
	Van	-0.4652	-0.83
	Mini-bus	-0.1449	-0.28
	Bus	0.0625	0.17
	Metro-bus	0.0000	(fixed)
ASC	Car-pool	-2.1551	-3.21
	Access	-0.0260	-1.64
	Waiting	-0.0175	-0.91
Time	Travel	-0.0945	-8.46
Transfers		-0.1831	-1.06
	AC	3.0854	6.95
	Wifi	1.2716	3.82
Perks	Ladies' seats	1.7976	4.71
	Individuals	0.0000	(fixed)
	Private	-0.7602	-2.17
Operator	Government	-0.3532	-0.95
Fare		-0.0086	-0.63
Fit	LL		-63
	Parameters		14
	Observations		120
	Respondents		30

Using the responses from the 30 new individuals in the second pilot, a new model was estimated, obtaining the parameter values exhibited below. As the number of observations was lower than in the first pilot, we estimated a simpler model, with a single travel time coefficient for all modes. This time, all coefficients showed the expected sign: negative for all time, transfers, and fare parameters, and positive for AC, wifi, and ladies' seats (Table 3). The level of significance of the parameters is not relevant at this stage, as the sample is very small, and they are expected to improve when a bigger sample is collected and analysed.

PART II

URBAN DEVELOPMENT

Policy Briefs

ADOPTION OF A PERFORMANCE EVALUATION TECHNIQUE FOR THE DEVELOPMENT OF A FRAMEWORK FOR THE CLIMATIC RESPONSIVE URBAN DESIGN

Salma Sherbaz and Humera Mughal

INTRODUCTION

The mass influx/migration of humans from rural areas and resulting changes in urban settings is known as urbanisation. A significant increase in the percentage of the world population living in urban areas has been observed over the past few decades. As per the United Nation's updated estimates for the year 2018, 55% of the world's population was living in urban areas and is expected to increase to 68% by 2050. A similar steady trend in the growth rate of the urban population has been observed in Pakistan. In 2019, the annual percentage growth in the urban population was around 2.7%.

Although urbanisation is mostly considered an indicator of economic, social, and political progress of a society, it can also lead to several challenges including urban sprawl, environmental and health issues, increasing crime and human insecurity-related problems, poor urban governance, weak financial capacity of cities and higher living cost, etc. Urban areas have significant energy consumption and CO2 emission footprint. The negative impacts of rapid urbanisation on the environment are profound and reach far beyond urban settlements themselves. Environmental degradation in urban areas is a serious developmental issue in Pakistan. A slight glance at the annual mean temperature, sea level, and rainfall patterns is ample to portend the looming crisis.

The goal of this research is to guide the designer for the early-stage climate-responsive urban design. The impact of different urban design elements, i.e., street canyon geometry (canyon length, width, height, orientation, and SVF) and greenery have been evaluated on the urban microclimate, which affects the energy load and thermal comfort in the built environment.

METHODOLOGY

Land Cover and Land Use Classification Map of Study Area

The study on which this policy viewpoint is based was carried out in Islamabad (planned) and Rawalpindi (semi-planned) located at 33.662883° Lat, 73.086373°Lon.

The concept of local climate zone (LCZ) was used to prepare land use and land cover (LULC) maps of the twin cities.

Remote-Sensing (RS) based Assessment of Urban Microclimate

For the analysis, freely available satellite (LANDSAT 8) images were used for the retrieval of LST. The Landsat-8 imagery of twin cities was acquired at 05:42 UTC (about 10:42 am local standard time) on July 02, 2021.

Computational Fluid Dynamics Based Assessment of Urban Microclimate

Urban flow simulations were performed using Envi-met software. The ENVI-met study areas of the twin cities are shown in Figure 3. AutoCAD was used to delineate building features in the imagery for the generation of 3D models (as shown in Figure 4). The simulations were performed on 10th June 2021, the hottest day of summer (2021) with the highest temperature of 43oC in the afternoon.

RESULTS AND DISCUSSIONS

Effect of Urban Design Elements on Microclimate

Relationship between the LST and urban design variables

To evaluate the relationship between the LST and different street canyon geometry variables (canyon length, width, height, orientation, and SVF), around 80 different street canyons of Islamabad and Rawalpindi were selected. The LST values inside this street canyon were extracted from the LST map of the twin cities. The following regression models were fitted between the dependent and independent variables using the response surface-based method.

Table 1: Coefficients of the estimated regression model for Islamabad with standard errors and t- value

Coefficients	Estimates	SE (Coefficient)	t- value	p-value
Constant	29.0734	0.8684	33.479	0
Canyon Orientation	-0.0054	0.00086	-6.267	0
SVF	6.9123	1.3095	5.279	0
Canyon Width	0.6721	0.08283	8.114	0
Canyon Height	-0.0482	0.0185	-2.604	0.011
Canyon Length	-0.0004	0.00068	-0.568	0.572
SVF*Canyon Width	-0.8601	0.11655	-7.38	0
R-Sq = 71.83%, R-Sq(pred) = 65.00%, R-Sq(adj) =69.38%				
Note: SE (Coefficient) are the standard error of coefficients				

Table 2: Analysis of Variance

Source	Degrees of Freedom	Sum of Square	Mean Square	F-ratio	P-value
Regression	6	15.5447	2.59079	29.32	0.000
Error	69	6.0972	0.08837		
Total	75	21.6420			

Table 3: Coefficients of the estimated regression model for Rawalpindi with standard errors and t-value

Coefficients	Estimates	SE (Coefficient)	t- value	p-value
Constant	34.3698	0.23495	146.283	0
Greenery Index	-6.0736	2.65306	-2.289	0.025
SVF	2.4011	0.91689	2.619	0.011
Canyon Width	0.0568	0.04280	1.327	0.188
Canyon Height	-0.0486	0.01134	-4.290	0
Canyon Orientation	0.004	0.00022	1.969	0.052
Canyon Length	-0.0028	0.00073	-3.837	0
SVF*Canyon Width	-0.3190	0.15308	-2.084	0.040
R-Sq = 47.61% R-Sq(pred) 38.64%, R Sq(adj)= 42.97% Note: SE (Coefficients) is the standard error of coefficients				

Table 4: Analysis of Variance

Source	Degrees of Freedom	Sum of Square	Mean Square	F-ratio	P-value
Regression	7	2.83829	0.405469	10.26	0.000
Error	79	3.12304	0.039532		
Total	86	5.96133			

CONCLUSIONS

The important conclusion derived from the current research can be used by designers for climate-responsive urban design in case of the future extension of these cities. The important results of the current research are:

- Being highly urbanised regions, most of the urban areas in the twin cities are associated with high LST.
- According to the regression analysis results, canyon height, width, length and orientation have a significant correlation with LST. The Skyview factor has a significant positive correlation with LST in both cities. Therefore, decreasing Skyview factors either by introducing the deep street canyons or increasing the greenery inside the wide canyon will reduce the LST intensity inside these street canyons.
- According to the CFD simulation results:
  - The intensity of shortwave radiation decreases with an increase in H/W ratios
  - An inverse relation between the air temperature and the H/W ratio can be observed for both cities. A reduction of 2.1° C and 4°C in the peak air temperature has been observed due to the increase in H/W ratios in the case of Islamabad and Rawalpindi, respectively.
  - In the case of Islamabad, street canyons oriented in the NE-SW direction are slightly warmer than NW-SE oriented canyons. Similarly, in the case of Rawalpindi, irrespective of the H/W ratio, the street canyons oriented in the E-W direction are warmer than canyons oriented in other directions (N-S and NE-SW).
  - For both cities, i.e., Islamabad and Rawalpindi, Tmrt has relatively low values in the deep street canyons.
  - In the case of Islamabad and Rawalpindi, a reduction of 2.3°C and 4.6°C respectively in PET peak values has been noticed due to the increase in H/W ratios.
  - In the case of Islamabad, NE-SW streets are up to 7.5°C (on the PET scale) warmer than NW-SE streets during peak PET times. Similarly, in the case of Rawalpindi, E- W streets having H/W= 0.73 are up to 5.15°C (on the PET scale) warmer than N-S streets during peak PET times.
  - However, a significant reduction in the PET intensity has been observed in the vicinity of trees. Thus, the thermal performance of a street canyon can be improved by increasing the tree coverage of these streets

POLICY RECOMMENDATIONS

- The study underscores the significance of altering contemporary regulations and bylaws to encourage more efficient layouts and elevations, such as vertical construction.
- The magnitude of the impact of different urban design variables on urban microclimate, and outdoor comfort may vary from city to city, an appropriate scientific intervention ought to be followed at the very inception stage to ensure climate-responsive urban planning and design.

PROSPECTS FOR THE DEVELOPMENT OF SOLID WASTE MANAGEMENT SYSTEM: A CASE STUDY OF METROPOLITAN CITY KARACHI

Shaista Alam (Late) and Ambreen Fatima

INTRODUCTION

Tackling the solid waste problem in a megacity like Karachi requires an effective policy framework and efficient implementation. A holistic understanding of the institutional capacities (technical, financial, human, and physical resources), actors involved in managing solid waste, household socio-economic conditions, and political issues along with how they are linked to the stakeholders under various phases of the SWM system given the ground realities is crucial for such a policy framework. The identification of the stakeholders and their interests is important in ensuring their participation and involvement in various waste management activities. Therefore, it is essential to assess the role, interest, and power structure of various stakeholders in the process of waste management. The report, on which this policy viewpoint is based, is unique as it provides an in-depth assessment of all the stakeholders involved in solid waste management from generation to disposal.

Aims and Objectives

Specifically, the objectives of the study were to:

- evaluate the capacity of the public sector in managing solid waste, i.e., the assessment of the public sector to highlight the major problems faced by the public authorities in managing solid waste and point out the inefficiencies within the system.
- Evaluate the role of the private sector (contractors directly hired by the public authorities or informally) in managing solid waste, highlighting their motives, and interest in entering the business.
- Estimate the extent of informality in managing the SW.
- Evaluating the prospects of collected waste for recycling and reuse.
- Estimating households' WTP for managing SW

By assessing the roles of public, private, and informal sectors in managing solid waste, the study provides policy options for the efficient management of solid waste using SWOT analysis.

METHODOLOGY

The study was based on a survey of 18 towns in Karachi. This helped in evaluating the role of district municipal committees (DMCs) in managing solid waste in localities across all 6 districts. The study collected primary information through key informant interviews and household surveys. In addition, small scrap dealers (kabarias operating both at large and small scale) and small-scale industries involved in recycling were also contacted for value chain assessment. To assess the objectives, the study performed:

	# Interviews/Surveys
Interviews of Key Officials (SSWMB & KMC)	6
Interviews of DMCs	6
Private Contractor	36
Informal Players	50
Households	460

KEY FINDINGS

Capacity Assessment Analysis

- According to SSWMB, total waste generated was around 9,839.1 (tons/day), waste collected was reported to be 8,265 (tons/day), and unattended remained at nearly 1,574.1 (tons/day).
- According to the information provided by the DMCs, the unattended waste ranged around 43% in Malir and West districts and 80% in the Central district. District East is the only district where no leftover waste was reported.
- Considering that the DMCs are operating with full resources available, it means that the resource needs to be increased from 40 to 80 percent.

Process of Collection and SWM – Public-Private Partnership (PPP)

Currently, the system that exists in Karachi can be grouped into 3 different models.

- Proper handling of the waste by the public sector through formal subcontracting.
- Waste collection through town/UCs contracting out informally to private contractors either on personal relation basis or political grounds
- Completely informal waste collection, which mainly operates in Orangi town. Oragni town is among the lowest income areas of Karachi

Furthermore, based on the survey of contractors and informal players (employees hired by the contractor) it can be concluded that:

- Solid waste in Karachi is still managed by private contractors (around 92%).
- Around 8 per cent of the public sector managing solid waste comes under the SSWMB contractual agreement made with the Chinese firms (Kangjie and Hangzhou).
- The door-to-door collection through outsourcing to Chinese firms is not very evident, which appears to be taking place in some areas of Korangi and East only.
- The hiring of contractors is around 69 per cent informal, 19 per cent formal, and 8 per cent based on personal relationships. Only around 3 per cent of hiring is based on experience, i.e., only 3 per cent of the contractors are hired based on having experience.

Private Contractors - Motives and Interest

- The cost of the public sector (KMC and SSWMB) is much higher than the cost of a small private contractor, who operates mainly through a horse and a cart or a 4-wheeler – Qingqi.
- The cost of the public sector is also higher as they are mainly involved in collecting waste from designated/undesignated sites and moving it to landfill sites. The public sector is not involved in the door-to-door collection.
- One contractor is responsible for the collection of waste from around 2,000 households.
- Contractors mainly operate by hiring 1 to 2 vehicles and employing 3 to 4 employees.
- The average cost per house on fuel is very minimum, which is less than Re. 1, while the average wage per household is Rs. 15.6 resulting in an average total cost per household of Rs. 16 only.
- The income generated as reported by a contractor is almost 65 per cent higher than the amount collected through fees; estimated revenue is also very high. The income from the collection by a contractor shows:
  - Fee per household – Rs. 179.7,
  - Income reported per month – Rs. 128,472,
  - Income generated (through fee collected from households) – Rs. 358,583,
  - Revenue (fee collected minus total cost) – Rs. 344, 023
  - Revenue per household – Rs. 163.7

Informally Hired workers

- The income generated (the number of households times fees) is around Rs. 226,018.
- Wage, if hired, is Rs 11,678,
- The total amount of waste collected (per day/worker) is kg 1,910.

- The amount of waste collected (per household/day) is kg 1.76.

Value Chain Analysis

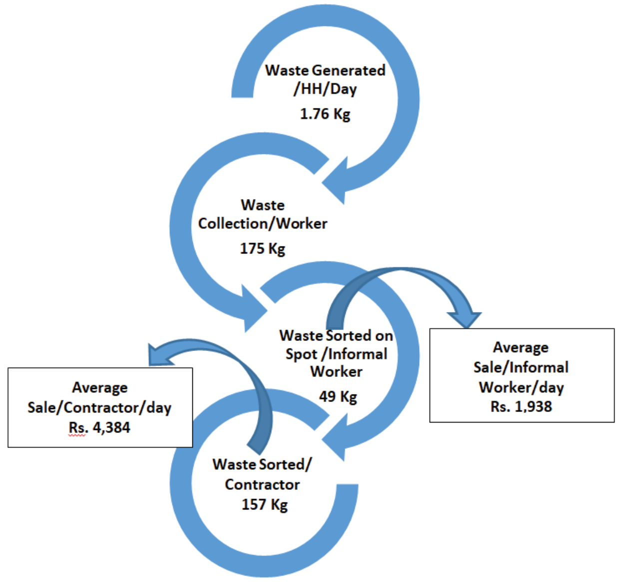
- Contractors hiring informal workers are sometimes involved in segregating waste and recycling. However, the public sector is not involved in reselling recyclable material because the public sector is not for profit.

- The main recyclable items are plastic, paper, cardboard, steel, and Iron.

- The average income generated by the contractors from the sale of these products is much higher than the income generated by the informally hired workers per day.

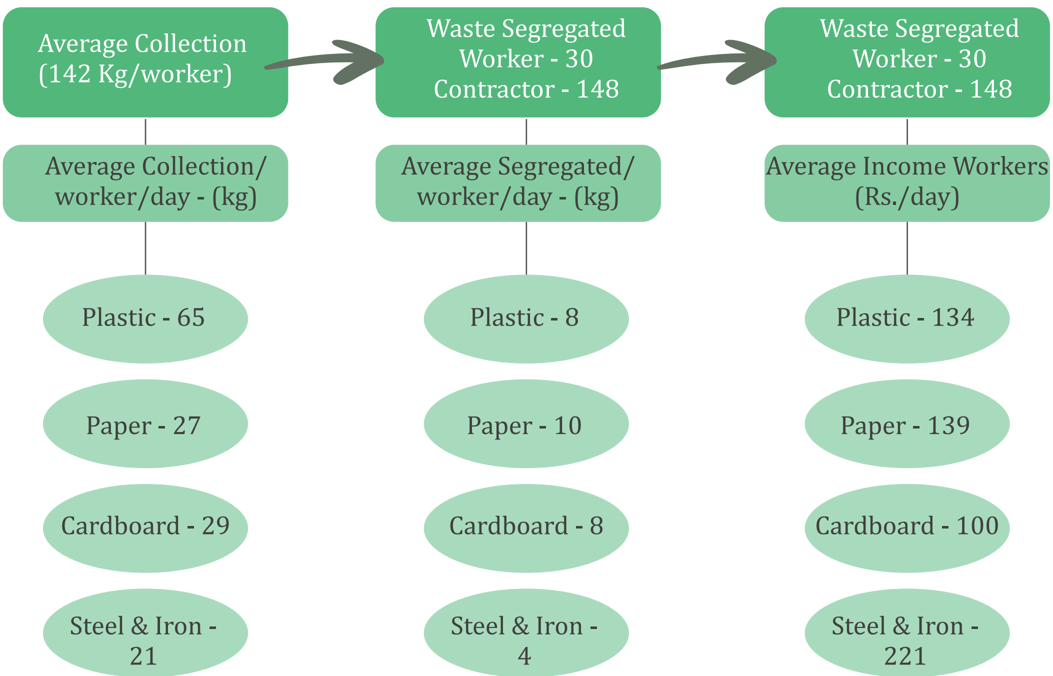
- Figures 1 and 2 provide a flow of waste from collection to segregation of recyclable material.

Figure 1: Generation, Collection, Segregation, and Income from the sale of Recyclable



Source: Authors' illustration based on the survey of private contractors and informally hired workers

Figure 2: Flow of Recycleable Material and Income Generated



Source: Authors' illustration

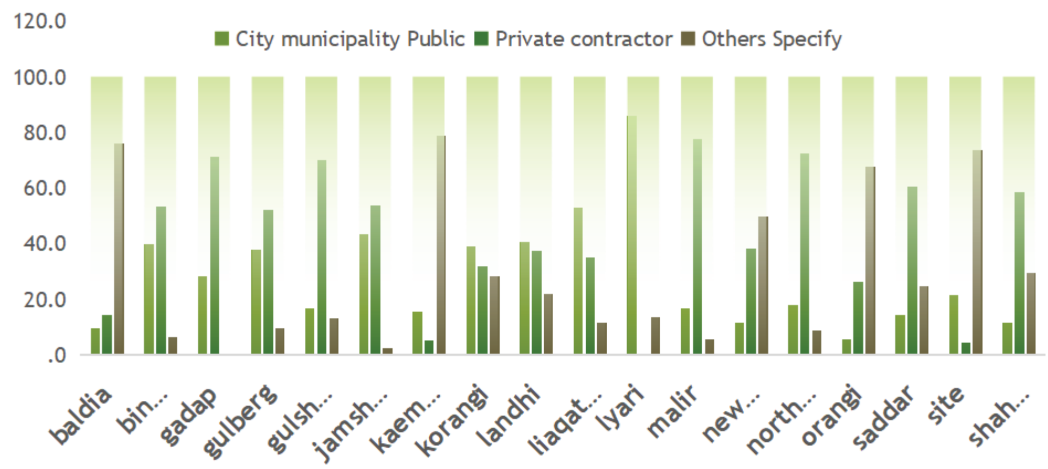
Household Socio-Economic and Demographic conditions

Basic information gathered during the household survey included solid waste management practices followed by households, their perceptions, behaviour, awareness, obstacles in handling solid waste, recycling and reuse activities (if any), recycling's prospects at the household level, households' expenditures on waste disposal, and household's willingness to spend on solid waste management.

A. HH Assessment of Waste Collection

Solid waste management in Karachi is in the hand of private contractors. The second largest waste collector is the informal sector (mainly Afghanis). Some part of the city is also managed by the city municipal system – DMC. The Lyari town is mainly managed by DMC, while the towns operated under complete informality are Baldia, Orangi, SITE, and Kemari.

Figure 3: Who Collects Waste from Households?

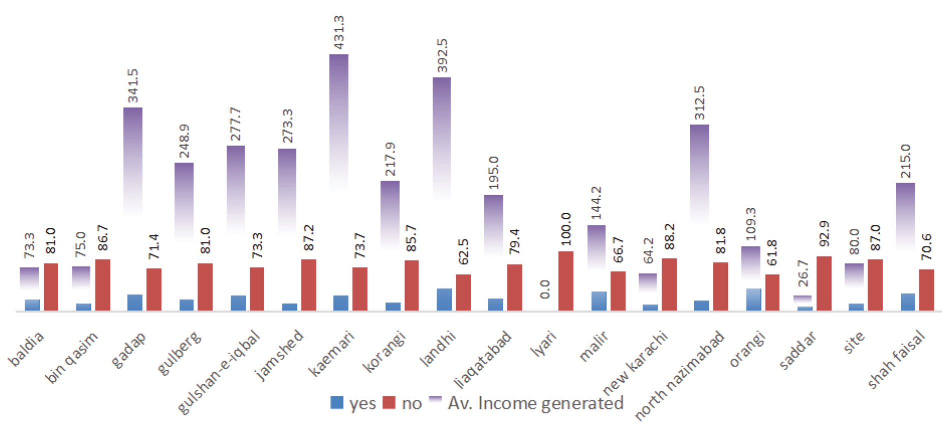


Source: Authors' estimations

B. Recycling and Reuse Activity

To evaluate the knowledge of the households regarding recycling three interrelated questions were asked. Figure 4 shows that households in Karachi were not only aware of recycling but also generated income through recycling. Households in Karachi generated, on average, Rs. 400 monthly from the sale of recyclable materials. The main recyclable materials are paper/cardboard, plastic, and metal.

Figure 4: Did the Household generate any income from the selling of waste?



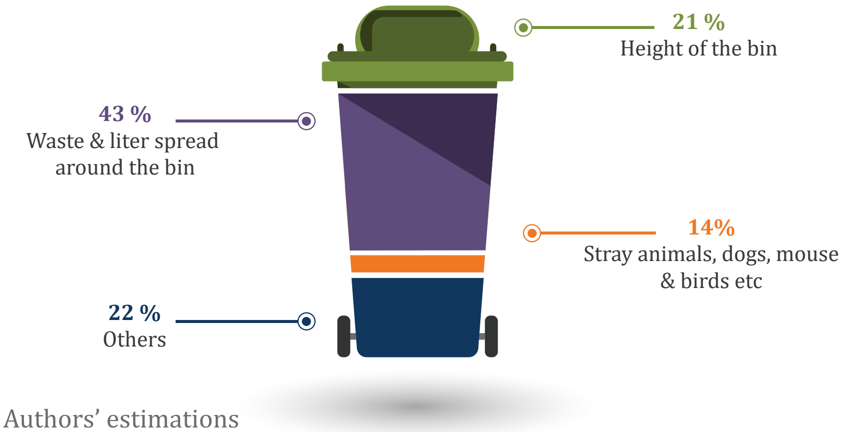
Source: Authors' estimations

C. Perception and Behavior Regarding SWM

- Households though were aware of the environmental consequences of waste but they still threw their waste alongside the bin.

- Around 43% of households reported that they threw the waste alongside the bin as the waste spread around the bin and the place was too smelly. Around 21% claimed that the bin was too high, while 14% claimed that they did not go near because of the animals around the bins.

Figure 5: Particular reseason for dumping outside bin



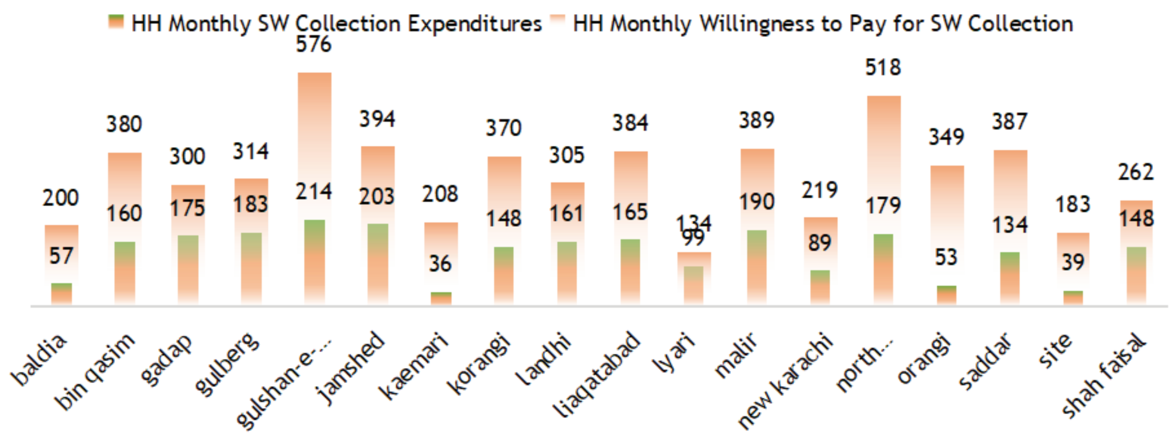
Source: Authors' estimations

- Further, surveyed households also showed their concerns regarding environmental degradation caused by waste.

D. Household Willingness to Pay (WTP) for Solid Waste

- Figure 6 shows the current expenditure household made on the SWM and what households were willing to pay for further improving the system by town.

Figure 6: Current Expenditure on SW collection and WTP



Source: Authors' estimations

E. Ability to Pay (ATP) vs. Willingness to Pay (WTP)

- The information regarding ATP and WTP is viable for policy designing. Policies formed without considering who will pay and how much ability they have to pay result in policy failure.

- Results show higher ATP than WTP for all the households in all towns of Karachi. The ATP was considered to be 1% of a household's disposable income.

Perception and Behavior Regarding SWM

A. Generation

Internal Factor	External Factor
Strength S-1: Households show their willingness to adopt environmentally friendly consumption. S-2: Awareness regarding the negative impact of SW mismanagement on the environment and health. S-3: Average earnings of households from the sale of recyclable waste is around Rs. 400 per month.	**Opportunities** O-1: There exists a wide scope for households to generate economic benefits from the sale of recyclable waste. O-2: Promoting paper bags or other degradable materials in daily transactions would contribute potentially to controlling SW generation. O-3: Individuals are concerned regarding waste management.
Weakness W-1: Statistics for industrial waste generation are not available for evaluation and monitoring.	**Threats** T-1: Growing population & uncontrolled migration influx

B. Collection

Internal Factor	External Factor
Strength S-1: Public-private partnerships through tendering for improving collection and controlling system informality. S-2: High ATP than WTP of HH in all towns in Karachi. S-3: Financial support received for SWM, nationally and internationally.	**Opportunities** O-1: Under the public-private partnership the government may utilise the informal network for efficient waste collection. O-2: Fundraising opportunities are available as HHs are willing to pay additionally for an improved SWM system. O-3: Profitable recyclable waste, if collected properly
Weakness W-1: Historically, responsibilities have shifted among federal, provincial, and local governments. W -2: Unclear duties and overlapping functions under the current structure W-3: Sub-contracting based on a personal relationship or under political influence	**Threats** T-1: Lack of interest in managing SW by stakeholders. T-2: Political influence in managing SW. T-3: Delay in waste collection exaggerates various health and environmental concerns.

C. Disposal Recycling

Internal Factor	External Factor
Strength S-1: Individuals agreed to segregate waste by type. S-2: Increasing industries for recycling, especially the informal ones, is contributing towards tackling and generating revenue from solid waste	**Opportunities** O-1: Segregated waste would expedite the recycling process as it can be directly sent to relevant recyclers. O-2: Around 20% of plastic waste collected is resalable, while only around 12% is currently sold. Further, through on the spot sorting of about 8 kg plastic, 10 kg paper, 8 kg cardboard, and 4 kg iron/steel collected daily is resalable and sold by the workers, while the workers claim that around 20% of the remaining waste is still resalable. O-3: Boosting the industrial recycling of food waste into animal feed could also be a potential revenue source.
Weakness W-1: Lack of coordination and connections between KMCs and informal pickers W-2: Informal dumping points: dumping of waste in the vicinity, streets, park, etc. W-3: Despite acknowledging the impact of SW on health and the environment, individuals behave reluctantly while disposing of their waste properly or in an environment-friendly manner. W-4: Untrained worker for collecting waste.	**Threats** T-1: Households don't bother where and how the waste is disposed of after collection from their houses. T-2: Lack of interest in managing SW by stakeholders. T-3: Lack of implementation of environmental legislation. T-4: Non-availability of standard procedures for disposal.

POLICY RECOMMENDATIONS

Based on the assessment study, the following conclusions and policy measures are recommended:

- The assessment highlighted that issues have been exacerbated by unclear duties, overlapping functions, and inadequate coordination among the numerous institutions responsible for solid waste management. The functions are largely divided between KMC and SSWAMB, resulting in a lack of coordinated planning and integration. There is a need to resolve the issue by clearly assigning the responsibilities; there should be only one authority responsible for the SWM.

- The assessment predicts high profitability from recovering recyclable material, mainly enjoyed by private contractors and informal workers. Given the profitability, the study recommends that the problem of solid waste management (SWM) can be dealt with by adopting policies for improved municipal solid waste services characterised by regular collection, timely transportation, careful disposal, and proper separation of recyclable waste.

- Households are concerned with the improved solid waste system and are ready to make efforts for it but for those who are reluctant to adopt sustainable waste management strategies, motivational aspects are needed.

WHAT IMPROVEMENTS IN PUBLIC TRANSPORT DO PASSENGERS VALUE THE MOST? EVIDENCE FROM ISLAMABAD, LAHORE, AND KARACHI

Ajaz Ahmed and David Palma

INTRODUCTION

Public transport is important to enhance cities' economic potential, generation of greater economic activity, and subsequent need for mobility and commuting. Public transport also helps people to rise out of poverty and overcome social exclusion (GOP, 2018). However, Pakistan lacks a decent and affordable public transport system. This issue is particularly serious in urban areas due to rapid urbanisation. Pakistan has a population of around 210 million, roughly 36% of which resides in cities which is expected to reach 50% by 2050 (GOP, 2017). Considering that a good public transport system is fundamental to the sustainable urban development of Pakistan, there is a need to transform Pakistani public transport into a more modern, sustainable, and effective one (GOP, 2018).

The existing public transport options in Pakistani cities are limited, disorganised, inappropriate, and inefficient, which have serious implications for citizens' mobility and productivity and social well-being (Adeel et al. 2016). While a handful of mass transit systems have been installed in Pakistani cities, they are not socially optimal due to expensive infrastructures and limited coverage (Qureshi & Huapu, 2007; Imran, 2009; Masood et al., 2011). This has led to greater use of car and taxi services, increasing the cost of mobility, but also worsening road congestion and pollution, and increasing gender and class inequality. A lack of a decent and affordable public transport system deters labour force participation and effectual use of time and human resources, having serious implications for individual workers, businesses, and overall society. The private sector has rushed in to fill the gap with ride-hailing services, which are relatively comfortable and efficient, but these services are unaffordable for low-income groups and, again, operate in a largely unregulated environment.

There is a lack of a coherent institutional framework for public transport in Pakistan (GOP, 2018) that can properly engage and facilitate the key stakeholders to design and implement an inclusive, affordable, and efficient public transport system. Therefore, there is a need to use more novel approaches such as the use of a market-based mechanism to incentivise the private sector to invest in bus rapid transit systems to make cities more inclusive, diverse, competitive, commuter-friendly, and liveable.

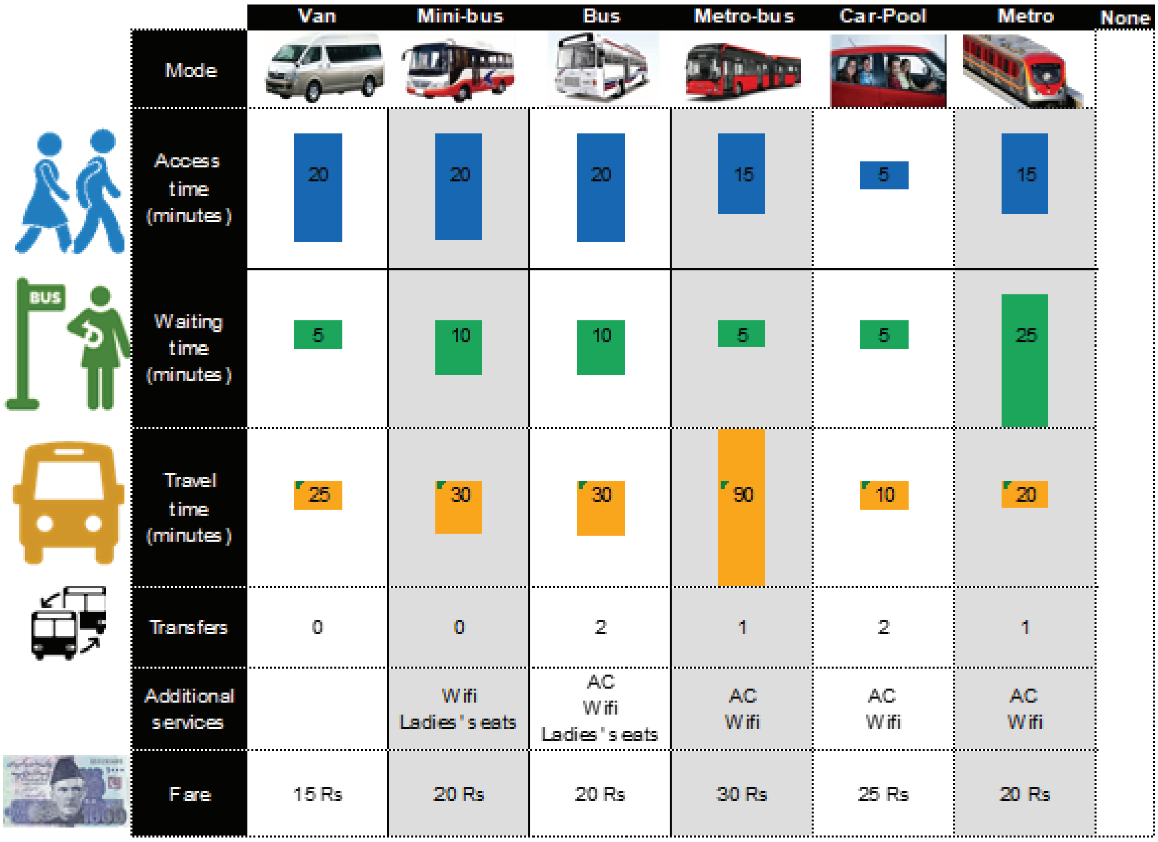
Using a stated preference survey and discrete choice modelling approach, this research investigated citizens' preferences and their willingness to pay for the key attributes of the public transport system in three major cities of Pakistan, namely Karachi, Lahore and Islamabad. The results of this research can help in designing economically efficient and socially optimal practical solutions to the problem of public transport using novel approaches such as market-based mechanisms based on the idea of economic incentive schemes, having the potential to transform urban mobility in Pakistan.

Special attention was given to the potential adoption of car-pooling systems in the three cities under study. Car-pool systems are usually implemented as digital platforms where car owners can offer rides to other users of the platform in exchange for a fee. Drivers do not operate as taxis, as they only offer to give rides within the vicinity of their usual commuting routes, or other trips they perform due to their activity patterns. In other words, drivers are only sharing their cars on their regular trips, not performing additional trips to serve others.

METHODOLOGY

A stated choice survey was designed and carried out in all three cities under study (Islamabad, Lahore, and Karachi). In the survey, the respondents faced four choice scenarios. In each scenario, the respondents had to imagine that they had to make a trip and had a series of different modes available to choose from, i.e., van, mini-bus, bus, metro-bus (Islamabad and Lahore only), car-pool, metro (Lahore only) or Qingqi (Karachi only). Each mode was described by six attributes: walking (also called access), waiting, and in-vehicle time (in minutes); the number of vehicle transfers within the same mode (e.g., changing from one bus to another); availability of services (air conditioning, free Wi-Fi internet access, and reserved seats for women); and the cost or fare for the trip. The respondents could state they would not travel under the given conditions. Figure 1 presents an example of a choice scenario. The respondents also answered a brief questionnaire revealing their main socio-demographic characteristics and travelling habits.

Figure 1: Example of A Choice Scenario (Each Respondent Had to Respond to Four Scenarios Similar to This)



The respondents' choices were analysed using a multinomial logit (MNL) model, as proposed by McFadden (1973) and discussed by Train (2009). This framework assumes that respondents have different levels of utility from each alternative depending on their attributes, and they choose the alternative that provides them with the highest utility. Negative attributes (e.g., a high fare) can be compensated by positive attributes (e.g., a short travel time). This framework is extensively used for analysing choice data and measuring preferences in multiple areas.

A total of 1,565 respondents participated in the survey, with 70% being male and 30% female (Table 1).

Table 1: Participants per City and Sex

	Islamabad	Lahore	Karachi
♂	408	360	326
♀	122	155	194
Total	530	515	520

KEY FINDINGS

The results of the analysis can be transformed into the willingness to pay (WTP) for attributes. These values represent how much an individual is willing to pay to enjoy a desirable attribute, or how much monetary compensation they need to endure an undesirable attribute. For example, a WTP of Rs X for air conditioning means that an individual is just as likely to choose any of two alternatives with the same characteristic, except for one of them having air conditioning and being Rs X more expensive. A positive WTP indicates that respondents are willing to pay to gain access to the corresponding attribute, while a negative one indicates that the respondents should be compensated with a lower price or travel cost if the attribute is present.

Figure 2 presents the WTP for an hour increase in travel time, for different modes, as well as for access (walking) and waiting time. All values are negative, as longer trips are undesirable. A higher negative value indicates that respondents using that mode value their time higher and, therefore, expect shorter travel times. In Islamabad, access and waiting time had the smallest WTP magnitude, which is unusual, but possibly caused by the pandemic, when individuals were weary of spending time inside vehicles with strangers. WTP Lahore showed a behaviour similar to other big cities of the world, where waiting and access time are considered more onerous than time spent in-vehicle, therefore, reaching higher negative WTP values. Qingqi had the most negative WTP in Karachi, probably due to this mode usually being employed for short (last mile) trips. Car-pool had a WTP of Rs-74, Rs-50, and Rs-67 in Islamabad, Lahore and Karachi, respectively, indicating that their potential users were willing to pay higher amounts for reducing their travel time, unlike potential bus users, whose WTP averaged only Rs-45 per hour. In line with the literature, most measured values are slightly lower than the minimum wage rate.

Figure 2: Willingness to pay for travel time increases (Rs/Hour)

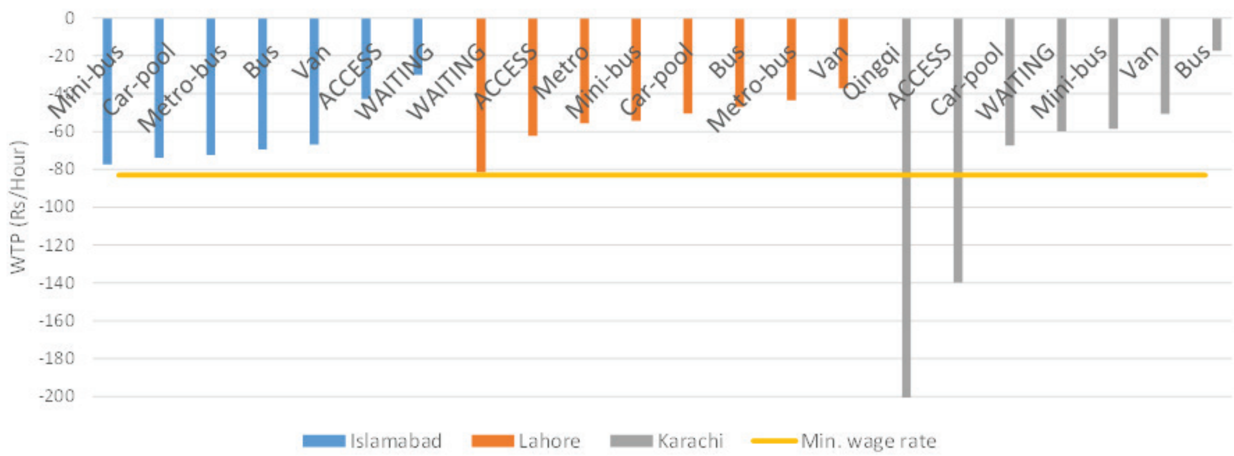
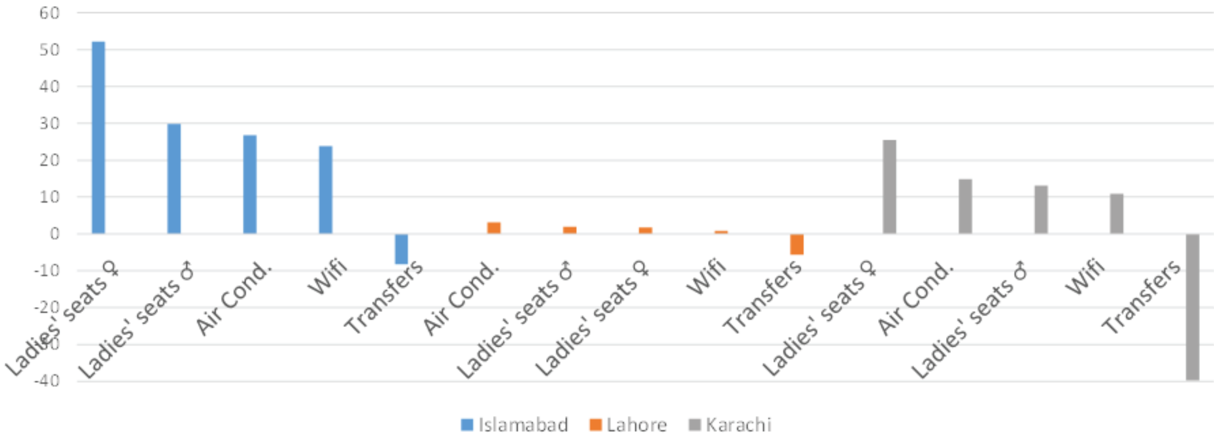


Figure 3 presents the WTP for additional services and transfers. These were the highest in Islamabad, followed by Karachi, and Lahore. Reserved ladies' seats among females were highly valued in both Islamabad and Karachi. This is a relatively simple and economic policy to implement, and it could attract a significant number of female users to public transport; it should be among the priorities when improving public transport in Islamabad and Karachi. Air conditioning and free Wi-Fi internet access were valued similarly, but with the second being significantly more economical to provide, it should be implemented before air conditioning. Finally, transfers were perceived very negatively by travellers in Karachi. This could be a problem if a more modern feeder-trunk public transport system is to be implemented. Feeder-trunk systems are structured in two layers: small buses that transport passengers to the main public transport corridors, where metro or Bus Rapid Transit systems carry a higher number of passengers. While efficient from an operational perspective, these systems do require users to transfer between buses or even between different modes (e.g., mini-bus to a bus, or bus to metro).

Figure 3: Willingness to Pay for Additional Services and Transfers



CONCLUSIONS

Karachi needs a better public transport system. Travellers are currently used to long trips. But implementing a better system would not be easy, as it would probably imply more complex trips with multiple transfers, something that travellers dislike in Karachi. Therefore, the new system should focus on reduced access and waiting times, as well as providing reserved ladies' seats if possible.

Results from Lahore show a behaviour typical of big cities with a more developed transport system, where access and waiting time are more onerous than in-vehicle travel time. Carpool systems could be implemented in the city to reduce the use of the car, as this city is the one that is most likely to adopt such a system.

Islamabad displays the biggest sensitivity to the provision of additional services while travelling. Adding air conditioning, Wi-Fi, and, especially, reserved ladies' seats in public transport could have a significant impact on increasing its use in this city.

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