Responsive Infrastructure and Service Provision Initiatives Framing Smart Environment Attainment in Nairobi

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Abstract This chapter will seek to document and profile various initiatives in infrastructure development and related services which are deemed smart. The chapter will focus on transport (mobility), water and solid waste management in Nairobi which are seen as either catalysts or potential in attainment of smart environment in Nairobi. Initiatives such as application of Information and Communication Technologies (ICTs) through Kenyan mobile, web and SMS platform, wants to address mobility, water access and waste management challenges in Nairobi. These three sectors are also considered key and basic to all *Nairobians* regardless of their social status, hence their understanding of how they are provided and accessed is key in understanding how smart approaches in their provision and use can have positive effects in meeting the elusive smart environment. The chapter discusses various initiatives in terms of infrastructure provided, services associated with those infrastructure and application of digital technology and how these are likely to support attainment of smart environment.

Keywords Nairobi · Smart environment · Smart mobility · Water · Solid waste management

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1 Overview

The goal of both the global and local commitments such as the Sustainable development Goals and Kenya's vision 2030 is to have sustainable cities that are not only functional and responsive to citizens needs but which also provide opportunities for all—including access to basic services such as water, transport and waste management—which are all geared towards making these cities environmentally clean. Integration of technology into different development sectors results in smart initiatives and offers unique opportunities for sustainable development in different countries. Smart infrastructure provides the foundation for all of the key themes related to a smart city, including smart people, smart mobility, smart water, smart waste management, smart governance and smart digital layers [1]. Attainment of smart environment status and negative pressures associated with urbanization are motivating cities in Africa (including Nairobi) to embrace Information and Communication Technologies (ICTs), which are the main drivers of smart solutions, and which enable such cities to deliver smart infrastructure and services that support attainment of smart environments. The immediate need for cities in developing countries is to provide responsive urban infrastructure to meet the increasing pace of urbanization. In the process of meeting infrastructure demands, smart infrastructure applications provide a way for such cities to achieve leapfrogging in technology [2].

This chapter documents and profiles various initiatives addressing infrastructure and service provision in Nairobi across three sectors—mobility (transport), water and solid waste management. The focus on these three sectors is due to their important role for the city's existence, as well as their ability to contribute significantly to carbon emissions, which is a big threat to attainment of smart living environments. The chapter also highlights some of the smart and ICT driven initiatives and strategies that are being applied in Nairobi, or which can be adopted to enhance efficiency in each of these sectors, towards attainment of sustainable and smart environments.

The enviable smart environment to be attained in this chapter is related to Cook and Das [3] understanding of the concept. They defined 'smart environment' as one that is able to acquire and apply knowledge about an environment and adopt to its inhabitants in order to improve their experience in that environment. They further note that intelligent automation can reduce the amount of interaction required by the inhabitants, as well as reducing utility consumption and other potential wastages [3]. It is out of this concern that this chapter is focusing on various initiatives in the transport, water and waste management sectors In line with technology application in these sectors frame's Nairobi inhabitants experience about attainment of smart environment.

2 Context of Smart Infrastructure and Services in Relation to Attainment of Smart Environment in Nairobi

Nairobi is the capital city of Kenya and an important economic, transport and ICT hub in Africa. Nairobi city was first established as a transportation centre in 1899 because it offered a suitable stopping place between Mombasa and Kisumu cities. Nairobi also had adequate water supply from the nearby Nairobi River and Mbagathi River [4]. The historical association of Nairobi with transport and water is critical in understanding how the city's transport and water infrastructure and associated services are provided and in particular how adoption of smart technology is shaping the provision of these basic services including solid waste management, as this is also one of the major service provision challenges facing Nairobi and other cities in Africa which are seen as hubs of innovations and modernization.

According to the 2009 population census report, Nairobi had a population of 3,138,369 and it is estimated to cover 694.90 km^2 with a population density of 4,516.29 persons/km^2. The Institute of Economic Affairs (2011) indicates that, Nairobi employed 25% of Kenyans and 43% of the Country's urban workers and it generated over 45% of the GDP by the year 2006 [5]. Nairobi's growing population size is both an opportunity and a threat to attainment of smart environment status. The Nairobi population is rich in terms of skilled labour which is critical for accelerated innovations associated with smart ideas in provision of infrastructure and services which eventually will lead to attainment of smart environment. The challenge associated with this growing population is the rapidly growing demand for mobility, water and waste management infrastructure and services which are increasingly becoming a threat to attainment of smart environment in Nairobi. Each of these elements are discussed in depth in the subsequent sections of this chapter.

3 Smart Mobility and Nairobi's Environmental Status

Smart mobility systems include mass transit systems as well as individual mobility systems that feature bicycle sharing, ride sharing (or carpooling), and vehicle sharing and, more recently, on-demand transportation. The availability of, and reliability of such systems in cities is a great asset in accessing other goods and services, but also plays a major role in promoting environmental sustainability due to their associated low levels of energy and space consumption, reduced traffic congestion as well as reduced pollution. This section focuses on the available mobility infrastructure options in Nairobi and how they can contribute to attainment of smart environments. Focus is put in three kinds of transport sectors—road, railway and air transport infrastructure systems.

3.1 Nairobi Mobility Infrastructure

a. Nairobi City Roads and Associated Infrastructure

According to the Kenya Roads Board (KRB) roads inventory and conditions survey conducted in 2009, Nairobi has a total road length of 14,719 km, 53% (7,730 km) of which are paved [6]. Based on the reports assessment of the roads status, 45% of Nairobi's roads are in either fair or good condition, while 55% are in poor condition (Table 1). The poor condition of majority of the city's roads is a major cause for environmental concern, particularly because these can lead either to driving in low speed using heavy gear, or driving in dusty environments, contributing to particulate high emissions of Particulate Matter (PM2.5).

The Nairobi City County Integrated Development draft plan 2018–2022 (CIDP) notes that the City has 300 km of non-motorized transport (NMT) facilities coverage, 39,000 street lights, 52 surveillance cameras, 22 traffic lights management systems (signalized junctions), 198 bridges, 41 overpasses (flyovers), 15 bus terminus and 96 city county traffic marshals, all of which are aimed at management of traffic and protecting and improving mobility through NMT [7]. The CIDP however still describes the current status of provided facilities as inadequate in terms of coverage to meet current and future demands as envisaged in the Vision 2030 [7]. Provision of NMT infrastructure supports green mobility modes such as walking and cycling, which account for nearly half of the city's modal share (Table 2). NMT infrastructure and modes promote environmentally friendly transport as they contribute to very limited amounts of air pollution, greenhouse gas emissions and have minimal noise pollution. Expanding provision of such NMT support infrastructure in Nairobi as envisaged in addressing the missing links identified in Nairobi Transport Masterplan in 2006 (NUTRANS) is likely to contribute significantly in attainment of smart environment in Nairobi city.

b. Nairobi Railway and Associated Infrastructure

Nairobi City has a railway network of 75 km and a total of 15 functional railway stations which are: Embakasi, Makadara, and Nairobi main terminal, Dandora, Githurai, Kahawa, Kibera, Dagoretti, JKIA, Syokimau, Makadara and Imara Daima railway stations. The expansion of Nairobi platform will help to improve public transportation in Nairobi for socioeconomic development [10].

According to the Kenya Railways Corporation (KRC), the Nairobi Commuter Rail Service (NCRS) development is formulated as part of Nairobi Metropolitan Transport Master Plan with the aim of integrating rail transport with other modes of transport, more so road and air transport. The project will be developed in three (3) phases [11] (http://krc.co.ke/nairobi-commuter-rails/).

Phase 1: This will be developed within the existing railway corridors to provide commuter rail services between Nairobi Railway Station and the following destinations: Ruiru, Syokimau, Jomo Kenyatta International Airport, Kikuyu, and Embakasi Village. This development includes the building of 26 new modern passen-

Table 1 Road length and conditions in Nairobi City

Paved road condition	Length in Km	Percentage of paved	Unpaved road condition	Length in Km	Percentage of paved	Cumulative condition	Cumulative (km)	Cumulative percentage
Excellent	13	0.2%	Excellent	12	0.2%	Excellent	25	0.2%
Fair	2,753	35.6%	Fair	1,593	22.8%	Fair	4,346	29.2%
Good	1,819	23.5%	Good	527	7.5%	Good	2,346	15.5%
Poor	3,145	40.7%	Poor	4,857	69.5%	Poor	8,002	55.1%
Total	7,730	100.0	Total	6,989	100.0	Total	14,719	100.0

Source Kenya Roads Board, Roads Inventory Data [6]

Table 2 Modal share in Nairobi

Reference	Public transport (%)	Walking (%)	Cycling (%)	Private car (%)	Train (%)	Institutional bus (%)	Others (%)
NUTRANS 2005 [8]	32.7	47.1	1.2	15.3	0.4	3.2	0.2
JICA 2006 [9]	36.0	47.0	–	16.5	0.4		

ger handling stations at the existing railway stations and at new locations. Syokimau, Makadara and Imara Daima railway station are complete and operational.

Phase 2: This development will also be within the existing railway corridor and will extend commuter rail services to: Thika, Limuru, and Lukenya.

Phase 3: This development will be within new railway corridors and will target the outlying satellite towns such as: Ongata Rongai, Kiserian, Ngong, Kiambu, Ruai and Kangemi.

While the commuter rail system has great potential for providing smart mobility solution to Nairobi residents and visitors, the main challenge has been the slow pace of expansion of the rail infrastructure as well as limited modernization of the stations in an integrated manner. This has made railway transport unattractive to various people using other modes of transport, with particular preference for small-capacity bus transport options which are a threat to smart environment. It is however noted that expansion of the rail lines and modernization of the stations is still one of the most feasible strategies of the city realizing its dream of Mass Rapid Transit (MRT) which has a great potential of operationalizing High Occupancy Vehicles (HOVs), which is a contributor to attainment of smart environment.

c. Airport and Associated Infrastructure

Nairobi city hosts 3 airports; Jomo Kenyatta International Airport, Wilson Airport and Eastleigh Airport. Jomo Kenyatta International Airport (JKIA) is the biggest Airport in East and Central Africa, and is the focal point for major aviation activity in the region. Its importance as an aviation Centre makes it the pacesetter for other airports in the region. JKIA, located 18 km to the East of Nairobi City centre, is served by 49 scheduled airlines. JKIA has direct flight connections to Europe, USA, the Middle East, Far East, and many parts of Africa. JKIA has five cargo facilities with a capacity to handle 200,000 tonnes of cargo annually, and an animal holding facility which occupies 4,318.95 square feet. The Airport has a runway measuring 4,117 m long and 45 m wide on 4,472.2 ha of land [10]. Wilson Airport is the second airport in the County. It has two runways one that is 1,463 m long and 24 m wide while the other is 1,558 m by 24 m with displaced threshold giving a landing distance of 1,350 m [10].

One of the notable challenges facing access and mobility to Nairobi's main airport (JKIA) is poor integration of transport modes. Proposals to link the airport with commuter train services and Bus Rapid Transit (BRT) will help in addressing this major transport missing link. The recently proposed installation of a solar powered cargo facility owned by Swissport Kenya limited and in terminals A, B, C and D of JKIA is a major footstep in enhancing environmental friendly footprints in the transport sector. This will enhance use of renewable energy, which is environmental friendly which is fully supported by Kenya's Energy Regulatory Commission (ERC).

3.2 Nairobi Mobility Services

Nairobi experiences heavy traffic congestion in most roads especially during the morning and evening peak hours. This can be attributed to the increasing number of private vehicles in the city. Between 2004 and 2013, private cars in the city of Nairobi increased from 147,387 to 253,298 cars, representing a 70% increase. In 2014, it was estimated that 46,000 vehicles passed through the city to other destinations on a daily basis; and that 84,000 vehicles moved into the city while 86,000 moved out of the city on daily basis [12]. The rapid growth in the number of private cars is purely attributed to lack of reliable public transport, hence a sizeable portion of the residents opt to invest in owning a private car for trips which could easily be undertaken by public transport. These high numbers of low occupancy vehicles contribute greatly to air pollution through emission of greenhouse gases, which is more significant during peak hours.

Nairobi city, just like many other African cities lacks real public transport services that are purely operated by Government. In Nairobi, apart from Nairobi Commuter Train Services and the a few buses operated by the National Youth Service (NYS), most of the residents rely on privately owned and managed public transport services (para-transit services) commonly known as *matatus*. Currently Nairobi city is lacking public scheduled buses, Bus Rapid Transit (BRT) and Light Rail Transit (LRT) but there are proposals introduce them in the very near future, as provided through establishment of Nairobi Metropolitan Area Transport Authority (NAMATA), which was created through the presidential order, under the legal notice 18 of February 2017.

Motorcycle taxi commonly known as *bodaboda* is also an emerging feature of Public Service Vehicles in Nairobi. Other forms of mobility in the city include the use of the three wheeled auto rickshaw commonly known as *Tuktuk* and use of traditional taxis.

Over the past decade or so, several smart mobility services have emerged in the city of Nairobi, with a cumulative effect of eased movement for commuters. Some of these services include e-hailing taxi services, traffic notification applications, cashless travel services among others as discussed below. Each service targets a unique market in the large pool of commuters, and has varying levels of convenience and cost implication on the user.

(a) Application of E-Hailing Taxi Services

ICT is an integral part of smart transportation [13]. Current exploitation of information technologies especially in application of mobile Apps in booking transport services including e-hailing taxi services (such as Taxify and Uber) and car-pooling is changing mobility patterns and options especially for the middle and high income earners in Nairobi who are able to pay for the services and associated conveniences. With internet usage in Kenya projected at over 67%, these ICT capabilities are primary inputs to smart mobility [14]. Such e-hailing services are likely to increase road safety and reduction of private cars moving one individual on the road, hence increased passenger capacities (car-pooling) which will further contribute to reduction in pollution and ultimately lead to attainment of smart environment. Such services are being extended to motorcycles and even online booking of long distance travel buses which reduces unnecessary movements, with a cumulative positive effect to the condition of the environment.

Other E-hailing related applications such as Ubabi Vanpooling society, which is a startup that offers a vanpooling solution for people who go to work in locations close to each other and those who leave work at relatively the same time, can vanpool to and from work. The Society was formed in response to a need to reduce traffic congestion in the City of Nairobi through encouraging private vehicle owners to leave their vehicles at home [15].

Another smart mobility technology is exhibited by Autotruck E. A Limited, which is a green technology company that fabricates and locally assembles electric powered three-wheeler light duty cabs and handcarts. It is set to reduce harmful emissions into the environment while offering taxi services and light transportation in African cities. The Ubabi vanpooling society and Autotruck E. A. Ltd are all part of 6 startups hosted by University of Nairobi C4dlab with the aim of achieving Transformative Urban Mobility Initiative (TUMI). From the orientation and focus of these two startups, the end result is to attain smart environment through various mobility technology and services.

(b) Digital Matatu

Digital *matatu* is based on data collection using GPS-enabled cell phone applications, which are used to generate valuable information that allows for the development of way-finding tools, both digital and analog, for transit users in the *matatu* (para-transit) sector. The application of the digital matatu is important for reducing movements, trips and time spent by passengers in locating various terminus facilities and bus stops, and in accessing and using of matatus within the city of Nairobi which lead to promotion of smart mobility which contributes positively to attainment of smart environment.

(c) Cashless Transport Fare system

This system was introduced to both regulate pricing for public transport services in Nairobi, and to also increase efficiency and convenience for commuters, who would load bus fare to special cards and use these to pay for individual trips. The cash-less fare was as a result of the then newly formed National Transport and Safety Authority (NTSA) published regulations instructing all Matatus to introduce and implement cashless fare systems as part of reform agenda for all Public Service Vehicles in Kenya in 2013 [16]. Beyond this, the cashless fare system was a good way of reducing paper money transaction and demand for such which in itself is a contributory factor to clean environment which indeed is a step towards attainment of smart environment.

The service was given special attention due to the choice by Matatu Owners to implement the next generation cross-platform for all Matatus. However, although the system had huge potential for improving services and creating order to both the passengers and the PSV operators and owners, it did not go far as its implementation by the matatu owners was only meant to conform to the requirements of the NTSA regulations.

(d) Proposed Mass Rapid Transit

There is a proposal by World Bank and other agencies to have a Mass Rapid Transit system in Nairobi to deal with growing mobility demand and to address the congestion the City is facing as informed by the demand forecasts in terms of peak hour peak direction traffic (PHPDT). Some of the proposals currently being discussed include 5 Bus Rapid Transit (BRT) corridors and a Light Rail Transit (LRT). The Nairobi Metropolitan Area Transport Authority (NAMATA) was formed purposely to provide for an integrated and sustainable public transport system within the Nairobi Metropolitan which covers 5 counties namely; Nairobi, Kiambu, Machakos, Kajiado and Murang'a.

The relevance of the mass rapid transit system in smart environment is that such systems support efforts geared towards lower energy consumption in terms of increase in fuel use efficiency and reduced greenhouse gas emissions per passenger per kilometer which is associated with high occupancy vehicles. This therefore shows the potentiality of attaining smart environment when this route is followed and embraced.

Other mobility issues related to land use are well articulated in the Nairobi Integrated Urban Development Master Plan (NIUPLAN) which is the first deliberate attempt to integrate land use in transportation planning in Nairobi. It also emphasizes on modal integration which are important contributors to efficient and sustainable mobility which are all key contributors to attainment of smart environment.

4 Smart Water Infrastructure and Services in Nairobi

This section begins with a description of the background to water and infrastructure and services provision. It then describes the current water infrastructure and service situation in Nairobi. This culminates in the analysis of the current water supply and demand nexus in the city. The section further describes various policy and legal interventions before looking at various WIS policies in the National Development plans in Kenya. Challenges facing water service provision in Nairobi have been described before immersing into smart water supply, use and management. The section goes on to outline the application of smart water technologies in Nairobi. Finally, the section ends with a conclusion and recommendation of achieving smart water infrastructure and services in Nairobi.

4.1 Background to Water Infrastructure and Service Provision

Various efforts to water infrastructure and service provision have advanced the supply, demand and market equilibrium as well as the provider and enabler approaches. The provider approach includes massive water infrastructure and service provisions by governments. The enabler approach, on the other hand, is geared towards mobilization of the private sector. The Kenya government from independence in 1963 adopted the provider approach to the provision of Water Infrastructure and Services However, it could not on its own meet the water infrastructure and services needs of a rapidly growing population. The shift in focus gradually led to commercialization and privatization of basic services including water [17].

Smart water infrastructure and services are necessary to avoid service disruptions and bottlenecks, and to also support a range of activities. However, it requires very high capital investment which is way beyond the means of urban residents. This gap makes the provider approach the viable option. Deliberate smart water infrastructure and services in an environment of other underlying factors is prerequisite to sustainability. The impacts of smart water infrastructure and services is the positive contribution that it can make to improve the other dimensions such as social, economic and environmental sustainability. Without embracing Smart water infrastructure and services may cause loss of opportunities to advance socially, economically, technologically or culturally [18].

The current initiatives towards water service provision in Nairobi are mainly twofold: development of new water projects, and enactment of policies and laws on better use and management of water resources. The first initiative includes several activities to increase water availability to the city, so as to bridge an ever increasing demand-supply gap. The ever-rapidly rising city population due to immigration and natural births in the city makes planning for water systems a herculean task. The city's water projects have exacerbated serious social, economic, environmental and even political ramifications to the counties. From the current supply of 444,500 cubic metres of water per day to the city, it means 40% which amounts to 178,200 cubic metres per day is lost. Accounting for the losses would have avoided further development of new schemes. Unfortunately, the losses continue to increase in absolute terms as the water demands increases.

The other initiative includes enactment of policy and laws to enable better use and management of water resources. International policies including the Sustainable Development goals (SDGs) identify access to water as a basic human right, while the World Health Organization (WHO) standards stipulate minimum standards for clean water. This is echoed in the Constitution of Kenya, Chap. 6 on the Bills of Right which states that "every citizen has a right to clean water" (Kenya, 2010). However, policy, legal and institutional initiatives have not comprehensively resolved the water problem in the city. The Water Act was enacted in 2002 to provide a framework to address the challenges of management of water supply in the country. The Act provided in its framework, various institutions at the national, regional and local

Table 3 Main water sources in Nairobi

S/no	Water facility	Details
1.	Thika Dam	Located in Ndakaini (Thika District). Completed in 1994 Utilises water from Thika river but is also linked to chania river through a 4 km tunnel which serves Ngethu Storage capacity is 70 million m^3
2.	Ngethu water works	Located in Gatundu North. Ngethu Phase 1: Commissioned in 1974, nominal design output is 61,000 m^3/day Ngethu Phase 2: Commissioned in 1984. Nominal design output is 157,000 m^3/day Ngethu Phase 3: Commissioned in 1997. Nominal design output of 222,000 m^3/day. Ngethu treatment plant is designed to produce a rated nominal output of 440,000 m^3/day of potable water (production)
3.	Sasumua Dam	Located in Njambini, Nyandarua. First stage completed in 1955 and second in 1968 Dam on Sasumua River but receives Kiburu and Chania waters Storage capacity is 15.9 Million m^3. Pipeline to Kabete is 60 km. Design yield is 59,000 m^3/day Current yield is 59,533 m^3/day
4.	Ruiru Dam	Located in Gthunguri, Kiambu Completed in 1950 Dam is on Ruiru River Storage Capacity is 2.90 million m^3. Pipeline to Kabete is 25 km Stores raw water with yield of 21,600 m^3/day The current yield is 19,343 m^3/day
5.	Kikuyu springs	Springs near Magana Flowers in Kikuyu. Has three springs Treatment is by chlorination only The yield is 4,000–5,000 m^3/day Pipeline to Nairobi is 10 km

Source NCWSC [51]

levels. Water Service Providers (WSPs) have the responsibility of providing water and sewerage services at the local level. This is the basis of creating the Nairobi City Water and Sewerage Company (NCWSC) (Table 3). On the other hand, Water Services Boards were created by the Act at the regional level to develop new water and sewerage infrastructure. This is the case of Athi Water Services Board (AWSB) which serves Nairobi and the neighbouring County of Kiambu. Despite the water sector reforms, the city of Nairobi City has over the years been experiencing, and still experiences serious shortage of water supplies. Even with the enactment of Water Act 2016 in line with the Constitution, the problem of water in the city of Nairobi still remains unresolved. Implementation of innovative technological solutions should be considered as a core component in the introduction of smart water services in Nairobi.

Table 4 Total current water supply to Nairobi with 444,500 cubic meters per day

Source	m^3/day
Thika (Ndakaini Reservoir)	360,000
Sasamua reservoir	60,000
Ruiru reservoir	20,000
Kikuyu springs	4,500
Total supply	444,500

Source NCWSC [51]

4.2 Water Infrastructure and Service Situation in Nairobi

From Kenya's independence in 1963 until the 1970s, the main source of water for Nairobi was the Kabete project. The first and second Nairobi water supply projects (WS I and WS II) developed the new Chania Scheme to improve and expand the distribution of treated water. The third Nairobi water supply engineering project which was commissioned in 1985 realized the Thika dam. The dam has a storage capacity of 70 million cubic meters. With the two water projects, the gross water availability increased from 165 to 200 litres per capita in the period from 1976 to 1995 [19]. The supply generally matched the demand though the population had increased threefold during the same period. The fourth project which is ongoing is the Northern Collector Project (NCP). This new project aims to serve the city of Nairobi and 13 satellite towns up to the year 2035. The NCP aims at tapping about 40% of flood water to ease some of its adverse effect to the environment. NCP will provide an additional 140 million litres of water to the city and its environs. The distribution network for the city of Nairobi receives treated water from Kabete, Kyuna, Kiambu and Gigiri reservoirs. The distribution area is segmented into 13 zones based on the reservoir supplying the water to the zone. Pipes are densely installed in the Western area of Nairobi City and sparsely installed in the Eastern area [19]. Figure 2 presents a diagrammatic view of the water sources and production capacities for Nairobi.

4.3 Current Water Supply and Demand Nexus in Nairobi

According to the water resources management authority (WRMA 2010), Nairobi City County has a water deficit of approximately 200,000 cubic meters per day. The current estimated water demand for Nairobi is 650,000 m^3/day compared to the production of 482,940 m^3/day [20]. According to Athi water services Board (AWSB), the city depends on supply from five water sources, with the bulk of water supply coming from Thika, Sasumua and Ruiru Dams. The other source is the Kikuyu Springs. In 2014, these projects supplied the city of Nairobi (Table 4).

Table 5 Water demand forecast

Year	Water demand (m^3/day)	Water supply (m^3/day)	Gap (m^3/day)
2000	363,400		
2005	450,200		
2010	557,700	444,500	113,200
2020	806,600	444,500	362,100

Source NCWSC [51]

From Table 5, it is clear the water demand is rapidly rising against a fixed supply which has led to water supply rationing in the city. An Environmental Impact Assessment carried out by AWSB in 2009 revealed that 50% of Nairobi's population living in informal settlements, have water consumption of about 34, 500 m^3/day. This amounts to only 8% of NCWSCs total daily supply to Nairobi City. The report by AWSB (2009) also indicates that about 75% of the city residents get water from pushcart vendors and kiosk resellers. According to the report, the vendor's prices ranged between KES 5 and KES 10 per 20-liter plastic jerry can. This amounted to between KES 250/m^3 and KES 500/m^3, with an average of KES 375/m^3 which is 7 times more than the official regulated rate of KES 53/m^3 for domestic consumers.

4.4 Legal Intervention

The Kenya government embarked on improving access to safe and clean water right from attainment of independence. The main theme initially was "water for all by the year 2000", however, the government missed the target and only an estimated one million out of a total population of 31 million had access to clean water in the year 2000 [21]. To overcome the problems in the previous water Act 372, the government moved towards commercialization of WIS services in line with the structural adjustment programmes through enactment of water Act 2002. The Act provided for the conservation, control, appointment and use of water resources in Kenya. The Water Act 2002 favoured commercialization which required that local authorities form autonomous water and sewerage companies with independent boards of directors to provide water services. The revenue received from water sales was expected to be reinvested in WIS service improvement. However, in line with the Kenya Constitution of 2010, the Water Act 2002 was repealed and replaced with Water Act 2016 which was aligned with the constitution.

4.5 Challenges Facing Water Service Provision in Nairobi

The City Momentum Index (CMI), developed by [22], rated Nairobi as number ten in the globe and as the most dynamic city in Africa. While innovation and technology were some of the determinants used to rank the cities, the technologies have not been holistically embraced in the water sector. Despite the ranking, Nairobi is facing serious water supply, use and management challenges more so involving water mismanagement arising from old and dilapidated infrastructure, poor billing systems, and illegal connections. According to Republic of Kenya [23] the main challenges facing water infrastructure and service provision are; control of unaccounted for water (UfW), Inefficiencies in old and dilapidated distribution network and demands for water & Sewer rehabilitation and expansion. Other challenges include old billing and customer management system that have inherent functional problems that hamper efficiency in operations and manual operational processes. Other challenges cited by NCWSC are obstruction and encroachment on to way leaves for water and sewer lines. For example, there are structures built on top of water and sewer lines. Also cited are problems of Illegal water and sewerage connections, destruction of sewer manholes to access sewerage for farming and staff over-establishment of over 500 employees. Political interferences, Massive Rural—Urban migration and Massive unplanned developments have also been cited.

4.6 Smart Water Supply, Use and Management

Shahanas and Sivakumar [24] Describes Smart water as a combination of intelligent water infrastructure with data analytics in a way that leads to actionable information [24]. Choi et al. [25] Defines a smart water city as a city that uses integrated water resource management together with smart ICT technologies. Integration can promote coordinated development and management of water, land and related resources. As a result, it can maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. According to Britton et al. [18], the architectural components of an ISWM includes stakeholder integrated information system (SIIS), decision support system (DSS), and ICT infrastructure and control.

Smart Water Management is a water management strategy capable of integrating and managing the entire process of the water cycle from analysis of current situations to purification, distribution, as well as using and recycling of water resources scientifically and systematically [25]. Ensuring adequate provision of water to city users is a major challenge, especially in regions experiencing a sustained high influx of urban residents and high per capita consumption. As clean and safe water is fundamental to any socioeconomic development, city leaders need to adapt smart water management and their reliance on technologies to support sustainable development and cater for rapidly growing water needs [26].

Smart Water Infrastructure has the potential to contribute significantly towards improved service delivery and efficiency of water services providers; reducing costs and water losses, streamlining operation and maintenance, and improving data and asset management in Water Service Providers, allowing for information-based decision making [27]. Smart Water Service entails improving water efficiency for the benefit of the city and its residents [26]. This is through using data and technologies as enablers, to increase efficiency of irrigation networks and reuse of water, allow for deferred investment in water production plants and optimization in pipe renewal, as well as preserve water resources by enhancing leakage management and enabling demand response programs (Veolia, n.d.).

Smart Water Service if applied in Nairobi would help curb the current unaccounted-for water crisis by managing leakages and reservation of water sources. Some of the smart water initiatives that have been implemented in Nairobi include smart water metering, and integration of various technologies for enhanced water systems as discussed below.

(a) Smart Water Metering (AMR/AMI)

Smart metering is a component of the smart water management that allows a utility to obtain meter readings on demand (daily, hourly or more frequently) without the need of manual meter readers to transmit information. Smart Metering has three components:

Automated Meter Reading (AMR) is a technology that automatically collects consumption data from a water meter or energy metering device [28]. This data is used for billing purposes; to Analyses usage and manage consumption, and to identify or resolve technical problems. AMR systems promote more cognizant water usage by revealing exactly how a site is using resources, and where reductions can be made to improve efficiency and lower costs. AMR continually gathers data and can provide this information on a real-time basis. Usage data can be viewed at any time, and once collected, is immediately stored in a repository of historical consumption information for comparative or analysis purposes.
Automated Metering Infrastructure (AMI) a fixed network system, with smart meters providing two-way communications between the water meter and the utility [27]. AMI improves the efficiency of water utilities and eliminates the costs of routine meter reading. Combined with GIS meter data management, AMI increases the accuracy and precision of the meter reading and reduces re-reads. The result is an accurate and timely readings that are ready for billing, with an identification of failed and failing meters before actual billing, improving the utility's cash flow.
Automated billing system involves taking the meter number and generating a bill for that meter by use of the database information collected from the meter reading [27]. When installed in Nairobi it would help in achieving SWM by reducing cases of billing errors thus making the system efficient.

According to Arniella [27] smart meters can benefit the water utility, the environment, and the utility's customers by: Lowering the cost of meter reading by eliminating manual meter reading; Enhancing employee safety by reducing the number

Fig. 1 Automated meter. Source KAPS [29]

of personnel on the road; Reducing billing errors and disputes; Monitoring the water system in a timely manner; Enabling flexible reading schedules, reducing delays in billing of commercial accounts; Providing useful data for balancing customer demand; Enabling possible dynamic pricing; Benefiting the environment by reducing pollution from vehicles driven by meter readers; Assessing Non-Revenue Water in real time or short intervals; Facilitating the data to establish the night water consumption patterns, analyzing the minimum night flows (MNF), and offering a more detailed feedback on water use patterns; Enabling customers to adjust their habits to lower water bills; Providing real-time billing information, reducing estimated readings and re-billing costs; Reducing customer complaint calls and increasing customer satisfaction; Improving the monitoring of potential meter tampering and water theft; and Detecting water line leaks sooner, so they can be repaired faster.

While smart meters have many benefits, they also present challenges to water utilities, customers, and the environment. Installation of these require Front-end capital investment; Long-term financial commitment to the new metering technology and related software; Ensuring the security of metering data and preventing cyber-attacks; Transitioning to new technology and processes with proper training; Managing public reaction and customer acceptance of the new meters; Managing and storing vast quantities of metering data and Disposing of the old meters.

Kenya Airports Parking Services (KAPS), Smart Water Metering System (SWMS) is the first of its kind in Kenya. According to Kenya Airports Parking Services (KAPS) [29] (Fig. 1), a Smart meter design for a SWMS is basically made of three building blocks:

Advanced/automated metering infrastructure(AMI)
Automated Meter reading(AMR) devices
Automated Meter Management(AMM) platform.

KAPS brings out the concept of automated meter management platform. This platform brings together the benefits of simplified water reading with the ease of managing data. KAPS has used a customer-oriented simple interface where; the water utility company can perform all technical measurement settings and customize functionalities of the system to suit their requirements. Finally, the customer can be able to log in and view analytical data of their water consumption [29].

(b) Internet of Things (IoT) for Smart Water Infrastructure and Services in Nairobi

The Internet of Things (IoT) refers to the use of intelligently connected devices and systems to leverage data gathered by embedded sensors and actuators in machines and other physical objects. [30] Points out that the definitions of the IoT vary depending on the context, the effects and the views of the person giving the definition. However, most of the definitions related to this vision have much in common, such as, the ubiquitous nature of connectivity, the global identification of everything, the ability of each thing to send and receive data across the Internet or the private network they are connected into [30].

The IoT application provides an efficient control and monitoring approach for water utility in order to reduce the current water loss. IoT uses internet and web-based applications that can help water utility operators improve water management systems. The IoT could prove to be one of the most important methods for developing more utility-proper systems and for making the consumption of water resources more efficient. Water demand in Nairobi has continuously increased over time arising from factors like population growth, spatial growth of the city or even lifestyle changes.

The solutions to the water problem in Nairobi are twofold. First, is supply-oriented solution that identifies and exploits new water sources. This has been the practice in Nairobi with new sources being more than 50 km from the city. If this trend continues the next sources will be from Mt. Kenya about 150 km away or even Lake Victoria 400 km. This of course has its own socio economic and environmental challenges. Secondly, is the demand-oriented solution that would consist smart exploitation, use and management of scarce water resource [31]. Reporting for the business daily, and further observed by the CEO of NCWSC, automated metering devices, are to be installed for the top 10,000 water users. NCWSC aims to connect 90,000 of its quarter of a million customers to the smart meters in five years, hoping to rid its system of illegal connections and inaccurate billings. However, Connecting 90,000 of a possible 250,000 water consumers against a population of 4 million is an indication that the problem is far from being solved. The missing link is the about 60% residents in informal settlements who have no connections and therefore do not pay for water. Moreover, procurement and installation of such meters require embracing a holistic approach that integrates different aspects of smart WIS.

There are two important characteristics associated with recent trends in water supply management; Functional integration and geographical distribution. These elements must be connected and automated in a proper way so that the entire system can be operational and functional. This would best done through innovations like the IoT. IoT can be used to enable real time water quality monitoring system.

Water quality monitoring is defined as the collection of information about the physical, chemical and biological characteristics of water at set locations and at regular intervals in order to provide data which may be used to define current conditions, establish trends, etc. [31]. Water quality is affected by both point and non-point sources of pollution, which include sewage discharge, discharge from industries, run-off from agricultural fields and urban run-off. Other sources of water contamination include floods and droughts and due to lack of awareness and education among users. The need for user involvement in maintaining water quality and looking at other aspects like hygiene, environment sanitation, storage and disposal are critical elements to maintain the quality of water resources. Main objectives of online water quality monitoring include measurement of critical water quality parameters such as microbial, physical and chemical properties, to identify deviations in parameters and provide early warning identification of hazards. Also, the monitoring system provides real time analysis of data collected and suggest suitable remedial measures [32].

(c) GIS application for Smart Water Infrastructure and Services in Nairobi

Geographic information systems (GIS) are an organized collection of computer hardware, software, and geographic data, supported by trained personnel to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. GIS operates primarily on spatial data but also include events and specific data [27]. One of the most applications of GIS is network analysis where the geographical phenomenon is analyzed in context of network such as streets, water network pipe, telephone and electric line and so on.

GIS technology can be used to achieve optimum management of water in Nairobi. Mapping of water resources is therefore increasingly important for effective water utility planning, use and management. Access to sufficient information of urban water distribution network is very difficult majorly because the establishment of urban water network is underground. Geo-referencing of the underground utilities and saving them in GIS geodatabases is the best way of locating them. Priorities in water management start with basic information; data is collected, imported, saved and managed in GIS [33]. Secondly, the water distribution networks are modeled and analyzed using GIS network analysis tool. Supported with comprehensive data, GIS is a very powerful technology for analyzing water utilities in critical conditions.

Water quality assessment with aid of GIS and IoT, are powerful tools for establishing relationships on water quality between impacts due to natural as well as human activities and their effect. GIS can be applied to analyze selected indicator parameters of existing water quality data. The analyses results show that some of indicator parameters of the water sources and distribution are spatially or regionally variable while others are randomly distributed [34]. Interpretations and assessments of these results then assists in getting information with respect to water quality conditions and status of sources and distributions [33]. This information may be used for implementing control measures and improvement to be in place.

(d) ICT Application to Smart Water Infrastructure and Services in Nairobi

As Kenya gears itself towards meeting Vision 2030 goals, scarce water resources in Nairobi puts pressure on the capital [35]. Finlay et al., goes on to point out that the application of ICTs in water management would need to employ both mobile technologies used at the local level, and the roll-out of broadband infrastructure which together would hold strong potential for water management. According to

Ndaw [36], potential benefits of integrating ICTs in water and sanitation projects as has been achieved in Nairobi are as follows:

Reduces the duration and costs of monitoring and inventory activities. Accurate data and information management systems are a precursor for sound management and decision support systems.

Improves efficiency gains of water service providers. ICTs can enable shortened response time, reduce travel distance and maintenance costs, optimize operations (production costs, energy efficiency etc.) and improve quality of service.

Improves collection rates of water service providers through ICT based-payment systems. Some of the most common ICTs adopted by utilities are e-payment systems which offer payment facilitation and increased reliability in billing and payment recovery, reduced administrative and payment transaction costs, and improved revenue collection. The Kiamumbi Water Trust (KWT) in Kenya established an M-PESA payment system in December 2010, enabling 550 households to settle their monthly water bills via mobile phone.

Ensure better services to the poor. Mobile phones, especially, are particularly well placed to serve the development needs of the poorest and most vulnerable populations. In Kenya, "Jisomee Mita" is an application that enables water consumers to use a mobile phone to query and receive current water bills, at a frequency of their convenience.

Strengthen citizen voice and accountability framework. ICTs can be used to promote public participation and create a system of transparency and accountability. "MajiVoice", a platform for communication between citizens and utilities, was successfully tested in Nairobi and enabled complaints rose from 400 to over 4,000 per month and 94% of submitted complaints closed from 46% in initial months. Other initiatives include Maji SMS and Maji Data.

Short Message Service (SMS) notifications and access to internet-based water bill are tools that allow water users and system managers to understand current water systems conditions and make informed forecasts. Other ICT initiatives include applications such as billing System, Meter Reading System (MRS), Customer complaints Management system (e.g. MajiVoice), Financial Management system, Procurement system, Dam Monitoring System, customer information management, automated communication with customers, water quality management and being developed is the Laboratory Information Management system (LIMS) for water quality [37].

5 Smart Waste Management

An increase in global population coupled with economic growth has resulted to an increase in the amount of wastes generated each year. In 2011, amount of wastes discharged globally was estimated at 10.4 billion tons, which is projected to increase to 14.8 billion tons by 2051. However, the amount generated by developing countries accounts for 56% of the world's total waste. Some of the problems associated with wastes generated from these countries include poor collection and low transportation capacity, open dumping, improper treatment of hazardous wastes [38]. The Sustainable Development Goal 11 (SDG 11) is on making cities inclusive, safe, resilient and sustainable. To attain this goal, one of the targets set is to reduce the adverse per capita environmental impact of cities by paying special attention to air quality and municipal and other waste management by the year 2030 [39]. This evidently sets the agenda for pragmatic, innovative and sustainable Solid Waste Management (SWM) systems. This section explores the potential for applying smart technologies in SWM in Nairobi.

5.1 Situational Analysis in Nairobi

Solid waste generation in Kenya has been increasing significantly, attributable to rapid urbanization. The current amount generated is about 4 million tones/year, and is projected to double by 2030. However, the rise in waste generation has not been accompanied by an equivalent increase in the capacity of county governments in dealing with the challenge [40]. As regards legal framework, issues pertaining to SWM are addressed under various legislations. Article 42 of the Constitution of Kenya (2010) [41] confers every Kenyan with a clean and healthy environment. Article 2 of the Fourth Schedule of the Constitution further gives the County Governments the responsibility for SWM. Regulation two (2) of the Environmental Management and Coordination (Waste Management) Regulations (2006) [42], additionally requires any person whose activities generate waste, to collect, segregate and dispose or cause to be disposed of such waste in a sustainable manner. Concerning physical planning, Part Three (Form PPA1) of the Physical Planning Act (Cap 286) [43] states deposit of solid wastes on land constitutes development and as such need to be controlled. Owing to this, the Act requires developers to state the method of solid waste disposal upon application for development permission. In 2015, the National Environment Management Authority (NEMA) of Kenya developed the National Solid Waste Management Strategy (NSWMS) [44]. The strategy seeks to establish a common platform for action between stakeholders to systematically improve SWM in Kenya. The main guiding principle is "zero waste principle" where wastes are seen as a resource that can be harnessed to create wealth, employment and reduce pollution of the environment. NSWMS is, however, not particular on any new and innovative smart strategy that may be perused towards sustainably addressing the prevailing problem of SWM in Kenya.

Despite the existing legal framework, to date, Nairobi City is still contending with the challenge effective SWM. For instance, a study done by UN Habitat [8], found that 30–40% of waste generated in Nairobi is not collected and that only 50 percent of the population is served. According to the NSWMS [44], although Nairobi City generates approximately 2,400 tons of waste per day, 65% remains uncollected. This could however be more owing to the ever rising population induced analogous increasing industrial activities from many sectors of the city. Currently, the end disposal of Nairobi's waste is open dumping at a site located at Dandora, in the

Fig. 2 Garbage trucks drive to the Dandora dumpsite in Nairobi. The dumpsite was declared a health hazard for the neighbouring residents in 2001, but chemical, hospital, industrial, agricultural and domestic waste are still dumped here and left unprocessed. *Source* Koech [48]. Adapted from Nairobi City Water and Sewerage Company Limited-Strategic Plan 2014/15—2018/19

Eastland's section of the city, located 7.5 km southeast of the Central Business District (CBD), covering an area of 26.6 hectares. Although it is several kilometers away from the CBD, the rapid growth of the city's population has resulted in settlements encroaching upon the dumpsite.

Areas adjacent to the Dandora dumpsite (Dandora, Korogocho and Kariobangi estates) experience several problems caused by various activities carried out at the dumpsite. These problems need to be addressed as a matter of urgency to save the deteriorating situation. As observed [45], the situation is giving the county government officials sleepless nights as they seek ways to tackle the garbage collection problem. Most city residents have tales of heaps of uncollected garbage lying in their neighbourhoods. The challenge is no different on some of the streets in the city centre, where piles of garbage remains uncollected for weeks, limiting use of the streets and emitting a foul smell.

5.1.1 Previous Policy and Strategy Interventions

There have been several attempts in the past to address the problem of SWM in Nairobi. From 1996 to 1998, the Government of Japan carried out a study on SWM in Nairobi City through its technical assistance programme. This study included the formulation of a Master Plan composed of a collection and transportation plan, a waste reduction and recycling plan, and a final disposal plan. The report recommended for institutional and legal restructuring plan, a private sector involvement and financial improvement plan, a waste collection system improvement plan, and a construction plan of a new final disposal site were proposed [46]. In 2010, a study entitled, "Preparatory Survey for Integrated Solid Waste Management in Nairobi City in the Republic of Kenya" was also undertaken by Japan International Cooperation Agency (JICA) in conjunction with the City Council of Nairobi. The study sought to review the current situation of SWM in Nairobi City and revise the Master Plan prepared in 1998. Among the recommendations included construction of new sanitary landfill site and closure of Dandora dumpsite; setting up of the Preparatory Unit (PU) in the Department of Environment (DoE) for the SWM Public Corporation (SWMPC); drafting of By-law for the establishment of SWMPC; and preparation for the introduction of the step-wise franchise system [38]. The recommendations were however largely not implemented.

Based on these earlier proposals, and in an attempt to address the earlier limitations, a preparation of a report, "Integrated Solid Waste Management Plan for the City of Nairobi, Kenya 2010–2020", was commissioned by UNEP and developed by a team constituting representatives from, among others, the City Council of Nairobi, and the University of Cape Town and University of Nairobi. Among the recommendations made were reducing waste quantities by introducing policies and instruments that regulate wasteful behaviour; extending resource recovery, both in terms of materials and energy, through source separation as an essential component of sustainable waste management and building environmentally sound infrastructure and systems for safe disposal of residual waste, replacing current disposal sites which need to be rehabilitated [47]. In the same year (2010), another study entitled, "Solid Waste Management in Nairobi: A Situation Analysis", was also undertaken by the United Nations Environment Programme (UNEP) on behalf of the City Council of Nairobi [47]. The study aimed at preparing technical document for the Integrated Solid Waste Management (ISWM) to explain in more detail the thinking, rationale, calculations, modelling and assumptions made in the development of the Specific ISWM Actions. Among the intervention areas proposed in the report included reducing waste generation at source; getting general waste collection and safe disposal right; zoning of waste collection; and waste separation at source with incentives. Figure 2 illustrates a key challenge facing SWM in Nairobi.

Further, in 2015, the County Government of Nairobi Assembly enacted the Nairobi City County Solid Waste Management Act, one of its kind in Kenya, in an attempt to address the challenge [49]. Its objective is to make provision for the management of solid waste in the county and for related matters. The Act under Section 17 makes it the duty of every occupier or owner or agent of a house, or other premise to clean or cause to be cleaned ten metres radius around his or her house or other premises or any area otherwise in his or her control, but which shall not include a main road or street. It moreover under section 18 commits the county government to provide appropriate waste containers for the disposal of solid waste in the public streets and other public places. Regardless of this noble initiative that was as well operationalized through comprehensive regulations, the problem of SWM still escalates in the city.

The foregoing review demonstrates that although several studies have been conducted on how the problem of SWM in the City of Nairobi could be sustainably addressed, most of them are limited to general administrative and functional areas such as waste reduction; collection; enforcement and financing. A scarcity in strategy and literature therefore exists on how the contemporary technological advances may be used to provide other alternative strategies in SWM.

5.2 *Towards Smart Waste Management in Nairobi City*

a. Adoption of Remote Sensing and GIS

GIS and Remote Sensing are indispensable, efficient and low cost tools in the study of environmental and developmental issues in recent times [50] Advances in remote sensing and image analysis techniques have made it possible to accurately and cost effectively study and measure variables of an extensive area of land in real time. This applies to SMW. Making use of a combination of remote sensing and field mapping, it is possible to implement spatial and temporal modeling to undertake the waste generation and disposal patterns in Nairobi in support of effective SWM strategies. This has a potential for contributing towards economic and environmental savings through the reduction of travel time, distance, fuel consumption and pollutants emissions. In particular, the techniques can be integrated to attain the following aspects of SWM, which are a basis for more complex analysis of patterns, and formulation of workable strategies:

(a) Mapping the location and spatio-temporal extent of unplanned solid waste disposal sites;
(b) Quantifying the amount of solid waste generated;
(c) Based on generation rates, predicting future amount of wastes likely generated; and
(d) Determining the optimal or least cost path/route towards the disposal sites.

Currently, the County Government of Nairobi lacks a database and information indicating the spatial location of solid waste dumping sites (legal or illegal) in the city's neighbourhoods. The use of GIS technologies thus provides the city with an opportunity for effective solid waste management. For example, using these smart mapping technologies offers the city authority a system to identify the most suitable locations for solid for waste collection sites within neighbourhoods, in consequence promoting efficiency in service delivery and budgeting. In addition, once mapping has been undertaken, it is possible to quantify the amount of solid waste generated from each site as well as to determine the optimal or least cost path/route to the disposal sites.

b. Adoption of ICTs in Monitoring Waste Generation

In this chapter, it is conjectured that the challenges facing SWM in Nairobi may be timely responded to through a further adoption of "smart waste management" concept. This is because one of the outstanding problems that epitomizes several neighborhoods of the city is that in cases where public bins are provided, there is usually no monitoring mechanism put in place by the County Government to determine how well these receptacles are used. The ideal requirement is that as soon as receptacles are filled, they should be emptied to avoid disposal of wastes on the ground. Generally, monitoring of solid waste generation, their collection from designated public receptacles and transporting them to disposal sites is usually a costly and time consuming undertaking. As such, the County Government invests a lot of resources in both collection and transportation of solid wastes.

It is thus suggested that with the advanced ICT development and applications in Kenya, the opportunity should be embraced as one of the options for providing an effective SWM in Nairobi, especially at the storage point where residents should have access to public solid waste collection bins. The objective is to monitor the extent at which the bins are used, thereby avoiding the time consuming process involved in physically monitoring if they are full or collecting wastes from bins which are not full, thereby escalating transportation costs.

A proposal for "smart waste management" application which can be readily integrated with android enabled smart phones is recommended. This entail investing in *intelligent* bins strategically placed in neighborhoods and fitted with ultrasound sensor nodes, programmable Interface Controllers, linked with Global System for Mobile Communications and GPS (Global Positioning System) to notify the server database on the coordinate and status of each bin. The database will maintain the details of each bin such as location, capacity, temperature and humidity. Since the bins have sensors, when users deposit wastes into them, their threshold levels will be continuously monitored at the Control Centre through a Graphical User Interface. In this case, as each bin nears their maximum holding capacity, the signal transmitted raises alarm on the need to empty them in order to prevent overflow, a major determinant for unsustainable open dumping around the bins leading to environmental degradation. Additionally, since the spatial location of each bin can be determined through GPS, an optimal least cost transportation path can be determined making it easier to locate a bin that is due for emptying. Moreover, through an android based mobile application, residents may query the system to determine the direction to the nearest bin within the neighborhood, including their status.

Monitoring the capacity of bins through of sensors presents an opportunity for leveraging on a more efficient SWM in Nairobi as it provides a system that monitors the status of the garbage bin and provides information to the concerned authorities to plan and manage the collection intervals from the bins. As observed in Nairobi City, one of the reasons why sold wastes overflows from bins is because they are not emptied at planned interval's.

6 Conclusion

The discussions in this chapter indicate that Nairobi faces huge environmental challenges from the existing infrastructure services that range from unsustainable mobility systems and unbalanced demand for water and goods increasing the environmental footprint, to challenges of solid waste management. A diversity of ICT-driven innovations which constitute smart systems are available at the global and local levels that can significantly address the prevailing challenges, while also creating more opportunities for rapid growth towards environmental sustainability.

Though globalization and modernization are the key drivers of smart infrastructure and associated services, they are yet to be fully appreciated in relation to how they can enhance attainment of smart environment, hence are purely seen as initiatives geared towards improving access and quality of life of citizens living and working in Nairobi. This also has implications related to the digital divide, where some services are associated such as smart taxis are associated with costs which is likely not to benefit the urban poor who at times are forced to walk long distances to access services due to lack of transport fees associated with alternative means of transport or forced.

This chapter finally concludes that the role of smart infrastructure and related services in attaining smart environment in Nairobi will be heavily dependent on the deliberate effort by various level of governments to link the two through policies, financial budgets and plans and proper management and governance of such projects which should also be based on affirmative in order to take the interest of the urban poor and other vulnerable groups such as those living with disability, children and the elderly among others. This will lead to embracing of the infrastructure and related services by many whose cumulative effect will be positive in terms of attainment of smart environment in Nairobi.

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