Introduction

Over fifty per cent of the world's population resides in or around metropolitan areas (World Bank, 2020). In search of better opportunities cities are growing bigger and bigger, by 2050 nearly two-thirds of the world's population will be urbanised (Marques et al., 2019). In the UK the population density spread ranges from more than 5700 people per square kilometre across London to a bleak 50 people in the rural areas (Nash, 2019). This scale of accelerated urbanisation poses a challenge to the sustainability and development of London city's infrastructure.

The growing population gives rise to increased waste generation, which transitively overloads the logistic frameworks that cater the waste management needs of populated cities like London. Furthermore, the scarcity of land is a major challenge that can translate into traffic congestion even in well-connected transport systems, waste disposal due to a shortage of waste landfill sites.

Smart cities with a connected mesh of sensor networks with software-based solutions offer a simple, scalable, and cost-effective approach (Fazio et al., 2012). By leveraging available smart technologies developed economies can devise robust frameworks for designing smart cities (Gaffney and Robertson, 2018). Whereas the developing economies can consult the design of developed smart cities while considering the economic feasibility and availability of landfill sites (Macke et al., 2019). The waste management lifecycle can be divided into three phases: collection, transportation, and disposal. We focus more on the surrounding logistical aspects through the three phases to achieve a secure disposal framework for smart cities. These phases apply to all wastes independent of the classification of wastes, their sources, the disposal locations, and the priority of disposal.

The dawn of faster and robust wireless networks like 5G accompanied by IoT frameworks are deemed to be one of the most sustainable solutions to support the needs of the polarised large-scale urbanisation (Zanella et al., 2014). Software-based solutions can leverage the use of real-time sensors and the well-established infrastructure of the information and communications technologies (ICT) industry to adapt to the dynamic requirements (Anagnostopoulos et al., 2015). Sensors can be planted on existing equipment that contains, carry, or interact with the waste to monitor and ensure autonomous, secure, and efficient utilisation of the infrastructure available. Waste disposal is critical yet often overlooked in day-to-day lives. A survey highlights the hazards of a disrupted waste disposal system including impact on citizens' health, emission of greenhouse gases and inefficient use of the landfills (Kaza et al., n.d.). Dumping of unmonitored, unsegregated wastes is illegal and has been identified to have a damaging ripple effect on the environment (Liu, Kong and Santibanez Gonzalez, 2017).

In this literature review, we focus on the various types of wastes and their priority of disposal, while taking into consideration the phases of waste management in their existing frameworks. Furthermore, we try to identify operational areas to induce cybersecurity on the wide attack surface caused by the increase in the number of IoT devices. We build on the challenges and opportunities identified by Anagnostopoulos and others in their survey to interpret the security posture of existing systems (Anagnostopoulos et al., 2015).

The UK government identifies the actors interacting with waste in three distinct roles to enforce the “duty of care” (Government Digital Service, 2012).

A. Producer or Holder
B. Carrier
C. Consignee

However, there are no solutions in place to monitor and record any malign incidents.

Type of Wastes

The UK government has issued meticulous guidelines and procedures to segregate waste into four broad categories. These guidelines also outline the roles and responsibilities of the parties involved in generating, moving, storing, treating and disposing of waste (GOV.UK, N.D.). The categories are based on factors including, decomposability, recyclability, sources, and contents of waste.

The four categories of waste are as follows:

1. Construction, demolition, and excavation (CD&E)
2. Commercial & Industrial waste(C&I)
3. Household Waste (WfH: Waste from House)
4. Others

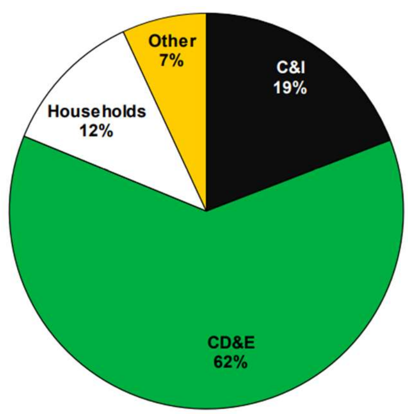

Figure 1: Waste generation split by source, UK, 2018 (Source: Defra Statistics)

1. **Construction, and demolition waste (C&D)**

The construction and demolition industry generates significant quantities of waste and is recognised as the principal contributor to environmental pollution (Menegaki and Damigos, 2018). Furthermore, the sector faces a major challenge in waste management, it requires strict segregation as it contains a variety of compositions of environmental pollutants like asbestos, oils, solvents, etc that can contaminate the surrounding ground or in some cases even the groundwater (Chen et al., 2021). Furthermore, C&D waste demands large areas in landfills. Emma (2021) in her article highlights the absence of regulations that enforce monitored transportation of C&D wastes which could lead to illegal dumping.

Summary of Issues: Segregation, monitoring volume of contents to forecast the landfill requirements and tracking location of the disposal logistics to avoid illegal dumping.

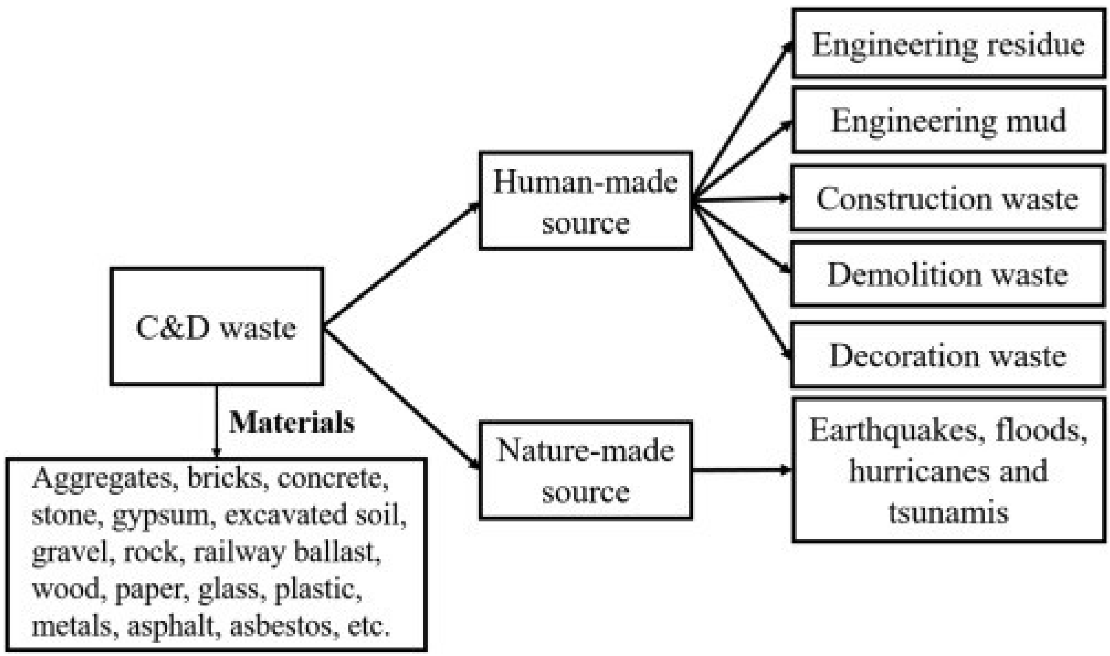

Figure 2: General classification and components of C&D waste. (Chen et al., 2021)

2. Commercial & Industrial waste(C&I)

C&I waste is independently regulated, and its adherence is the legal responsibility of the companies involved in generating, transporting, and dumping the waste. C&I waste may include Animal By-Products, Clinical waste; hazardous waste; Sewage Sludge generated by various manufacturing industries. This type of waste includes toxic elements including mercury and even radioactive by-products which require special attention during collection, transportation, and disposal. Hence, the UK government enforces recording of details like pH level, radioactivity, flammability, toxicity, heavy metals, chemicals, etc before collection and after disposal by registered waste carriers.

Summary of issues: Documentation and segregation of contents, monitoring volume to identify spillage, detection and recording emissions if any, tracking the location of disposal logistics to avoid illegal dumping.

3. Household Waste (WfH: Waste from House)

In London, the waste segregation and management are organised by the boroughs. London has a very limited landfill capacity and is forecasted to be filled by 2025. Hence, household waste has to be separated into packaging, recycling and electronics before collection.

i. Food

Despite the drastic reduction in waste generation, food waste still accounts for a staggering twenty per cent of the total household waste. This has forced the local boroughs to introduce independent waste management for food waste (Stephen, 2015). Exclusive segregating of food waste will not only help in controlling the environmental damage but will also bestow us with the needed data to forecast the area and resources required for treatment.

ii. Packaging waste and recyclables

The importance of recycling in waste management cannot be overemphasised. Not only does it reduce the area used in the landfills, but also decreases air and water pollution caused by incineration, thus preserving the natural resources. Even while recycling rates are increasing, the volume of waste produced is escalating at a faster rate (Environment Agency, 2022).

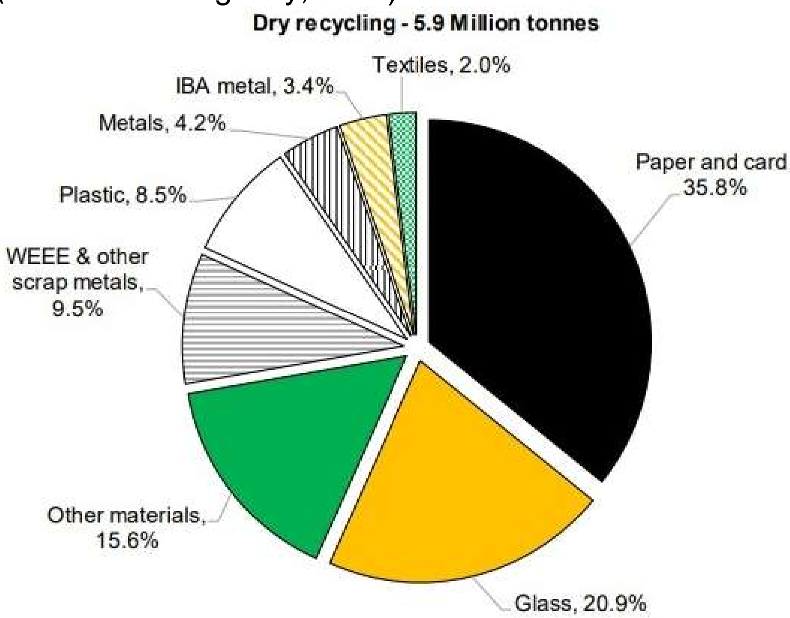

Figure 3: Waste from Households (Dry recycling composition, UK, 2019) (Source: Defra Statistics)

iii. Electronic waste

Household electronic waste can come from a range of sources as mentioned below.

a. Kitchen appliances (Oven, microwave, blender, etc.),
b. Household equipment (Lights, batteries, TV, washing machines etc).
c. Cyber waste (Old computers, laptops, smartphones, tablets, smart home devices, smart sensors etc.)

Day-to-day household equipment and kitchen appliances contain toxic chemicals like lead, CFC and other heavy metals from bulbs, tube lights, refrigerators and air conditioners which if not recycled carefully can end up in landfills and harm the environment.

Under the Data Protection Act 1998, all personal data must be kept secure and disposed of correctly, to ensure that any information deemed confidential or personal is not accessible to others. It is important to identify and dispose of cyber waste securely to ensure the data from the devices cannot be recovered even from storage devices (BS EN 15713:2009). Household devices like laptops, smartphones and tablets can contain sensitive data like photos, personally Identifiable Information (PII), financial records, other delicate information of the people in the household. Moreover, the smart devices IoT based devices like speakers, doors locks, alarm clocks, blubs etc that were once connected to the house network contain credentials and information about the home network can vulnerate the users on the networks. The NIST guidelines for media sanitization suggest deleting, formatting and in some cases overwriting the data partitions before selling, disposing of the devices to ensure that the data cannot be recovered and misused. In case of destruction, the process should be vetted to the appropriate level to ensure confidentiality (Kissel et al., 2014).

Summary of issues: Recording & Segregation of waste based on contents, monitoring volume, identifying spillage, recording emissions if any, tracking the location of the disposal logistics to avoid illegal dumping, confirmation of destruction, report of recycling.

4. Other types of waste include healthcare waste, vehicular waste

i. Healthcare waste

Healthcare waste comprises both infectious and non-infectious waste. Most of them are obtained via hospitals. Besides, those wastes are poisonous considering that they endanger the living organisms and surroundings if no longer managed properly. The essential challenge is that COVID-19 is inflicting a waste spike due to the use of personal protection in the healthcare industry (Klemeš et al., 2020). Research shows medical waste is a greater risk after the pandemic due to the need for the decimation of any residual pathogens and due to the virus's survivability on distinctive surfaces like plastic masks (van Doremalen et al., 2020). WHO technical officer, Maggie Montgomery confirmed the increase healthcare waste due the use of personal protective equipment (PPE) in facilities by up to ten times since beginning of pandemic (Manojna and Emma, 2022). As a result, the waste management system must endure a comprehensive structural shift inclusive of segregating and cautiously treating waste to ensure safety protocols for waste collection workers. The medical industry is under enormous pressure to find alternatives to curtail the carbon footprint entering into landfills due to single-use products like PPE and masks. (World, 2022).

ii. Vehicle and oil-based wastes

Vehicles and oil waste are categorised as hazardous (oil filters, components containing mercury & PCB's) and non-hazardous waste (brake pads, vehicle glass & metal). Vehicle recycling is essential to ensure proper waste disposal. It provides various environmental benefits by reusing or safely disposing of heavy metals and toxic compounds such as fuel, coolants, brake fluids, and so on.

Summary of issues: Segregation of waste, isolation of infectious waste, priority of disposal, monitoring volume to identify spillage, tracking the location of disposal logistics to avoid illegal dumping.

Conclusion

The research sheds light on the importance of waste segregation based on sources and contents to help us understand the trends of waste generation. Implementation of IoT technologies through the phases of waste collection, transportation, disposal, and recycling enables efficient utilisation of available logistical infrastructure. As author the (Malapur and Pattanshetti, 2017) proposes the implementation of smart bin which can aid in waste collection and transportation process. Sensors (i.e., GPS, RFID, camera, weighing scale) mounted in bins connected through wireless networks can produce notable data over the cellular network which can be used to optimise the routes for timely collection. The sensors deployed in the smart bin can communicate to the centralised control servers to suggest the volume of waste filled by transmitting a sound pulse with a high frequency which indicates the time taken for the sound's echo to return. Furthermore, the transportation phase analysis by Theodoros presented the dynamic routing algorithm (Anagnostopoulos, Zaslavsky and Medvedev, 2015) which identifies the vandalised or overloaded vehicles that need replacement. He suggests both high & low-capacity vehicles to reduce the operational cost for transportation. Along with this he also came forth with a new model called top-k (Anagnostopoulos et al., 2015) which resolved queries for dynamic scheduling. In this approach when the capacity level exceeds the maximum, each smart bin sends an alert, and the results exhibit accuracy and efficiency.

While concluding, we use the NIPP Risk Management Framework adopted by the Department of Homeland Security as an understructure to evaluate the security quotient in prospective waste management systems (Water and Wastewater Systems Sector-Specific Plan ,2015). This framework takes into account the three critical elements Physical, Cyber and Human to safeguard all important infrastructure elements for waste management.

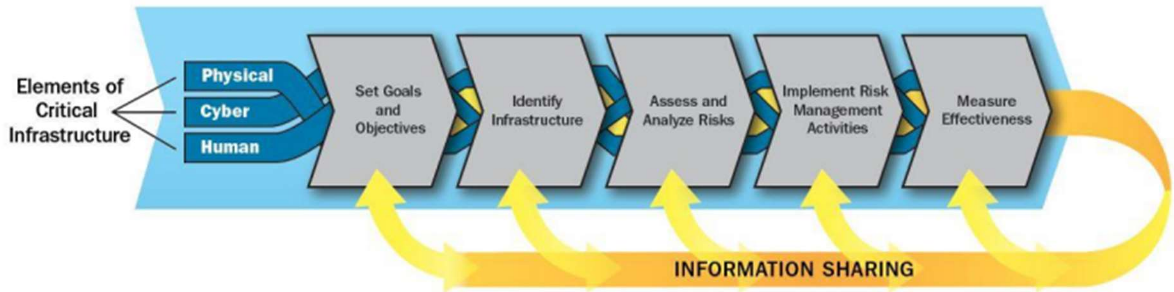

Figure 4: NIPP Risk Management Framework.

Autonomous solutions covered in the literature above largely focuses on the effective utilisation of various sensors and algorithms to improve the implementation of waste management systems for smart cities. However, they do not address issues and risks associated, while dealing with a wide attack surface due to the increase in number of IoT devices in the network. The sensory devices once deployed in the user premises will be extremely difficult to patch and manage. Overlooking cybersecurity in the designing phase of waste management systems can not only make them vulnerable to cyberattacks but can also choke the city's infrastructure. In worst case, this can trigger a chain reaction inflicting emission and contamination of the environment risking human life and the mother earth.

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