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GIS Analysis and Optimisation of Faecal Sludge Logistics at City-Wide Scale in Kampala, Uganda

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Abstract: The majority of residents in low- and middle-income countries are served by onsite sanitation. Equitable access to sanitation, including emptying, collection, and transport services for the accumulation of faecal sludge remains a major challenge. Comprehensive information on service coverage by mechanical faecal sludge emptying service providers is lacking. The purpose of this study is to analyse the spatial distribution of service coverage and identify areas without faecal sludge emptying services in Kampala, Uganda. The study uses GIS (geographic information systems) as a tool to analyse real-time data of service providers based on GPS (global positioning system) units that were installed in a representative number of trucks. Of the total recorded 5653 emptying events, 27% were located outside Kampala city boundaries. Of those within Kampala city boundaries, 37% were classified as non-household customers. Areas without service provision accounted for 13% of the total area. Service provision normalised by population density revealed much greater service provision in medium- and high-income areas than low- and very low-income areas. The employed method provides a powerful tool to optimise faecal sludge management on a city-wide scale by increasing sustainability of the planning and decision-making process, increasing access to service provision and reducing faecal sludge transport times and costs.

Keywords: safely managed sanitation; information and communications technology; collection and transport; service coverage; faecal sludge management; onsite sanitation; Sub-Saharan Africa

1. Introduction

Globally, 2.7 billion people rely on on-site sanitation with containment technologies, such as septic tanks and pit latrines [1]. In urban areas of Sub-Saharan Africa and Asia, 65%–100% of the population is served by these technologies [1,2]. On-site sanitation can provide a sustainable and more affordable option to sewer-based sanitation, either as a standalone solution or in combination [3,4]. However, currently, there is a lack of sustainable management of faecal sludge, the material that accumulates in containment technologies. If faecal sludge is not emptied, collected, and delivered to appropriate treatment, there are serious impacts to public and environmental health. Emptying, collection and transport services are the critical link in city-wide faecal sludge management, from household-level users, to treatment for resource recovery and safe end-use or disposal [2,5].

Providing sanitation is a public good and the responsibility of public authorities. Yet, private service providers also play a key role in faecal sludge management. Hence, cooperative public-private partnerships are essential [6]. Faecal sludge is emptied manually or mechanically, both with distinct advantages and disadvantages [7,8]. Manual service providers fulfil a crucial need in densely populated, low-income urban settlements ("slums") with narrow roads or paths that are not accessible to trucks [9]. However, manual service provision is often informal and unhygienic. Additionally, this faecal sludge typically does not get transported to treatment but directly dumped in the surrounding environment, as appropriate solutions are lacking [10–12]. Mechanical emptying services are provided by motorised trucks with vacuum pumps. This is currently the most advanced technology for faecal sludge emptying, collection, and transport, based on efficiency and limited human contact with faecal matter. However, these services are costly. For example, in Kampala, fuel costs make up 25% to 35% of the cost for emptying and transport [12]. A method to optimise logistics of city-wide emptying services could greatly reduce these costs.

The use of logistical tools and information communications technology to analyse emptying services in low- and middle-income countries is limited. However, previous studies in the field of solid waste management have used spatial data imbedded in geographic information systems (GIS) for evaluating, visualising, and optimising the logistics of waste collection systems [13,14]. In the context of faecal sludge management, Kennedy-Walker et al. [15] implemented a model-based approach to reduce transport time of faecal sludge. Using the potential of available technologies and tools for analysis of transport routes between the location of faecal sludge emptying and discharge locations would allow for optimisation of many aspects of faecal sludge management.

The objectives of this study were to use GPS (global positioning system) and GIS tools to identify the scale of operation of mechanical faecal sludge emptying services, and to evaluate ways to optimise faecal sludge logistics at a city-wide scale to increase access to equitable sanitation services. These innovative methodologies and tools for the analyses of faecal sludge management were found to be effective for this purpose.

2. Materials and Methods

2.1. Context Area

This research was conducted in Kampala, the capital of Uganda. Kampala has a total area of 178 km^2 at an altitude of 1140 m, and a tropical climate with two rainy seasons. The city is divided into five municipal divisions (Central, Makindye, Rubaga, Kawempe, Nakawa), which are further divided into 99 parishes. Of the total city area, 64% is classified as residential with about 1.5 million inhabitants [16]. The population doubles during the day, as many people commute into the city [17]. Approximately 60% of the city residents live in informal low-income settlements, which cover 10.8% of the total city area [18,19]. Of the Kampala residents, 92.5% are served by on-site sanitation (projected for 2013), with pit latrines being the most prevalent containment technology (36.9%), followed by septic tanks (27.6%), ventilated improved pit latrines (26.1%), raised pit latrines (5.4%), public toilets (2.8%), and other (1.2%), including open defecation and bucket latrines [20].

Faecal sludge in Kampala can only be legally discharged for treatment at two locations, the Bugolobi wastewater treatment plant or the Lubigi faecal sludge and wastewater treatment plant, both operated by the National Water and Sewerage Corporation (NWSC). Mechanical emptying service providers (vacuum trucks) and formal businesses operating with semi-mechanised emptying technologies (e.g., the Gulper—a direct lift pump that can be operated by a team of 2–3 people), discharge faecal sludge at either of these locations. Illegal dumping by these businesses has not been observed. However, it is known that within the informal sector (manual emptying), faecal sludge is dumped directly into the environment, along with pit latrines that are broken open at the bottom and directly drain into the environment [21]. Lubigi faecal sludge and wastewater treatment plant started operating in 2014, and was already at design capacity of 400 m^3 faecal sludge per day within the first months. The process flow includes settling/thickening tanks, followed by co-treatment of the supernatant with wastewater in stabilisation ponds, and drying beds for the solids.

Bugolobi wastewater treatment plant has a design capacity of 32,000 m^3 of wastewater per day, and was not designed for the additional loading of faecal sludge [22]. However, since there are no other options available, discharge of faecal sludge at Bugolobi is allowed and constitutes around 200 m^3 per day to the influent. Hence, Bugolobi is not operating as designed or meeting effluent regulations due to solids overloading and technical difficulties. The treatment flow at Bugolobi consists of settling tanks with supernatant going to trickling filters, solids going to digesters (if operational) followed by drying beds. Overall, around 59% of excreta that is managed as faecal sludge is safely managed, for more detailed information, please refer to Schoebitz et al. [23].

2.2. Research Implementation

The data collection took place between March and July 2015. A literature study and field observations were carried out to obtain an overview of the urban sanitation system and key stakeholders. A stakeholder analysis was conducted to assess the organisational structure, mode of operation, and responsibilities of faecal sludge emptying services. Collaborative working relationships were established to ensure transparent communication of the aims and objectives of the study, and to obtain permission of participants. Operating trucks, names of drivers, truck volume, working procedures, ownership, and association membership were recorded.

2.3. Data Collection

Trucks of mechanical emptying service providers participating in the study were equipped with a GPS data logger GT-730FL-S (CanMore Electronics Co.; Zhubei, Taiwan). This data logger was connected to an XTPower MP 10400 powerbank (Model PB-AS025) (DBK Electronics Co.; Shenzhen, China), which served as an external battery to allow continuous recording for approximately 7.5 days. The data logger was configured to create a waypoint every ten seconds. Data loggers and batteries were stored in closable plastic containers, packed with paper to prevent moisture accumulation and to provide a buffer to external influences. The container was placed behind the driver's seat and exchanged on a weekly basis. Battery exchange and data export were performed at the treatment plants during faecal sludge discharge or while the truck was waiting there for customers. To support this task, an employee of the association was appointed and remunerated.

2.4. Data Interpretation

CanWay software (*CanWay*, version 1.1.12; (CanMore Electronics Co.; Zhubei, Taiwan, 2016) was used to export recorded waypoints from the data loggers and GPS data were analysed with ArcGIS (*ArcGIS*, version 10.2.2; Esri: Redlands, CA, USA, 2013). For the identification of faecal sludge emptying events, Python scripts were developed. The travel velocity was calculated by dividing time and distance between two waypoints. Prior to implementation of the study, field testing was conducted to evaluate the potential for kinematic errors. Emptying events were simulated by stopping the truck. While stopped, errors showing movement of 1–3 km/h were occasionally observed. To account for this error, trucks were only recorded as moving if their velocity was greater than 4 km/h. For trucks belonging to either the Private Emptiers Association (PEA) or the Kampala Private Emptiers Association (KPEA), an emptying event was defined as a period of more than 15 min without movement. For trucks belonging to the Kampala Capital City Authority (KCCA) this period was reduced to 10 min, as it was observed that KCCA trucks required less time for the process of emptying the containment. In addition, the following events were filtered out from the analyses:

- Any event between 7 p.m. and 6 a.m., when the treatment plants are not open for discharge.
- Any events longer than three hours, which were considered as waiting time.
- Any events recorded at the treatment plant that were considered as discharge of faecal sludge or waiting time.

To cross-check validity of the recorded emptying events, the total number was compared with obtained NWSC records from the treatment plants, where each discharge event is documented. In addition, factors that might affect the scale of emptying services were evaluated to determine the representativeness of the selected research period, including monthly precipitation (e.g., containment technologies fill up faster), increased income during crop harvest periods (e.g., increased income), and timing of school fees and public holidays (e.g., decreasing emptying service requests due to extra expenditures).

All identified emptying events that were recorded during the period of this research are provided as supplemental material to this paper, including year, month, day, and time, as well as the x- and y-coordinates of the event.

2.5. Data Analyses

The following steps were performed to identify and interpret the scale of operation of mechanical faecal sludge emptying services:

1. GIS analyses of the spatial distribution of emptying events inside the boundaries of Kampala and the Greater Kampala Metropolitan Area, and outside the Greater Kampala Metropolitan Area.
2. GIS analyses of service coverage in low-income informal settlements with KCCA statistics [24]. A 100 m buffer was added to the perimeter of the designated boundaries of informal settlements to account for their informal nature, which means they do not have precise boundaries and are difficult to map, show an uncontrolled sprawl, and experience rapid growth [25].
3. Identification of high-frequency emptying services. Locations with more than six recorded emptying events during the research period (i.e., more than two emptying events per month) where defined as such, indicating a non-household origin of faecal sludge.
4. Identification of areas without service provision during the study period. For analysis, a 0.5×0.5 km grid that divides the area of Kampala into 809 cells, each of 0.25 km^2, was projected over the city map. A cell was defined as an area without service provision if no emptying event took place during the three month research period. This grid was, furthermore, applied to classify these areas into areas with and without residents.
5. To analyse the scale of service provision on the parish level, the emptying frequency was calculated (Equation 1). Population and area are based on data obtained from Fichtner Water and Transportation [20].

$$Emptying\ frequency = \frac{emptying\ events\ [n]}{\frac{parish\ population\ [cap]}{area[ha]}} \times 1000 \quad (1)$$

Areas with no residents, and previously identified locations with frequent emptying events, were excluded to ensure that the analyses were based only on household-level emptying services. R open-source software (*R: A Language and Environment for Statistical Computing*, version 3.3.2; R Foundation for Statistical Computing, Vienna, Austria, 2016) was used for analyses [26].

To evaluate how GIS analyses could contribute to optimisation of faecal sludge emptying, collection and transport logistics in Kampala, a location-allocation analysis was performed. For this analysis, the road network was used to identify the shortest travel distances between the currently operating treatment plants and the recorded emptying events. Distances between the treatment plants and emptying events where then compared with linear distances between emptying events and future treatment plants in Kinawataka and Nalukolongo. These treatment plants are currently planned under the Kampala Sanitation Program and will provide two additional discharge locations for emptying service providers [20].

3. Results and Discussion

3.1. Overview of Service Providers

In total, 63 private faecal sludge emptying, collection and transport trucks are operating in Kampala, of which 25 are members of the PEA, 37 of the KPEA, and one remains independent. KCCA, the public service provider, had four trucks in operation during the research period. These primarily operated within the public sector (e.g., schools, markets, public, and communal toilets). Emptying services in institutional, industrial, and commercial areas are performed by both private and public service providers [12].

Depending on the truck volume, the trucks are operated by one driver and one to two assistants. Faecal sludge is transported either to Lubigi or Bugolobi treatment plants for discharge. At the time of the research, the discharge fee was USD 2.0–5.6, depending on the truck volume. In between service calls, while trucks are waiting, they are based at either of the treatment plants (23 at Bugolobi, 44 at Lubigi). Private service providers wait at the respective treatment plant for customer calls, whereas KCCA operates continuously with a defined list of customers to be serviced daily. Manual faecal sludge emptying services are available, however, data on the scale of operation is lacking [12].

Private service providers are directly contacted by the customer and the fee for emptying services ranges from USD 17–28 per trip, depending on factors such as distance, truck volume, presence of solid waste in the containment, and density of sludge [12]. The existing truck volumes are: 2–3.9 m^3 (23 trucks), 4–5.9 m^3 (28 trucks), 6–7.9 m^3 (3 trucks), and 8–11 m^3 (13 trucks).

Private service providers report that factors such as timing of heavy rain, monthly pay day, harvest period, due date of school fees, and public holidays influence the frequency of emptying requests. However, based on NWSC records during the period of this study, none of these factors showed an indicative influence. It is possible that they do have an effect though, as these factors mainly affect households. In previous studies, up to 50% of faecal sludge discharged at treatment is from non-household sources, and so these types of household level influences may not be observable [23].

3.2. Scale of Operation

In total, 34 out of 67 trucks operating at the time were equipped with GPS data loggers. KCCA trucks were equipped for a five week period, with all other trucks were equipped for twelve weeks. During the research period, 5′653 emptying events were recorded. The data were assumed to be representative of the patterns of service delivery for all trucks in the city, as 51% of all trucks that were monitored included representative numbers from a range of factors, which could affect the spatial distribution of emptying events. This included 56% of the trucks based at Bugolobi and 48% based at Lubigi, 64% of trucks belonging to the PEA and 38% belonging to the KPEA, and a range of operating truck volumes including 56% of 2–3.9 m^3 trucks, 46% of 4–5.9 m^3 trucks, 100% of 6–7.9 m^3 trucks, and 38% of 8–11 m^3 trucks. Additionally, in comparison to NWSC records of discharge events at treatment, this study captured 65% of emptying services provided by private service providers and 112% by KCCA. Private service providers performed an average of 2.1 emptying events per truck per day, whereas KCCA trucks performed 5.8 events per truck per day. Reasons for this significant difference appear not to be that KCCA is more efficient in emptying, but in scheduling emptying events, as drivers are provided with a daily schedule and are providing services to containment technologies that are readily accessible. This indicates that private service providers could also potentially operate at increased capacity with more effective planning of emptying schedules, such as proposed call centres [27], which could also contribute to an increase in overall service delivery.

3.2.1. Spatial Distribution of Emptying Events

An overview of all recorded emptying events, of which 73% were located within Kampala boundaries, 22% in the Greater Kampala Metropolitan Area, and 5% outside the Greater Kampala Metropolitan Area is provided in Figure 1 (for supplemental report with additional maps available, see [28]). Collected faecal sludge is most frequently transported to the closest treatment plant to the emptying location. Due to urbanisation, population growth and limited unoccupied areas within Kampala boundaries, it can be expected that demand for faecal sludge emptying services outside Kampala, but within the Greater Kampala Metropolitan Area, will continue to increase within the near future. This demonstrates the importance of thinking outside of political boundaries when planning for faecal sludge management infrastructure and emptying service delivery.

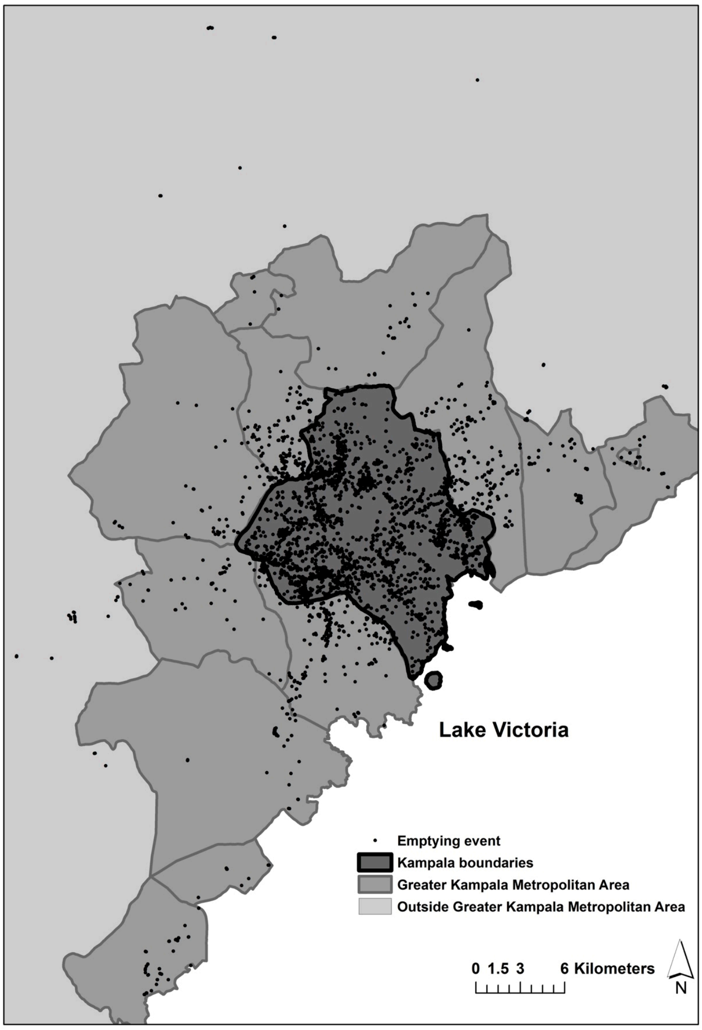

Figure 1. Distribution of all emptying events recorded during this study, within Kampala's boundaries, the Greater Kampala Metropolitan Area, and outside the Greater Kampala Metropolitan Area (n = 5653).

3.2.2. Service Coverage in Low-Income Informal Settlements

As illustrated in Figure 2, 37% of all recorded emptying events were located within informal settlements. However, when considering this high frequency of emptying events population density should also be considered, and it should not be confused with adequate access to improved sanitation [29], as 68% of residents of informal settlements in Kampala share toilet facilities with an average of 82 users [18]. The high frequency of emptying events are, therefore, explained by an inadequate number of toilet facilities per capita, resulting in overuse and rapid filling of containment technologies. The increased population density in informal settlements is also a factor for increased demand for emptying services, which is not fully captured in these numbers as manual emptying is also taking place where access to trucks is not feasible. Service provision in these areas could potentially be improved by linking manual and mechanical service provision with transfer stations.

Information on volumes and filling rates of containment technologies in Kampala is, for the most part, not available [30]. Customers frequently do not know volumes of their faecal sludge containment and service providers have to estimate based on qualitative assumptions [12]. This illustrates the future need for more in-depth quantification and characterisation studies for the appropriate planning of faecal sludge management and sizing of treatment facilities.

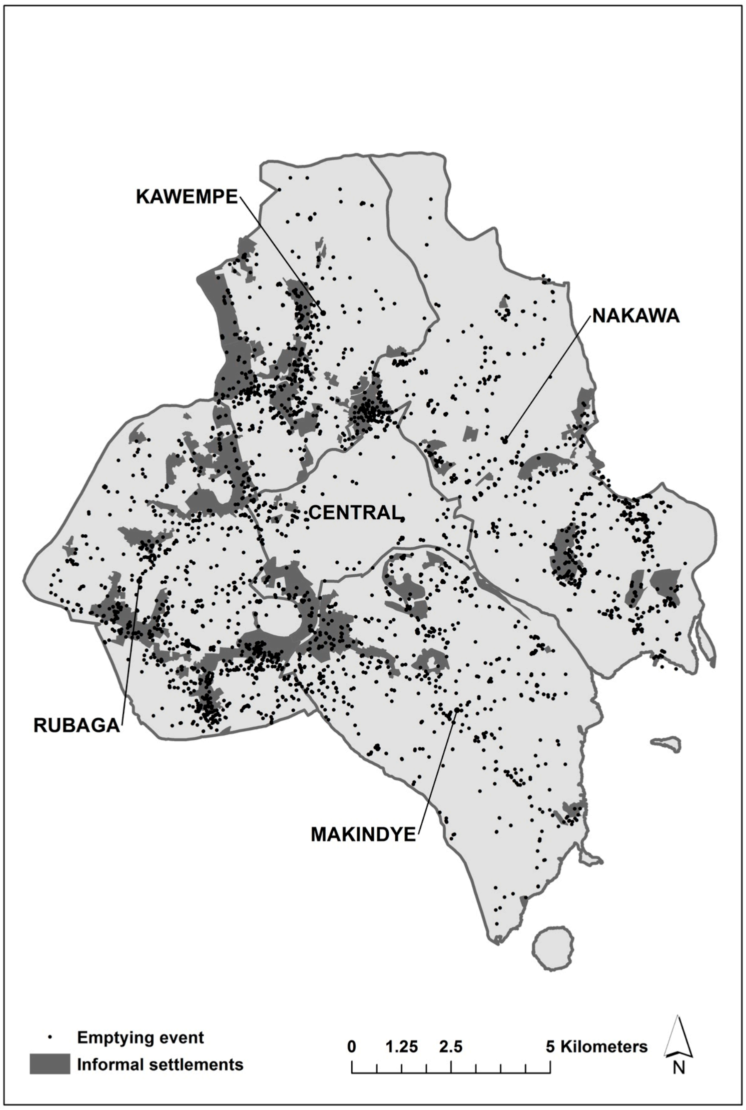

Figure 2. Emptying events within Kampala's boundaries, and the location of low-income clients (n = 4146).

3.2.3. High-Frequency Non-Household Emptying Services

Of the 1525 (or 37%) recorded emptying events 98 were from customers with high-frequency emptying services. These locations were non-household sources (e.g., commercial establishments, workers in industries, public toilets), which have faecal sludge emptied much more frequently than household-level users. It is imperative to consider non-household faecal sludge quantities, as Kampala doubles in size during the day with people commuting into the city [17]. It can be expected that faecal sludge from non-household sources has different physico-chemical characteristics due to shorter retention times and different inputs to the containment (e.g., kitchen, bathing), which highlights the importance of carrying out quantification and characterisation on a scale that is relevant to planned infrastructure (e.g., city-wide or neighbourhood scale). Faecal sludge is highly variable due to factors that range widely at the household level, such as soil characteristics, ground water, system inputs, quality of construction, type of containment, and it is also not homogenised during transport in the sewer as is wastewater [4]. Not taking this into account can lead to inappropriate designs and management plans; for example, using literature values instead of actual local characteristics led to over-design of a treatment plant by 200% over capacity [31]. Accurate designs are important to ensure appropriate treatment performance, not waste financial resources, which, among other factors, contribute to sustainable long-term operation of faecal sludge treatment plants [32].

3.2.4. Areas without Service Provision

As presented in Figure 3, 54.7 km^2, or 31%, of the Kampala area did not receive any service provision during this study. To evaluate service provision, areas within Central Division that are connected to the sewer and non-residential areas were removed, resulting in a total adjusted area of 23.6 km^2, or 13%. Obviously, it cannot be extrapolated that emptying could never occur in these areas. However, identification of urban areas without mechanical emptying service provision over a three month period is valuable for a service delivery assessment, to identify areas for priority interventions by the municipality, and to identify untapped markets that the private sector could fill. Parts of informal settlements that were difficult to access could be accessed with manual emptiers using semi-mechanised equipment (e.g., the Gulper), and mechanical service provision elsewhere [21].

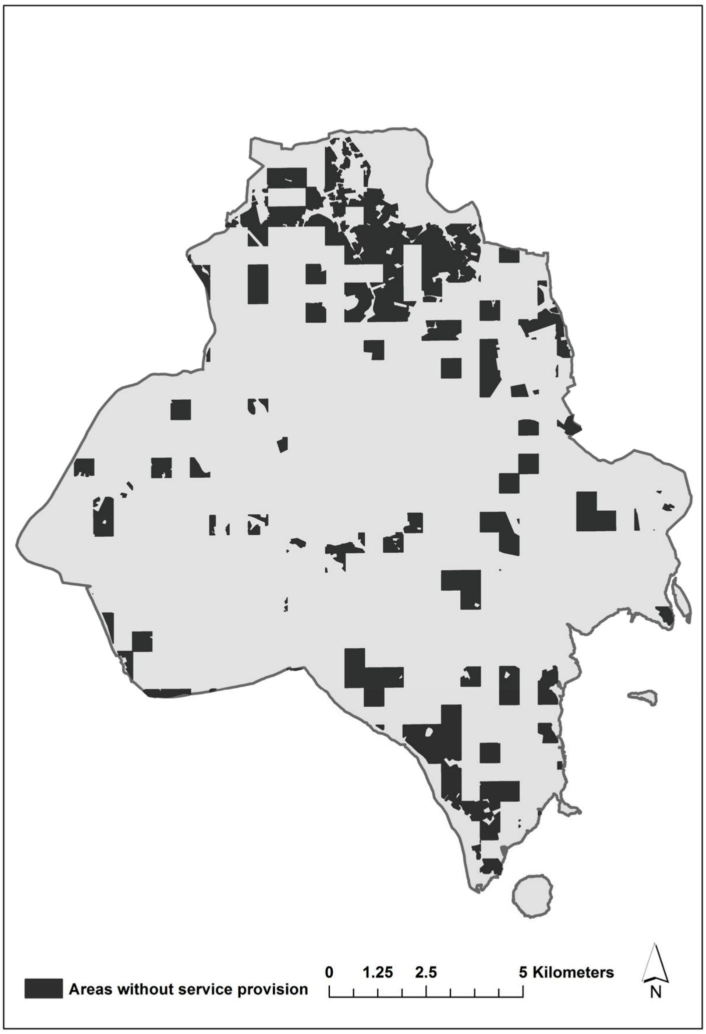

Figure 3. Areas not receiving mechanical faecal sludge emptying services within Kampala's boundaries, adjusted for non-residential clients and access to sewers.

3.2.5. Influence of Population Density on Frequency of Emptying

Hypothetically, income, type of containment technology, and population density could be indicators for levels of service provision. For example, in low-income areas, residents are less able to afford emptying services, and/or locations are not accessible for trucks [7,21]. In areas where unlined pit latrines are the prevailing type of containment technology, faecal sludge is typically not serviced by mechanical emptying with trucks due to the risk of collapse during emptying [20,33]. In Kampala, population density is also an indicator of income level and containment technology. To further evaluate service provision at the household level in Kampala, the frequency of emptying events during this study was normalised to land area and 1000 population equivalents on a parish level (Equation (1); data for analyses in supplementary material, 1000 was selected for ease of analysis) as defined by the following four levels of service delivery:

1. Low frequency: Emptying events $> 0 < 50/1000$ cap $\times$ ha
2. Medium frequency: Emptying events $\geq 50 < 200/1000$ cap $\times$ ha
3. High frequency: Emptying events $\geq 200 < 500/1000$ cap $\times$ ha
4. Very high frequency: Emptying events $\geq 500/1000$ cap $\times$ ha

As shown in Figures 4 and 5, adjusting emptying events for population density reveals that areas that have the highest levels of service provision were in medium- and high-income areas (Figure 6) and these areas also have lower resident population densities. Parishes with the lowest levels of service provision were in low- and very low-income areas and have higher resident population densities. Even though 37% of all emptying events inside the Kampala boundaries were recorded in informal settlements, 32% of those were non-household sources of faecal sludge that were not included in this analysis. Based on this analysis, it appears that household-level users in informal settlements are greatly underserved by toilet facilities and also mechanical faecal sludge emptying service providers. This is not surprising, as the cost for emptying events (USD 17 and USD 28 per trip) can be as high as half of the yearly household income in low-income areas [12,18]. These results could indicate that a significant proportion of accumulated faecal sludge in low-income areas ends up directly in the environment, which is in line with estimates of up to 75% of excreta in Kampala not being safely managed in very low- and low-income areas of Kampala [23]. Policies and regulations need to be developed for equitable access to sanitation, beyond just toilet facilities that also includes faecal sludge management.

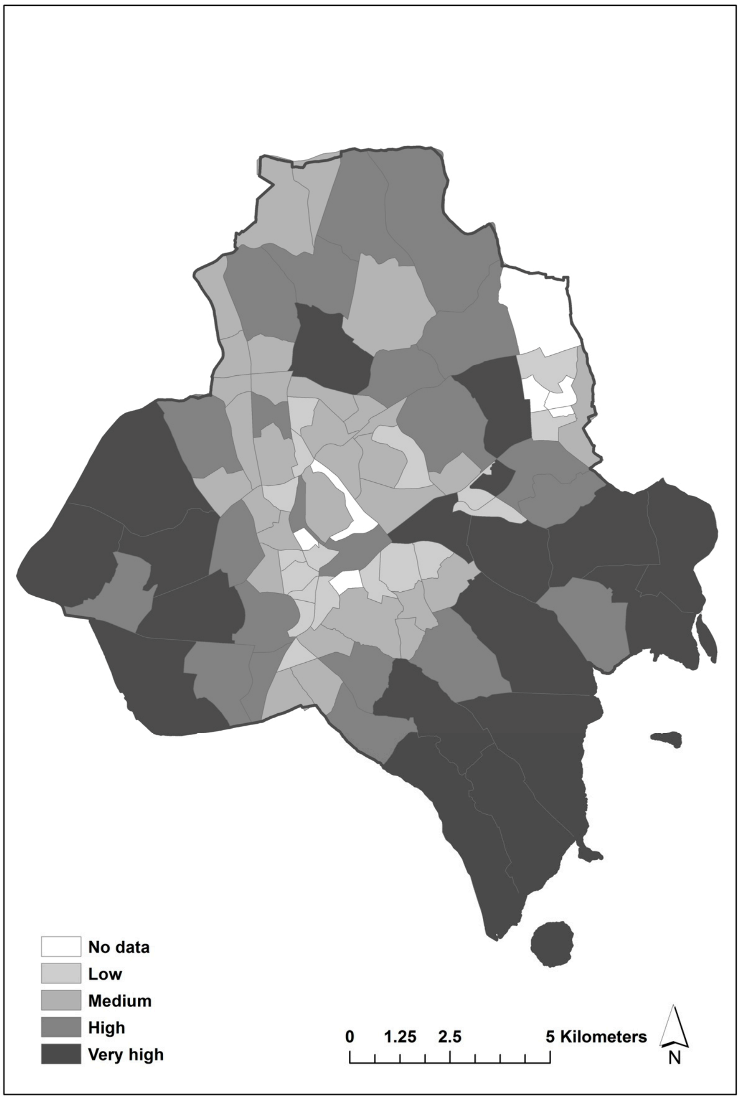

Figure 4. Emptying frequency normalised to population density, based on population, area, and number of recorded emptying events at the parish level within Kampala boundaries.

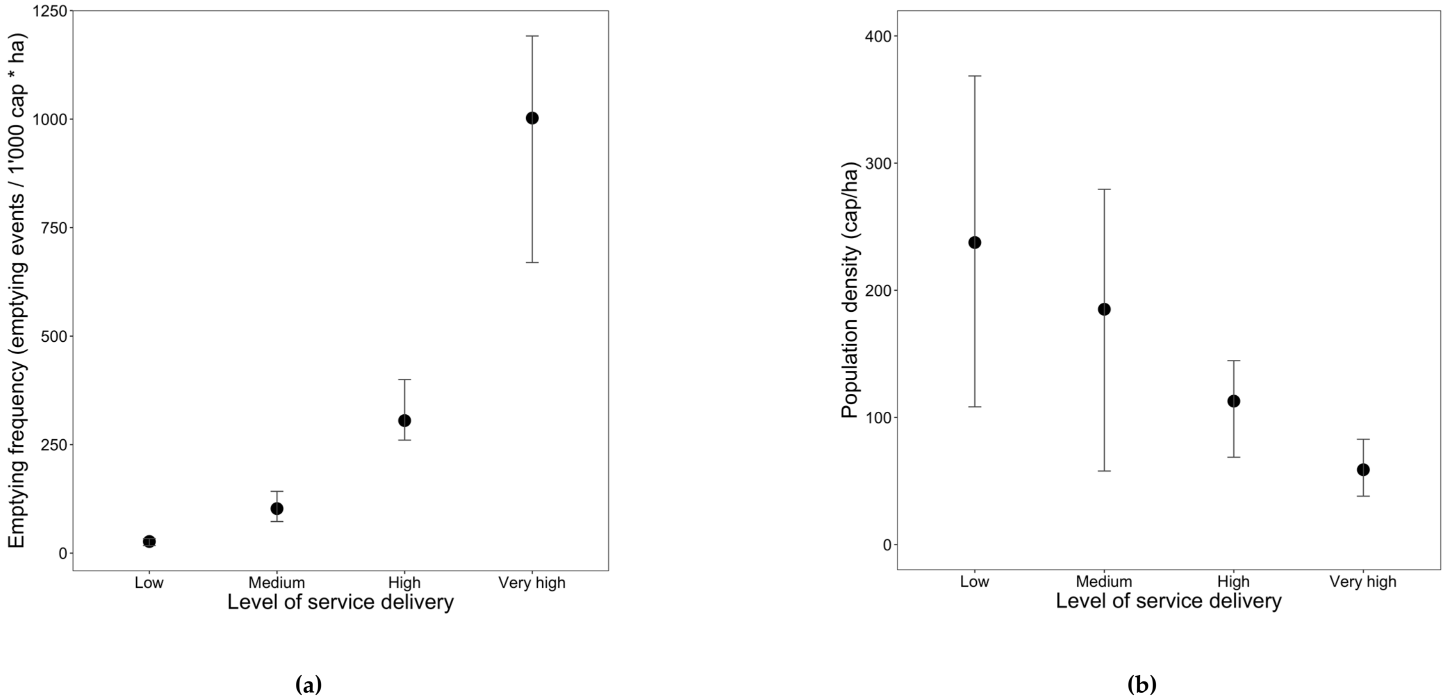

Figure 5. Median and $Q_{25,75}$ of emptying frequency **(a)** over four levels of service delivery; and **(b)** median and $Q_{25,75}$ of population density over four levels of service delivery.

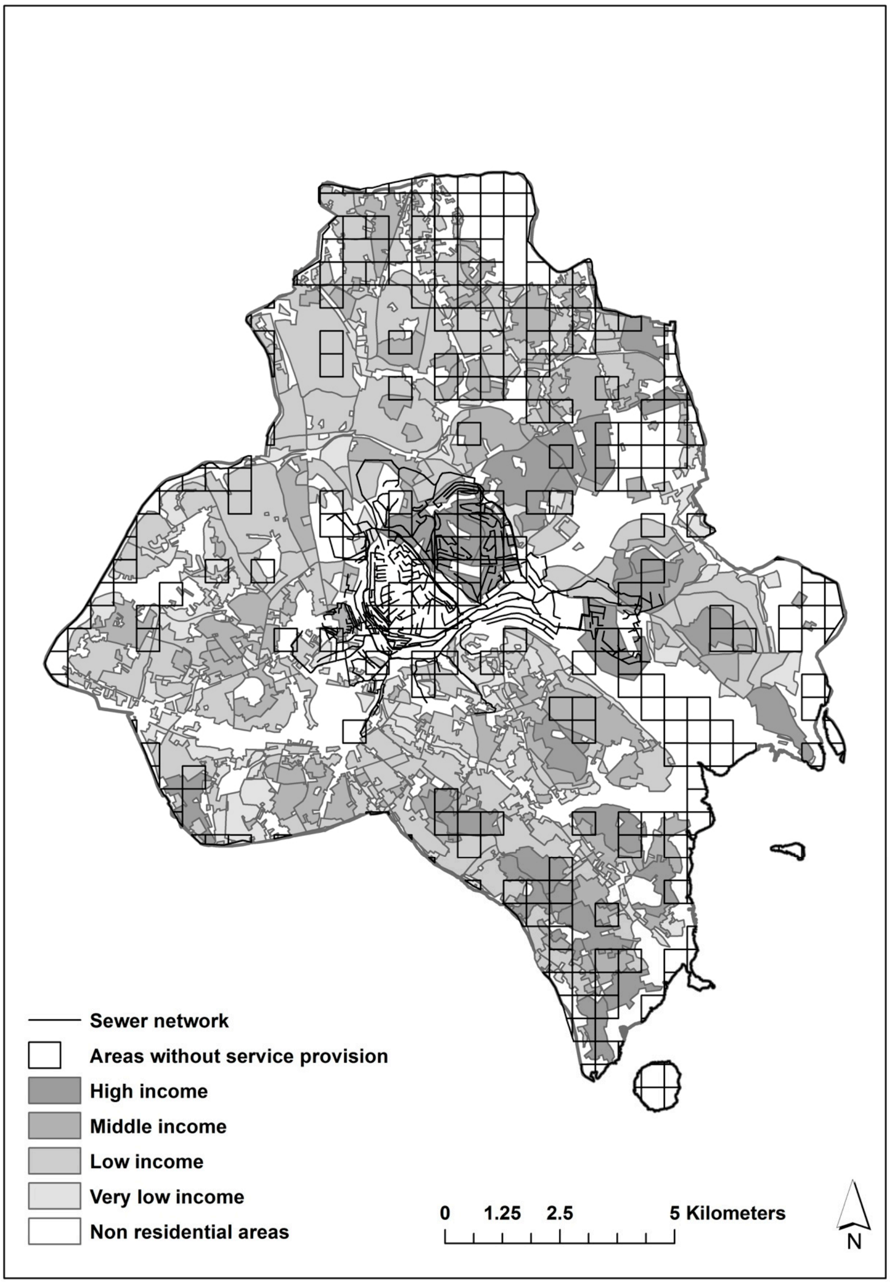

Figure 6. Spatial illustration of income level, and coverage of the sewer network, in relation to areas with no service provision during the period of this study.

3.3. Optimisation of Faecal Sludge Logistics

An analysis of spatial GIS data can also be useful for reducing travel times and transport costs, thereby reducing overall costs of sanitation provision. Route analysis and road network modelling with hypothetical data of faecal sludge emptying, collection, and transport is possible in regions with well-established road networks; for example, in Switzerland [34]. However, this relies on basic assumptions, such as consistent speed limits, fuel consumption, truck volumes, containment volumes, and reduced idling with increased density. These assumptions are simply not viable in dense, urban, low-income cities in Sub-Saharan Africa, where fully-functional road networks do not even exist, and possible routing changes are not predictable.

As road network analysis was not considered viable, analysis was performed with linear distance as an indication of how much travel distances could be reduced with additional treatment plants. Figure 7 illustrates linear distances between emptying events and present location of Lubigi and Bugolobi treatment plants (a) and linear distances between emptying events, present location of Lubigi treatment plant, and future location of Kinawataka and Nalukolongo treatment plants (b). Figure 7a shows all emptying events in this study with average linear distance to existing treatment plants, compared to Figure 7b that includes the three treatment plants that are planned in the Kampala Sanitation Program [20]. The analysis reveals a reduction in linear distance from 6.4 km to 5.4 km. As more information on infrastructure, daily quantities of faecal sludge produced and delivered, and the possibility of transfer stations becomes available, this type of analyses could greatly increase the overall efficiency when siting treatment plants and transfer stations. For transfer stations to be effective in reducing transport costs, it would require onsite dewatering and treatment of supernatant, with dewatered sludge being transferred to treatment plants. In addition to reducing transport times, distances, and costs, it is known that there is an economy of scale for the level of centralisation and decentralisation of treatment facilities which could also be optimised, in addition to strategies to meet growth [35]. However, identifying locations for treatment plants and transfer stations is also part of a complex decision-making process that in addition to distances includes factors, such as planning restrictions, residents' influence on decision-making, and the cost of land [15].

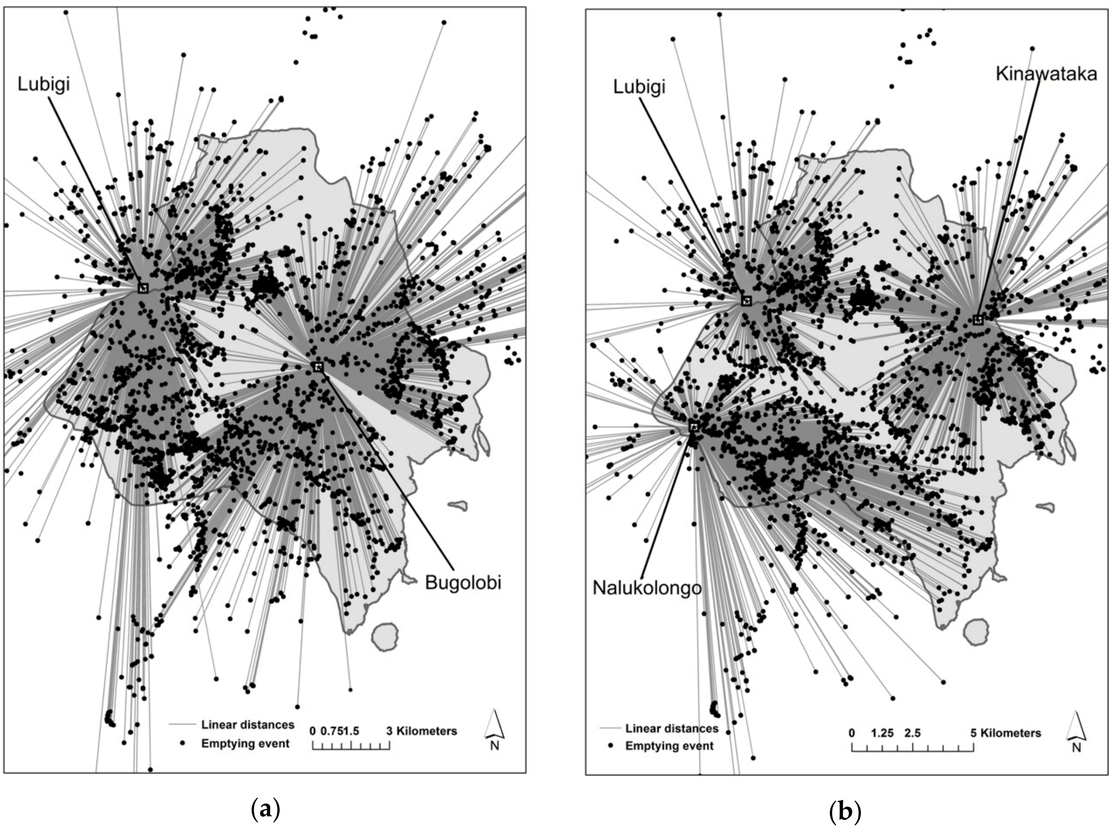

Figure 7. Linear distances between emptying events and present location of Lubigi and Bugolobi treatment plants (**a**) and linear distances between emptying events, the present location of the Lubigi treatment plant, and future location of the Kinawataka and Nalukolongo treatment plants (**b**).

The use of GIS tools for optimisation of faecal sludge collection and transport at city-wide scale provides an opportunity to increase sustainability of the planning and decision-making process by increasing access to service provision and reducing faecal sludge transport times and costs. The method is applicable anywhere, but variables need to be adapted to the local situation; for example, sufficiently detailed spatial data (e.g., GIS map layers or crowd-sourced information). However, the analyses in this study were limited to mechanical emptying service providers. To increase the benefits for planning of city-wide sanitation service provision, and the potential for optimisation, the methodology could be extended to include logistics of manual and informal emptying, direct discharges, and non-emptiable types of containment.

4. Conclusions

The benefits of employing GIS analyses as a component of planning include:

- *Access to sanitation:* Identifying areas that lack adequate access to sanitation for priority intervention by local municipalities to increase equity of service coverage.
- *Underserved areas*: Identifying areas where manual or mechanical private entrepreneurs could profitably increase service provision, and increase access to faecal sludge management.
- *Future demand:* Identifying areas with rapidly growing and high population densities with a need for increased service provision.
- *Identify service areas:* Locating areas outside of the municipal boundaries, which are being served by treatment plants within boundaries.
- *Optimise locations:* Siting of treatment plants and transfer stations to optimise transport distances could greatly reduce transport costs and impacts to traffic.
- *Quantification and characterisation:* Identifying sources of faecal sludge, which could be combined with other tools to increase accuracy of quantification and characterisation for appropriate design.
- *Existing infrastructure:* Optimising usage of existing infrastructure.

Supplementary Materials: The records of the research data are available online at www.mdpi.com/2071-1050/9/2/194/s1.

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Author Contributions: Lars Schoebitz, Fabian Bischoff and Linda Strande conceived and designed the experiments, Fabian Bischoff carried out the data collection; Lars Schoebitz, Fabian Bischoff, Charles B. Niwagaba, Rosi Siber and Linda Strande analysed the data; Charles B. Niwagaba hosted the research, contributed access to emptying service providers and institutions, contributed ideas, and reviewed and revised the paper; Rosi Siber provided the methods and analytical tools, and reviewed and revised the paper; Lars Schoebitz, Fabian Bischoff, Linda Strande and Christian Riuji Lohri contributed to writing the paper. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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