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Mapping Population Densities and Waste Management Systems in Mombasa County: A Literature Review of GIS and Remote Sensing Techniques

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Abstract:
Mombasa County is one of the five counties along the coastline of Kenya. Currently, Mombasa County has a human population of 1.2 million people, and the population is rapidly increasing through rural-urban immigration and natural births. However, the inadequacy of well-established waste management systems on the mainland and coastlines of the County is a threat to the well-being of the local residents. Poorly disposed of wastes both on land and at sea can lead to health problems not only for humans and terrestrial animals but also for aquatic animals such as fish, with the latter being one of the main sources of affordable proteins for poor coastal communities. This paper aimed to conduct a review of the spatial human population density of Mombasa County and the geospatial location of waste dumping sites and their proximity to settled areas. This literature review synthesized existing research on the application of Geographic Information Systems (GIS) and Remote Sensing techniques in mapping population densities and assessing waste management systems. The review began by examining studies that investigate population distribution patterns in urban and rural areas, utilizing GIS to analyze demographic data and satellite imagery. It explored methodologies used to estimate population densities, including dasymetric mapping, spatial interpolation, and land use classification techniques. Key findings were that limited studies have utilized GIS technologies to assess the population in Kenya. GRASP and Random Forest (RF) were the main techniques previously used to assess population densities in the rural Taita Hills area and along the coastal region. The population has exponentially increased in Mombasa County since the 1950s and is projected to increase further. Additionally, waste management in Mombasa County is majorly controlled by the county government. Ten geo-tagged waste collection spots were identified during the review, spread across the residential areas. In conclusion, the county should endeavor to employ GIS techniques to assess the rapid population change within the county and have targeted interventions to address the disparities in waste collection systems against population increase.

Keywords: *Mombasa County, waste management, GIS and population density mapping*

1. Introduction

1.1. Background

Mombasa, situated along the southeastern coast of Kenya within the Coastal region, lies approximately 200 nautical miles into the Indian Ocean and covers an area of 229.9 Km^2. It stands as Kenya's second-largest city and shares borders with Kilifi County to the north, Kwale County to the southwest, and the Indian Ocean to the east. Administratively, the county is divided into six sub-counties, namely Mvita, Nyali, Changamwe, Jomvu, Kisauni, Likoni, and thirty county assembly wards. The sub-counties are further sub-divided into thirteen (13) divisions, thirty-three (33) locations and sixty-two (62) sub-locations. The county boasts a diverse economy anchored by key industries such as manufacturing and processing, the renowned Port of Mombasa, Kenya Ferry Services, Container Freight Terminals, and a flourishing hospitality sector. Additionally, Mombasa's rich historical significance is evident through its numerous tourist attractions and designation as a host to various world heritage sites, reflecting its status as an ancient urban center (CIDP 2023).

1.2. Research Objective

The primary objective of this literature review is to analyze methodologies used for mapping population densities in Mombasa County using GIS and Remote Sensing techniques.

2. Methodology

The study utilized a systematic review approach to comprehensively gather and analyze relevant literature concerning population dynamics and waste management in Mombasa County, as well as using GIS techniques to study population change in Kenya. The systematic review method allowed for the identification, selection, and evaluation of existing literature on these topics in a transparent and rigorous manner. To collect pertinent information, an extensive literature search was conducted across various databases and sources, including Google Scholar and the websites of relevant journals. The search aimed to identify peer-reviewed research papers, reports, and publications that addressed the aforementioned study areas and ranged between 1990 and 2023. Keywords utilized to do the search included: Kenya, Mombasa County, Waste Management, GIS and population densities mapping. The data obtained from the systematic review were synthesized to provide a comprehensive overview of the current state of waste management in Mombasa County and opportunities for the utilization of GIS techniques.

3. Urbanization and Population Dynamics in Mombasa County

Cities in developing nations are witnessing a surge in population expansion and heightened levels of waste production, which can be attributed to socio-economic changes (Wekisa & Majale, 2020). Mombasa County has witnessed population growth over the years. According to Kiranga 1992, the growth has particularly been influenced by rural-urban migration in search of employment opportunities. As a result, the population in Mombasa County has exponentially increased from 911,000 in 2009 to 1,208,333 as of the 2019 census. This population is projected to increase to 1,422,440 by the year 2027. Currently, the distribution of population and the arrangement of settlements in the County are shaped by their proximity to essential social and physical infrastructure networks, including roads, housing, water, and electricity (CIDP 2023). Of the total population, Kisauni Sub-county is the most populated sub-county in the County with a population of 291,930 owing to factors such as access to low-cost housing, whereas Changamwe has the lowest population of 131,882 that can be attributed to poor infrastructure and inadequate social amenities. Conversely, the Mvita sub-county has the highest population density with 10,543 persons/KM^2, while the Kisauni sub-county presents the lowest population density of 3,328 persons/KM^2 (KNBS 2019). This generally implies the need for targeted policies and programs to improve the infrastructure and social amenities.

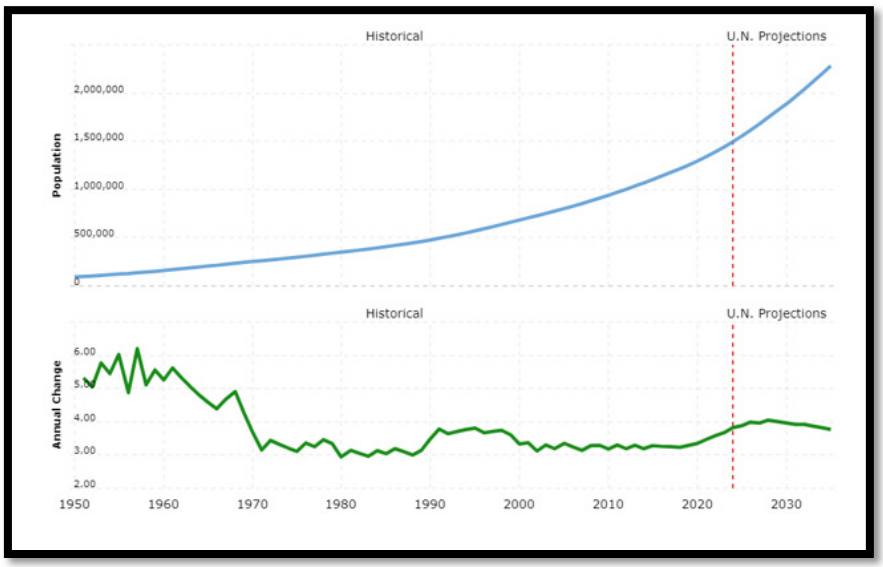

Figure 1: Mombasa County Population Trend
Source: Https://Www.Macrotrends.Net/Cities/21708/Mombasa/Population

3.1. Methodologies for Mapping Population Densities using GIS and Remote Sensing

Understanding population distribution and density is crucial for effective urban planning, resource allocation, and sustainable development initiatives. Geographic Information Systems (GIS) and Remote Sensing techniques have emerged as valuable tools for mapping and analyzing population densities, offering spatially explicit data that can inform evidence-based decision-making. For Mombasa County, employing advanced spatial analysis techniques is imperative for addressing the complex dynamics of urban planning and its waste management. Several techniques have been devised for mapping population census data, for example, areal weighting interpolation, prophylactic interpolation, and dasymetric mapping (Mennis, 2003; Zandbergen & Ignizio, 2010). Remotely sensed data, such as land cover data, have been extensively utilized as supplementary information in dasymetric mapping methods to identify potential human settlement areas for population redistribution (Jia & Gaughan, 2016). In Kenya, a study by Siljander *et al.* (2011) utilized a mixed method of remote sensing to predict population distributions in rural Taita Hiils, with findings that corresponded to those reported by the KNBS 2009 census. The study concluded that predictive modelling techniques like GRASP could be an alternative to estimating population distributions, especially in areas experiencing rapid population growth. Similarly, Linard et al. 2017 employed remote sensing techniques to model population distribution along the Kenyan coast between 1979 and 2009. The study utilized Random Forest (RF) models to estimate dasymetric weighting layers for redistributing population counts within administrative units. By adopting similar approaches, Mombasa County can develop robust

population models that accurately capture demographic changes over time, thereby facilitating more informed urban planning and sustainable development strategies.

Author	Research Topic	Methodology	Findings/Remarks
Siljander, M., Clark, B.J.F., and Pellikka, P.K.E., 2011.	A predictive modelling technique for human population distribution and abundance estimation using remote-sensing and geospatial data in a rural mountainous area in Kenya.	GRASP regression, Geospatial GIS-and Remote sensing-based data layers	The findings conclude that remote-sensing and geospatial data can be effective in predicting human population distribution and abundance, especially in areas with limited census data or rapid population growth and land-cover change
A. Gaughan, F. Stevens, C. Linard, Peng Jia, A. Tatem., 2013	High-Resolution Population Distribution Maps for Southeast Asia in 2010 and 2015	integration of high-resolution satellite imagery, census data, and geospatial modeling techniques	The research produced high-resolution population distribution maps for Southeast Asia in 2010 and 2015, providing valuable insights into population dynamics in the region.
Linard, C., Gilbert, M., Snow, R.W., Noor, A.M., and Tatem, A.J., 2012	Modeling spatial patterns of urban growth in Africa with spatial regression, GIS, and remote sensing.	Spatial regression analysis, GIS-based spatial analysis, Remote sensing data analysis	The study utilized spatial regression, GIS-based spatial analysis, and remote sensing data analysis to model spatial patterns of urban growth in Africa, providing valuable insights for urban planning and sustainable development initiatives.
F. Stevens, A. Gaughan, C. Linard, A. Tatem., 2015	Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data	Random Forests algorithm alongside remotely-sensed and ancillary data	The study demonstrated the efficacy of Random Forests and remotely-sensed data in disaggregating census data for precise population mapping, enhancing the accuracy of population distribution estimates.
Pierre Deville, C. Linard, Samuel Martin, M. Gilbert, F. Stevens, A. Gaughan, V. Blondel, A. Tatem., 2014	Dynamic population mapping using mobile phone data	spatiotemporal distribution of MP calls	The findings provide a near real-time understanding of patterns and processes in human geography.
Ezra Wekisa, C. Majale., 2020	Spatial distribution of waste collection points and their implications on quality of life in Mombasa County, Kenya	GPS, GIS, Spatial analysis	Collection points are inadequate and has led to the emergence of informal collection points and exposed the residents to communicable diseases.
Muiruri, J. M., Wahome, R., & Karatu, K. (2020)	Study of residents' attitude and knowledge on the management of solid waste in Eastleigh, Nairobi, Kenya	Rapid Appraisal Approaches	The study highlighted the disparity between residents' knowledge and attitude towards solid waste management in Eastleigh, Nairobi, emphasizing the need for behavioral change and community involvement to improve waste management practices in the area.
Kibetu, D. K., & Muchiri, D. (2017)	Using GIS to Select Ideal Sites for Municipal Wastes Transfer Station: Case Study of Embu Municipality	GIS Modelling and Spatial Analysis	The findings underscored the importance of leveraging GIS technology in waste management planning to address the challenges faced by local authorities in dealing with waste disposal and volume reduction effectively.
James, K. K. (2020)	Using GIS in Dumping Site Selection: A Case Study of Homa Bay Town	GIS, GPS, satellite imagery	The findings emphasized the importance of proper waste management policies, the use of GIS technology for efficient waste collection, and the need for sustainable waste disposal practices to protect the environment and public health.

Table 1: Related Literature Materials

3.2. Assessment of Waste Management Systems in Mombasa County

Mombasa grapples with a daily waste generation of 2,200 tons but only manages to collect 65%; this leaves a significant portion (35%) uncollected, creating a potential health risk for residents (Athman, 2017). Due to increased

urbanization and continued migration into the county, waste generation is projected to increase by 30%. This indicates a growing challenge for waste management authorities and necessitates proactive measures to handle the escalating waste volumes effectively. According to the CIDP 2023, the waste collection fleets have grown from 10 to 22 between 2018-2022, and the area is projected to increase to 43 trucks to ensure the efficiency of waste collection. However, some households use private waste handlers who charge high collection fees; as a consequence, most households dump their waste in undesignated areas (Wekisa & Majale, 2020). These wastes find their way to the only designated landfill in Mwakirunge.

3.3. Spatial Analysis of Population Densities and Waste Management Infrastructure

A spatial analysis of population densities and waste management infrastructure provides insights into the interplay between demographic trends and waste management systems. According to Wekisa and Majale (2020), the county is served by nine designated waste collection points strategically placed in densely populated areas and on major accessible roads.

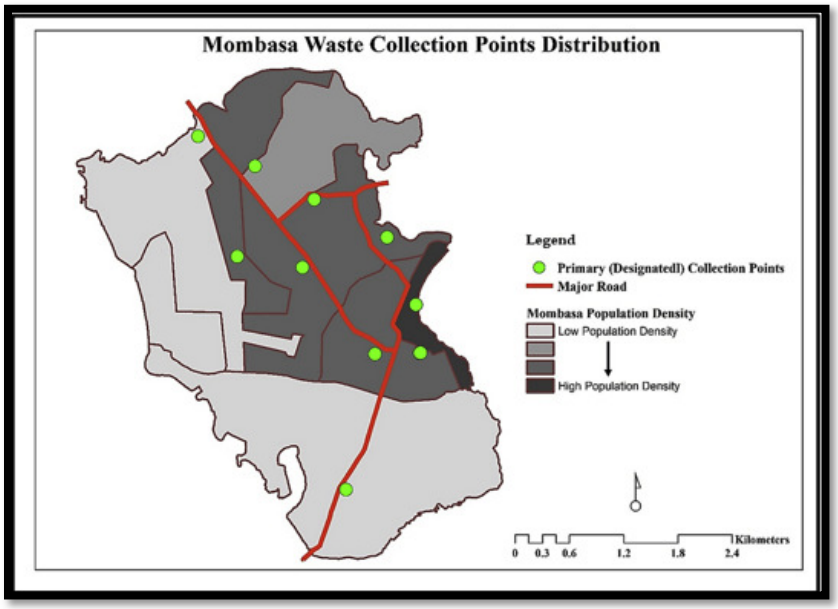

Figure 2: Spatial Distribution of Waste Collection Points
Source: Wekisa and Majale 2020

3.4. Challenges and Opportunities for Sustainable Waste Management

One of the most pressing challenges is the lack of proper infrastructure and resources. The existing waste collection system struggles to keep pace with the growing population and waste generation. Furthermore, inadequate waste disposal facilities exacerbate the problem. The primary landfill, Mwakirunge, is located far from the city center, increasing transportation costs and environmental concerns. Additionally, the reliance on open burning to manage uncollected waste releases harmful toxins into the air, negatively impacting public health. Public behavior also plays a crucial role. Limited awareness about waste segregation and responsible disposal practices leads to littering and illegal dumping, further burdening the already strained waste management system. Additionally, the informal waste collection sector, while providing a livelihood for some, often lacks proper training and equipment, hindering efficient and environmentally sound waste handling. Lastly, there are inadequate facilities and technologies for promoting circular economy transition.

Mombasa County presents several opportunities for advancing waste management practices to address the growing challenges associated with increased urbanization and population growth. Implementing efficient and sustainable solid waste management systems is paramount, with strategies such as composting organic waste and exploring waste-to-energy technologies offering promising solutions. Establishing a Waste Management Information System can facilitate data-driven decision-making while fostering civic engagement can enhance community participation in waste management initiatives. Additionally, promoting waste recycling and transitioning to a circular economy model can minimize waste generation and promote resource conservation. Monitoring and evaluating waste characteristics at the source can inform targeted interventions while enhancing the delivery of waste management services and regulating waste collection, transportation, and disposal, which are essential for effective operations. Collaboration through partnerships and stakeholder networking can leverage resources and expertise while fostering waste management. Enterprising initiatives can spur innovation and entrepreneurship in the sector. By capitalizing on these opportunities, Mombasa County can develop robust waste management systems that are environmentally sustainable and responsive to the needs of its growing urban population.

4. Implications for Urban Planning and Environmental Management

The findings from the spatial analysis of population densities and waste management infrastructure have significant implications for urban planning and environmental management in Mombasa County. Understanding the spatial distribution of population densities enables urban planners to identify areas of high population concentration and anticipate future growth trends. This information is invaluable for guiding land-use planning decisions, infrastructure development, and service provision to meet the needs of a growing population. Additionally, mapping waste management infrastructure highlights areas with inadequate waste collection services and informs targeted interventions to improve coverage and efficiency. By integrating spatial analysis into urban planning processes, authorities can optimize resource allocation, enhance service delivery, and promote sustainable development practices that mitigate environmental risks associated with waste accumulation and improper disposal. Moreover, leveraging Geographic Information Systems (GIS) and Remote Sensing techniques can facilitate real-time monitoring of urban dynamics and inform evidence-based policy formulation for addressing emerging challenges in waste management and environmental sustainability.

5. Conclusion and Recommendations

In conclusion, the spatial analysis of population densities and waste management infrastructure in Mombasa County underscores the importance of employing advanced GIS and Remote Sensing techniques to inform urban planning and environmental management strategies. The findings highlight the need for targeted interventions to address disparities in waste collection services and improve coverage in underserved areas. Furthermore, the projected increase in waste generation necessitates proactive measures to enhance waste management infrastructure and capacity to meet future demand. To achieve this, it is recommended that Mombasa County invest in upgrading waste collection fleets, expanding waste disposal facilities, and implementing public awareness campaigns to promote responsible waste disposal practices. Additionally, partnerships with private sector stakeholders and community-based organizations can facilitate resource mobilization and foster collaborative approaches to addressing waste management challenges. Furthermore, integrating spatial analysis into urban planning processes can enhance decision-making and promote sustainable development practices that prioritize environmental conservation and public health. By implementing these recommendations, Mombasa County can enhance its waste management systems, improve urban livability, and ensure a cleaner and healthier environment for current and future generations.

6. References

i. Athman, A. (2017). Mombasa County seeks innovative ways to deal with waste management. *Italicize Title of Periodical/Journal, Volume Number*(Issue Number), Page Numbers.
ii. CIDP. (2023). The county government of Mombasa Third County integrated the county's vision, mission and core values county vision.
iii. Jia, P., & Gaughan, A. E. (2016). Dasymetric modeling: A hybrid approach using land cover and tax parcel data for mapping population in Alachua County, Florida. *Applied Geography, 66*, 100–108.
iv. Kiranga, J. M. (1992). Migration trends in Mombasa District.
v. Kenya National Bureau of Statistics (KNBS). (2019). 2019 Kenya Population and Housing Census: Volume II.
vi. Linard, C., Kabaria, C. W., Gilbert, M., Tatem, A. J., Gaughan, A. E., Stevens, F. R., Sorichetta, A., Noor, A. M., & Snow, R. W. (2017). Modelling changing population distributions: An example of the Kenyan Coast, 1979–2009. *International Journal of Digital Earth, 10*(10), 1017–1029.
vii. Mennis, J. (2003). Generating surface models of population using dasymetric mapping. *Professional Geographer, 55*(1), 31–42.
viii. Siljander, M., Clark, B. J. F., & Pellikka, P. K. E. (2011). A predictive modelling technique for human population distribution and abundance estimation using remote-sensing and geospatial data in a rural mountainous area in Kenya. *International Journal of Remote Sensing, 32*(21), 5997–6023.
ix. Wekisa, E., & Majale, C. (2020). Spatial distribution of waste collection points and their implications on quality of life in Mombasa County, Kenya. *Journal of Urban Management, 9*(2), 250–260.
x. Zandbergen, P. A., & Ignizio, D. A. (2010). Comparison of dasymetric mapping techniques for small-area population estimates. *Cartography and Geographic Information Science, 37*(3), 199–214.
xi. Make sure to italicize the titles of journals and capitalize only the first word of the title and subtitle, as well as proper nouns, in titles of articles, chapters, and books.