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Original Article

Impact of Population Dynamics on Solid Waste Generation Trends in Dar Es Salaam Metropolitan

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ABSTRACT

Rapid population growth observed across the global landscape can be traced from the dawn of the last half of the twentieth century. The period is marked by enormous land use and land cover changes, the rising rate of declining biological resources as well a continuous high rate of urbanisation. Dar es Salaam City, once a fishing village but now the most industrialised and urbanised city in Tanzania, has not been spared of such changes. This article composition intended to uncover the correlation between population growth and solid waste generation in the city of Dar es Salaam. The data inputs involved Tanzania's national population census for the years 2002, 2012, and 2022, but also shapefiles for Dar es Salaam City and the United Republic of Tanzania. Dar es Salaam city's wards, the lowest but one administrative level in Tanzania, were central in this study as the lowest unit of analysis. Data management for this spatiotemporal study was done in Microsoft spreadsheet, while data analysis involved the use of the ArcMap platform of ArcGIS version 10.5. The results show a strong relationship between population growth and municipal solid waste generation in Dar es Salaam city. From the visual results, the overall impact of population on solid waste generation is well presented across both census years. Despite varying at different times in the twenty years of the study period, wards such as Kunduchi, Mabibo, Majohe, Mbagala Kuu, Mbezi, Mianzini, Saranga, Segerea, Vingunguti, Wazo, and Charambe produced significant amounts of solid waste. Across the study period, Vingunguti and Majohe were revealed to be the only two wards in the city that have continued generating high solid wastes. These visual results display the almost exact location of a high waste generation hence delivering information necessary for strategic and informed decision-making, henceforth, policy formulation towards solid generation and management.

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INTRODUCTION

Globally, solid wastes, which means any discarded material from human activities (Mohsenizadeh et al., 2020; Popp, 2020) has a broad spectrum. Literature (Chen et al., 2020; Kazuva & Zhang, 2019; Nyampundu et al., 2020; Popp, 2020) provides that solid waste includes bottles, metals and plastic scrapers, glasses, and food/animal products, disposable carrying bags, wood and or malfunction electronic devices. The quantities of waste in each of the aforementioned categories have been on record rise since the onset of the midst of 20th century (da Silva et al., 2019; Kumar & Agrawal, 2020; Naveen, 2021; Sanjeevi & Shahabudeen, 2015; Yau, 2012). While markets and shopping places are explained to accounting a huge quantity of solid waste (Nyambod, 2010; Nyampundu et al., 2020), globally, construction industries/sites are the lead sector in solid waste generation (Coelho & De Brito, 2012; Tam & Lu, 2016; Villoria Sáez et al., 2012; Zheng et al., 2017).

According to literature (Naveen, 2021; Nyampundu et al., 2020; Warunasinghe & Yapa, 2016), the generation and management of solid waste is a global challenge in most Anthropocene landscapes, in particular, in developing countries. Various works of literature (Nyampundu et al., 2020; Warunasinghe & Yapa, 2016) epitomise population growth, rate of urbanisation, economic/income status, industrialisation as well as space and place values utilisation as key drivers for solid waste generation. Across global regions, solid waste generation (SWG) is projected to be 3539 Mt in 2050 from 1999 Mt in 2015 and 635 Mt in 1965 (Popp, 2020). Literature (Ghosh, 2016) provides the global average rate of SWG in kg/cap/day to be 0.74 and 0.47 in East African Community (EAC) region. Comparing SWG between low- and high-income earners, the rate stands at 0.26 and 0.78 kg/cap/day (Aryampa et al., 2019; Wang et al., 2021). Such coefficient of SWG for Dar es Salaam Metropolitan is 0.82 kg/cap/day (Aryampa et al., 2019; Nyampundu et al., 2020; Wang et al., 2021).

The complexity of urban solid waste management is hinged on the level, quantity, and quality of solid waste information required and available (Chen et al., 2020; Khan et al., 2022; Naveen, 2021; Nyampundu et al., 2020; Popp, 2020). The way and means of accessing, processing, and consuming such information are further explained to be central to any solid waste management strategy (Chen et al., 2020; Nyampundu et al., 2020; Popp, 2020). Data on the quantity of urban SWG is profoundly associated with the performance of civil servants among many stakeholders. What is clearly known because of its conspicuous nature are the piles of solid waste in many parts of Dar es Salaam Metropolitan. According to Kazuva et al. (2021) and Kazuva and Zhang (2019), SWG can be mapped using the recognisable SWG coefficient index available, census population data, and geographical information system platform.

While this article highlights the many factors that drive SWG, the impact of population growth on SWG can vividly be explained using Dar es

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Salaam Metropolitan's population trends in the past twenty years, from 2022. Apart from population growth, SWG in this East African coastline metropolitan is further influenced by growing income (Aryampa et al., 2019; Kazuva & Zhang, 2019; Nyampundu et al., 2020). However, the challenges of accessing data on income growth at the ward level hindered its utilisation in this article. According to Kazuva et al. (2021), an effective strategy for solid waste generation and management should involve spatial-temporal analysis techniques. In such consideration, this article maps the spatial-temporal distribution of SWG across the Dar es Salaam Metropolitan landscape.

MATERIAL AND METHODS

Study Area

The study was conducted in Dar es Salaam, a region covering a total area of 1,800 km^2, of which landmass is 1,350 km^2. The study area is the most populous and industrialised city in Tanzania which sits at latitude 6^o 37′ 20.4212″S and longitude 39^o 8′ 42.0144″E at about 24 meters above sea level on the western shoreline of the Indian Ocean. Dar es Salaam is home to over 5.3 million people (NBS 2022) in five administrative districts of Ilala, Kinondoni, Temeke, Kigamboni, and Ubungo. It receives an average of 172 millimetres of rainfall annually, with a maximum and minimum temperature of 29.5 ^{o}C and 21.7 ^{o}C, respectively.

With a population growth rate of 5.6, this metro is the third among the fastest-growing cities in Africa and ninth at the global level (Coffetti et al., 2022). The city experiences an acute shortage of residential units annually, with over 75 per cent of place and space values being informal settlements. Literature (Pasquini et al., 2020; Todd et al., 2019) provides that such informal settlement attracts informal jobs by 40 per cent. Combining the multiplier effect of informal settlements and jobs characterises a great deal of SWG and solid waste management (SWM) challenges. As Aryampa et al. (2019) describe a city's SWG as being a result of both population growth and economic growth, innovations and knowledge creation for city's SWM is required now more than tomorrow. Collection and landfill disposal capacity of only 15 per cent of an estimated 4252 tons of daily SWG proves the overburdened of SWM across all five districts/municipalities in Dar es Salaam city.

In view of this background, the research study dwelled on developing a solid waste minimisation model at source, such as reducing, recycling and or reusing wastes as a strategy to relieve the dumpsite overburden at municipal levels. (*Figure 1*).

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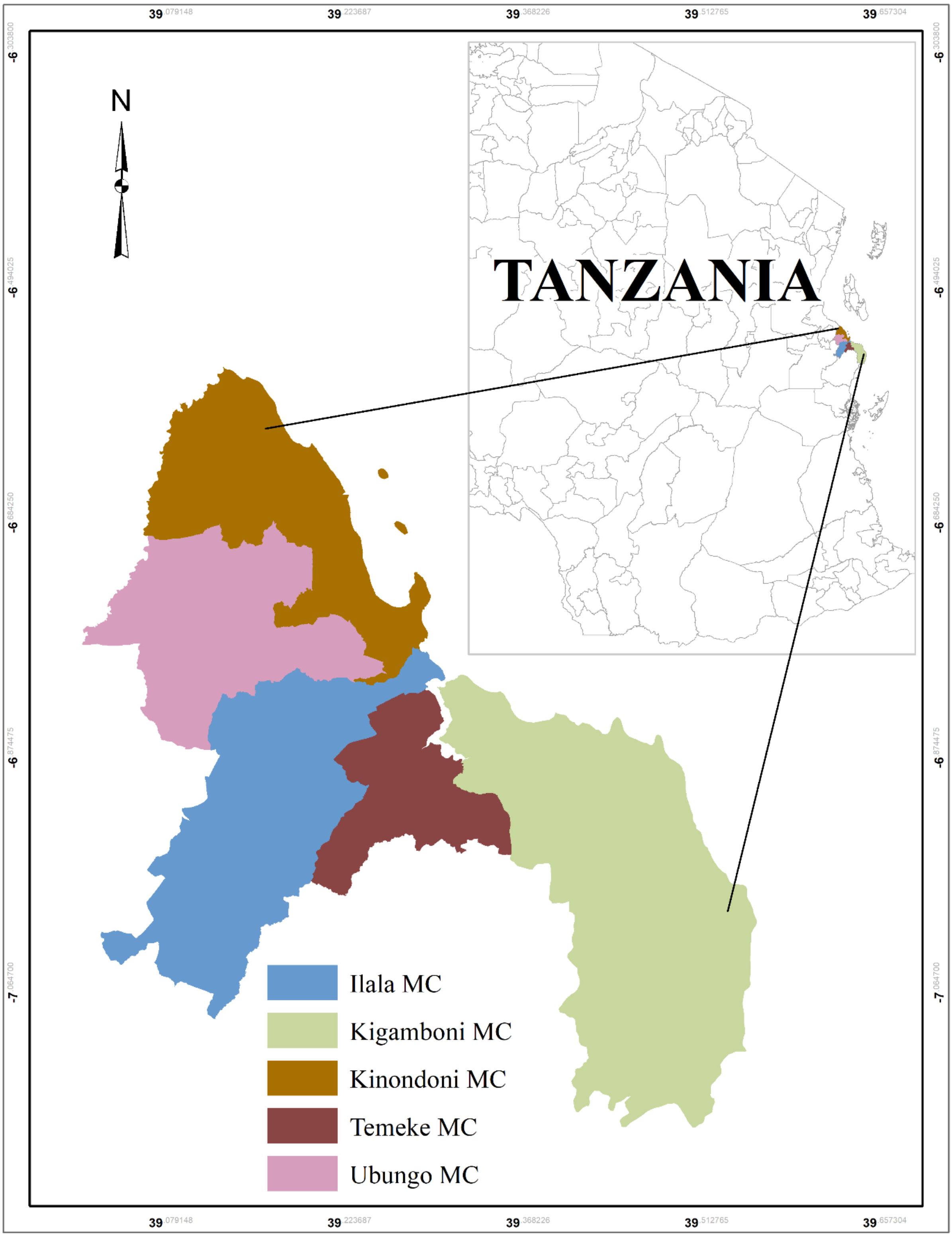
Figure 1: Map of Dar es Salaam City, Displaying Study Area



Data Type and Sources

The study utilised National Bureau of Statistics Census Population Data for years 2002, 2012 and 2022 to analyse SWG across Dar es Salaam Metropolitan. The rate of SWG for Dar es Salam has been widely studied such that it has a recognisable SWG coefficient of 0.82 kg/cap/day (Aryampa et al., 2019; Gebremedhin et al., 2018; Kazuva et al., 2018; Mbuligwe et al., 2002; Nyampundu et al., 2020). The shapefile for Dar es Salaam city applied in this study was freely

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downloaded from the Tanzania National Bureau of Statistics (NBS) website (https://www.nbs.go.tz/index.php/en/census-surveys/gis/568-tanzania-districts-shapefiles-2019). Further data management was done in Microsoft spreadsheet and ArcMap 10.5. The full set of data used in this study is provided in this article as Appendix I.

Geostatistical Analysis Inverse Distance Weighing

Spatial interpolation is a useful GIS technique for estimating unmeasured data based on measured samples of the same variables (Kim et al., 2021). The advent of remote sensing (RS) and geographical information system (GIS) have proved to solve some challenges emanating from physical infrastructures, time, and financial resources with respect to data access and utilisation. Furthermore, physical-legal complexities in data capturing, management and consumption contributed significantly to the wide application of spatial interpolations in environmental sciences, geoscience and continuous spatial surface data (Manyama et al., 2021; Morano et al., 2017).

According to Lam et al. (2015) and Zarco-Perello and Simões (2017), interpolation science provides efficient techniques to map and understand continuous spatial phenomena, in particular, the spatial-temporal physical changes on the global landscape. Studies (Martínez de Anguita et al., 2011) epitomise that knowing GIS procedures (Tang et al., 2015), the quality of the work to be performed and the geographical boundaries of the study sites; interpolation offers an opportunity to understand and predict the occurrence, distribution and magnitude of an environmental phenomenon with respect to social and economic factors. Studies (Zarco-Perello & Simões, 2017) exemplify spline, kriging, natural neighbour and inverse distance weighting (IDW) as the commonly used geostatistical analysis tool for geospatial interpolation methods.

In this study, IDW, a geostatistical analysis tool, treated SWG values available at the ward (last but one lowest administrative level in Tanzania) as values at points within a certain cut-off distance (Kazuva et al., 2021), hence applied to understanding the spatial distribution trends of solid waste in the year 2002, 2012 and 2022 in the landscape of Dar es Salaam Metropolitan.

DATA ANALYSIS AND RESULTS

Using the SWG coefficient of 0.82 kg/cap/day for Dar es Salaam and population census data for Dar es Salaam for National Census for the years 2002, 2012 and 2022, the study produced SWG data per each administrative ward in the five districts of Dar es Salaam Metropolitan. Availability of ArcMap 10.5 skills enabled further management of such ward-based SWG data. The results of data analysis in the ArcMap platform are presented in *Figure 2a*, *b* and *c*.

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Figure 2: Dar es Salaam Metropolitan SWG Trend (kg/cap/day) from 2002 – 2022

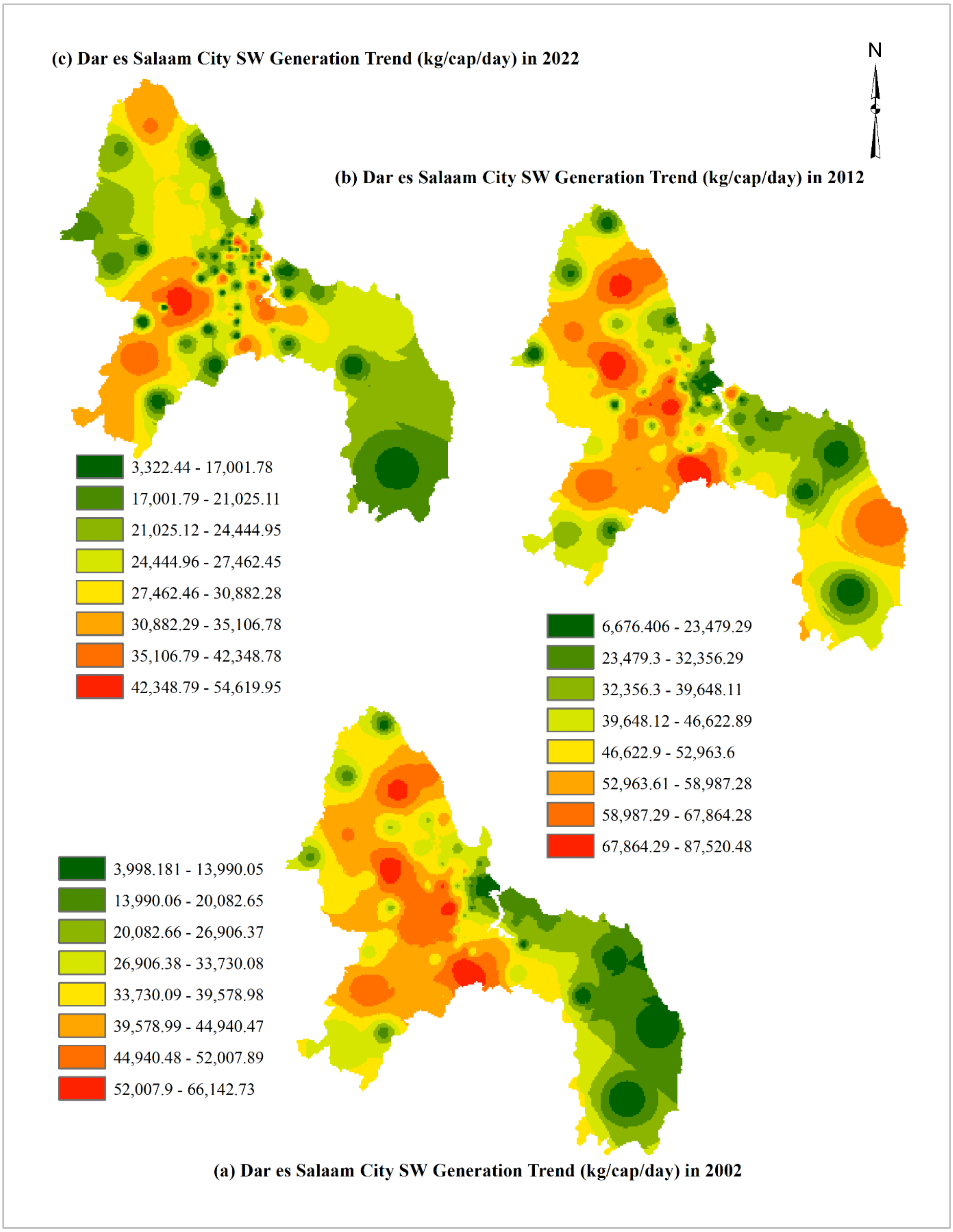

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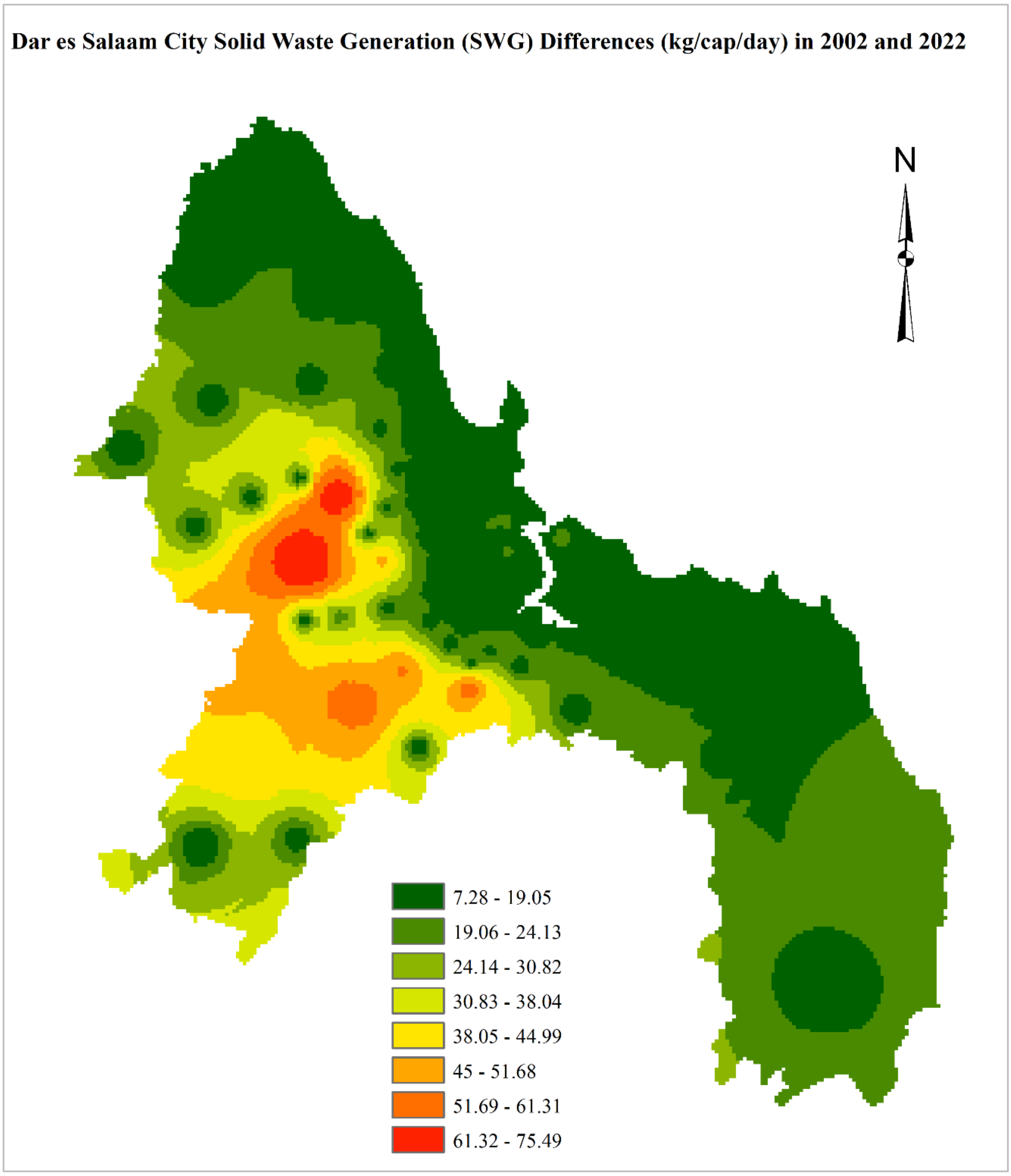
Figure 3: Overall SWG in Dar es Salaam City (kg/cap/day) from 2002 to 2022



DISCUSSION

From the visual results presented in *Figure 2* and *Figure 3*, the overall impact of population on solid waste generation is well presented across both census years. Comparing the northern and southern parts of Dar es Salaam City, there is more solid waste generation (SWG) in the northern than in the southern part in the same periods. Such high SWG in the northern part of the city could be associated not only with population growth as census data display but also expanding built environment infrastructures (Tam & Lu, 2016; Zheng et al., 2017). In the central business district (CBD), high SWG is linked to increasing tall building residential infrastructures (Ali & Al-Kodmany, 2012).

Further demographic analytics display the CBD area to be dominated by middle-income earners and young adults (Alananga & Igangula, 2022). According to Alananga & Igangula (2022) and

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Yaacob et al. (2019) such demographic clusters tend to be higher spenders and choosy hence more SWG in their vicinity. Rising urban population increase material consumption; hence waste generation also increases. Similarly, population growth results in rising population density, which indirectly accounts for higher material demand and supply (Kazuva et al., 2018; Kazuva & Zhang, 2019; Thomson & Newman, 2018) which ends up in solid waste generation. According to Biswas and Singh (2021), growing income due to increasing activities as a result of population growth results in disposable income, henceforth, huge SWG.

The findings generally show a decreasing trend of SWG in the city of Dare es Salaam. The highest SWG (kg/cap/day) was observed in 2012 with a range of 67, 864.29 to 87, 520.48. Comparing 2002 and 2022 the range was 52, 007.9 – 66, 142.73 and 42,348.79 – 54,619.95, respectively (*Figure 2*). These SWG dynamics could be linked to population growth rate differences, which are 5.60 per cent in 2012, 4.42 per cent in 2002 and 5.08 per cent in 2022. The increasing population in a certain locality triggers demand in socio-economic infrastructures to cater for education, health, transport and water services among many needy services for daily livelihood (Kumar & Agrawal, 2020). The dynamics observed in SWG are strongly linked to the concept of population growth versus demand and supply of human livelihood, which all end-up producing various wastes, SWG being the highest.

Generally, the amount of solid waste generation was very low in the whole of the southern part of Dar es Salaam city (*Figure 2c*). This is contrary to the trend in 2012, in which the same area experienced increasing solid waste generation (*Figure 2b*); the trend observed displayed a significant decrease in SWG (*Figure 2c*). In the period between 2012 and 2020, there was government intervention at the local level, and political will from the head of state influenced local government by-laws hence an improvement in solid waste management.

Across the study area, there were wards that at varying periods displayed dominance in high SWG, these include Kunduchi, Mabibo, Majohe, Mbagala Kuu, Mbezi, Mianzini, Saranga, Segerea, Vingunguti, Wazo and Charambe. Further analysis displayed Vingunguti and Majohe to be the only two wards in the city that have been consistently leading in huge SWG in the years 2002, 2012 and 2022. All these wards are informal settlements (Mkalawa, 2016). The dominance of informal settlement in the list of high SW-generating wards underlines the role of land use plan contribution to solid waste generation (Kazuva et al., 2021; Kirama & Mayo, 2016; Senzige et al., 2014). Analysing the difference in SWG in the city between 2002 and 2022 (*Figure 3*) shows that the wards close to the dumpsite (old or existing) experienced high solid waste generation. This is likely to be the factor for high solid waste generation in Majohe, which is in the vicinity of the current Pugu dumpsite, while Vingunguti is just a doorstep to the old Vingunguti dumpsite.

On the other hand, effective local government programme on solid waste management (SWM) from 2002 to 2022 communicates the reason for the improvement of SWM in the study area (*Figure 3*). While in the past 20 years, the coastline has displayed significant improvement, the periphery of the city continues to experience high SWG (Kazuva et al., 2021). This could be attributed to the city's urbanisation rate, construction activities and sand mining.

CONCLUSION

The solid waste generation trend in Dar es Salaam Metropolitan contributed to several factors; these include population growth, rate of urbanisation, economic/income status, industrialisation, as well as space and place values.

According to the study findings, when comparing SWG coverage for the years 2002 (*Figure 2a*), 2012 (*Figure 2b*) and 2022 (*Figure 2c*), the highest amount of SWG was observed in 2012, ranging from 67, 864.29 to 87, 52048 kg/cap/day. The study found that SWG is increasing in the

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western peripherals of the city and in the vicinity of old and existing dumpsites. Furthermore, the study shows high SWG in informal settlements than in formal. This could be communicating the need for land use planning as a strategy to reduce the impact of population growth on SWG trends in developing countries such as Tanzania.

AUTHORS' CONTRIBUTION

Abdon Mapunda, a doctoral student at the University of Dar es Salaam designed this research article, collected and analysed the data, and prepared the manuscript. Dr Richard Kimwaga and Shaban Kassuwi supervised the research progress to the manuscript revision.

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Appendix 1: Dar es Salaam Population and Solid Waste Data for Year 2002, 2012 and 2022

Ward Name	Lat	Long	2002 Pop	2012 Pop	2022 Pop	2002 WASTE	2012 WASTE	2022 WASTE
Azimio	-6.87	39.26	58177	76832	48732	47,705	63,002	39,960
Buguruni	-6.83	39.24	53446	70585	49530	43,826	57,880	40,615
Bunju	-6.63	39.13	45610	60236	38516	37,400	49,394	31,583
Buza	-6.89	39.24	41708	55082	35476	34,200	45,167	29,090
Chamazi	-6.96	39.22	48195	63650	41534	39,520	52,193	34,058
Chang'ombe	-6.84	39.26	14615	19302	12298	11,985	15,828	10,084
Chanika	-7.02	39.08	33250	43912	28597	27,265	36,008	23,450
Charambe	-6.92	39.25	77183	101933	34243	63,290	83,585	28,079
Gerezani	-6.82	39.27	5509	7276	4649	4,518	5,966	3,812
Goba	-6.73	39.15	32309	42669	27078	26,493	34,989	22,204
Gongo la Mboto	-6.88	39.15	43396	57312	36388	35,585	46,996	29,838
Hananasif	-6.79	39.27	28103	37115	23380	23,045	30,434	19,172
Ilala	-6.83	39.26	23536	31083	19514	19,299	25,488	16,001
Jangwani	-6.81	39.27	13362	31083	10538	10,957	25,488	8,641
Kariakoo	-6.82	39.27	10434	17647	8355	8,556	14,471	6,851
Kawe	-6.72	39.22	50819	13780	42376	41,672	11,300	34,748
Keko	-6.83	39.27	26625	67115	21337	21,833	55,034	17,496
Kibada	-6.89	39.33	6500	35163	5384	5,330	28,834	4,415
Kibamba	-6.77	39.04	21871	8585	18582	17,935	7,040	15,237
Kiburugwa	-6.90	39.25	59751	28885	69168	48,996	23,686	56,718
Kigamboni	-6.83	39.31	23091	78911	18517	18,935	64,707	15,184
Kigogo	-6.82	39.24	43624	30496	36423	35,772	25,007	29,867
Kijichi	-6.89	39.29	52394	57613	43763	42,963	47,243	35,886
Kijitonyama	-6.78	39.24	44017	69195	37070	36,094	56,740	30,397
Kilakala	-6.87	39.24	34035	58132	27713	27,909	47,668	22,725
Kimanga	-6.82	39.19	59483	44949	50186	48,776	36,858	41,153
Kimara	-6.80	39.17	57983	78557	97749	47,546	64,417	80,154
Kimbiji	-7.00	39.51	4854	76577	3760	3,981	62,793	3,083
Kinondoni	-6.78	39.27	16082	6411	13550	13,187	5,257	11,111
Kinyerezi	-6.84	39.15	29050	21239	7097	23,821	17,416	5,820
Kipawa	-6.87	39.20	56169	38366	46908	46,058	31,460	38,465
Kisarawe II	-6.96	39.41	6289	8306	5172	5,157	6,811	4,241
Kisutu	-6.81	39.28	6291	8308	5881	5,158	6,813	4,822
Kitunda	-6.91	39.21	43260	57132	20705	35,473	46,848	16,978
Kivukoni	-6.81	39.29	5105	6742	4148	4,186	5,528	3,401
Kivule	-6.93	39.18	54542	72032	23451	44,724	59,066	19,230
Kiwalani	-6.86	39.23	62311	82292	70104	51,095	67,479	57,485
Kunduchi	-6.66	39.20	56802	75016	46993	46,577	61,513	38,534
Kurasini	-6.84	39.29	19833	26193	16265	16,263	21,478	13,337
Kwembe	-6.82	39.08	43083	56899	36379	35,328	46,657	29,831
Mabibo	-6.81	39.22	64918	85735	54032	53,233	70,303	44,306
Mabwepande	-6.66	39.09	19278	25460	16189	15,808	20,877	13,275
Magomeni	-6.80	39.26	18475	24400	15052	15,150	20,008	12,343
Majohe	-6.95	39.12	61822	81646	34428	50,694	66,950	28,231
Makangarawe	-6.88	39.25	40352	53291	33654	33,088	43,699	27,596
Makongo	-6.76	39.19	33162	43796	27349	27,193	35,913	22,426
Makuburi	-6.81	39.20	43469	57408	35686	35,644	47,075	29,263

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Ward Name	Lat	Long	2002 Pop	2012 Pop	2022 Pop	2002 WASTE	2012 WASTE	2022 WASTE
Makumbusho	-6.79	39.25	51559	68093	42904	42,279	55,836	35,181
Makurumla	-6.80	39.24	47970	63352	39707	39,335	51,949	32,560
Manzese	-6.79	39.23	53387	70507	44518	43,778	57,816	36,505
Mbagala	-6.90	39.26	39815	52582	33048	32,648	43,117	27,099
Mbagala Kuu	-6.91	39.28	56618	74774	47935	46,427	61,315	39,307
Mbezi	-6.74	39.09	55588	73414	47120	45,583	60,199	38,638
Mbezi juu	-6.72	39.20	31302	41340	26108	25,668	33,899	21,409
Mburahati	-6.81	39.24	25838	34123	21553	21,187	27,981	17,673
Mbweni	-6.59	39.14	10424	13766	8736	8,547	11,288	7,164
Mchafukoge	-6.82	39.28	8093	10688	7078	6,636	8,764	5,804
Mchikichini	-6.82	39.26	19316	25510	15466	15,839	20,918	12,682
Mianzini	-6.93	39.26	76211	100649	44951	62,493	82,532	36,860
Miburani	-6.85	39.27	33536	44290	27693	27,500	36,318	22,708
Mikocheni	-6.76	39.24	24947	32947	21096	20,457	27,017	17,299
Mjimwema	-6.86	39.36	21042	27789	17460	17,254	22,787	14,317
Msasani	-6.76	39.27	37042	48920	31405	30,374	40,114	25,752
Msigani	-6.80	39.12	41730	55111	35428	34,218	45,191	29,051
Msongola	-7.01	39.14	18522	24461	15563	15,188	20,058	12,762
Mtoni	-6.87	39.28	44961	59378	37086	36,868	48,690	30,411
Mwananyamala	-6.78	39.26	38284	50560	32045	31,393	41,459	26,277
Mzimuni	-6.81	39.26	16269	21486	13894	13,341	17,619	11,393
Ndugumbi	-6.80	39.25	27896	36841	23148	22,874	30,210	18,981
Pembamnazi	-7.10	39.47	7324	9672	5997	6,005	7,931	4,918
Pugu	-6.90	39.12	37422	49422	18837	30,686	40,526	15,446
Sandali	-6.85	39.25	39874	52660	32855	32,696	43,181	26,941
Saranga	-6.79	39.15	78844	104127	66696	64,652	85,384	54,691
Segerea	-6.84	39.20	63085	83315	34244	51,730	68,318	28,080
Sinza	-6.78	39.22	30701	40546	25990	25,175	33,248	21,312
Somangila	-6.91	39.45	14601	19283	12055	11,973	15,812	9,885
Tabata	-6.83	39.22	56594	74742	47272	46,407	61,288	38,763
Tandale	-6.79	39.24	41480	54781	33869	34,013	44,920	27,773
Tandika	-6.87	39.26	37474	49491	31833	30,729	40,583	26,103
Temeke	-6.85	39.25	19723	26047	16586	16,173	21,359	13,601
Toangoma	-6.93	39.32	33754	44578	28625	27,678	36,554	23,473
Tungi	-6.83	39.32	17703	23380	14607	14,517	19,172	11,978
Ubungo	-6.78	39.21	42414	56015	34947	34,780	45,932	28,657
Ukonga	-6.87	39.17	60601	80034	73077	49,693	65,628	59,923
Upanga Magharibi	-6.80	39.27	10204	13476	8802	8,367	11,050	7,218
Upanga Mashariki	-6.80	39.28	8456	11167	7714	6,934	9,157	6,325
Vijibweni	-6.86	39.32	21966	29010	18319	18,012	23,788	15,022
Vingunguti	-6.84	39.23	80979	106946	66366	66,402	87,696	54,420
Wazo	-6.68	39.16	68772	90825	56762	56,393	74,477	46,545
Yombo Vituka	-6.88	39.23	58303	76999	48584	47,808	63,139	39,839