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Temporal changes in Rainfall and Temperature influence on Solid Waste Generation in Bungoma county Urban centres, Kenya

Temporal changes in Rainfall and Temperature influence on Solid Waste Generation in Bungoma County Urban Centres, Kenya

Godfrey Wekesa Wafula, Tom Ouna & Hellen Kamiri
Karatina University, Kenya

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Abstract
Globally, temperature and rainfall play an integral role in the management of solid waste in urban areas. This is because many countries especially, the developing countries conventionally rely on both variables in the management of waste. However, the urban environment faces many threats as a result of challenged waste management practices due to these climate stressors. This research aimed to assess how temporal changes in temperature and rainfall influence solid waste generation. The study was carried out in Bungoma county urban centres, specifically Bungoma town, Webuye, Kimilili, Kapsokwony, Chwele, and Sirisia townships. The study applied a stratified sampling technique to select the urban and peri-urban centres while random sampling was used to select respondents in residential dwellings, business people, urban residents, and officers from government institutions including public health and environment, water, and natural resources were interviewed. Ancillary data was collected using questionnaires and interview schedules while historical data was obtained to validate observed data. Data was analysed using descriptive and inferential atistics and summarized using tables, charts, and graphs. he findings of the study indicated that rainfall and mperature significantly influenced the generation of solid waste.

Introduction

Climate variables such as rainfall and temperature play a key role in solid waste management globally (Monni et al., 2006). The impact of climate variables runs across the whole cycle, from solid waste generation and collection to infrastructure maintenance costs, management costs, aspects like recycling and composting, energy costs, health and safety, and financial implications on resilient infrastructure (Bhada-Tata & Hoornweg, 2016).

Rainfall and temperature have economic impacts on solid waste management, specifically on infrastructure, which is key in this field. Alterations in temperature and rainfall have different impacts on different types of infrastructure, depending on the infrastructure function, site, construction, materials, age, and condition (Monni et al., 2006).

Urban waste is a major challenge in developing nations. Numerous diseases and disruptions of the reality of a clean and conducive ecosystem are some challenges that have largely been attributed to factors surrounding waste. Therefore, there is no surprising coincidence in the availability of numerous studies focusing on overriding waste issues in urban areas. However, most of these existing studies have inclined to discuss environmental waste issues from the perspective of its existence rather than generation. Even those who have ventured into the area of how waste is generated have tended to blame the human and socio-economic factors. Yet, evolving realities indicate that this could just be a small segment of the problem. Given this apparent need to think beyond human influence, this study sought to conceptualise its scope in examining how non-man-made factors of a climatic nature influenced a generation of waste and whether any measures towards mitigating waste-related effects could be suggested. Specifically, the study endeavoured to establish the impacts of the climate variables (rainfall and temperature) on solid waste generation to devise strategies that could curb this waste despite these significantly influential climate variables.

The study relied on the Systems Theory advanced by Boulding (1956). The theory capitalises on the emergence of parallelisms in different disciplinary interpretations of reality and consequently provides a platform for the integrated study of complexity in the human experience. In the most basic definition, a system is a group of interacting components that conserves some identifiable set of relations with the sum of the components plus their relations (i.e., the system itself). This theory was useful to this study in guiding its interpretation of the complexity of naturally occurring phenomena of rainfall and temperature fluctuations and how they influence human experience and reaction regarding waste generation. The questions of the interactions between climatic systems, their direct impact on waste generation and the desire to mitigate effects became clearer through this theory.

Climate stressors can directly and indirectly impact solid waste facilities (Gichamo & Gökçekuş, 2019). For example, while higher temperatures may directly alter decomposition rates, climate change may also affect access to roads, ports, and energy, indirectly limiting waste collection and operation of waste management sites (Kalina, 2020). On the other hand, flooding poses the biggest threat to solid waste infrastructure. Without proper water catchment systems around a landfill, heavy rain events can degrade the landfill, causing breaks in the containment structure that allow debris and leachate to escape from the landfill and contaminate local resources (Bhada-Tata & Hoornweg, 2016). Heavy rainfall increases the moisture content of solid waste stored in the open. In tropical climates, large amounts of vegetation can be expected in the waste, and seasonal climates may result in huge piles of leaves during certain times of the year (Cayumi et al., 2021).

The climate also influences the types and yields of crops. Therefore, the food waste generated by residents, e.g. sugarcane waste in countries where vendors sell cane juice on the streets, may result in huge amounts of crushed cane during certain seasons (Gamez et al., 2020). Higher temperatures and drought may also increase fire risks at waste facilities (Ibrahim, 2020). Rim-Rukeh (2014) reported that dump site fires affect atmospheric pollution and, consequently, on-air quality in Nigeria. Trends & Framework (2010), in dealing with solid waste and climate impacts, alludes that climate aspects affect the management systems, which in turn influence climate, especially greenhouse gas emissions.

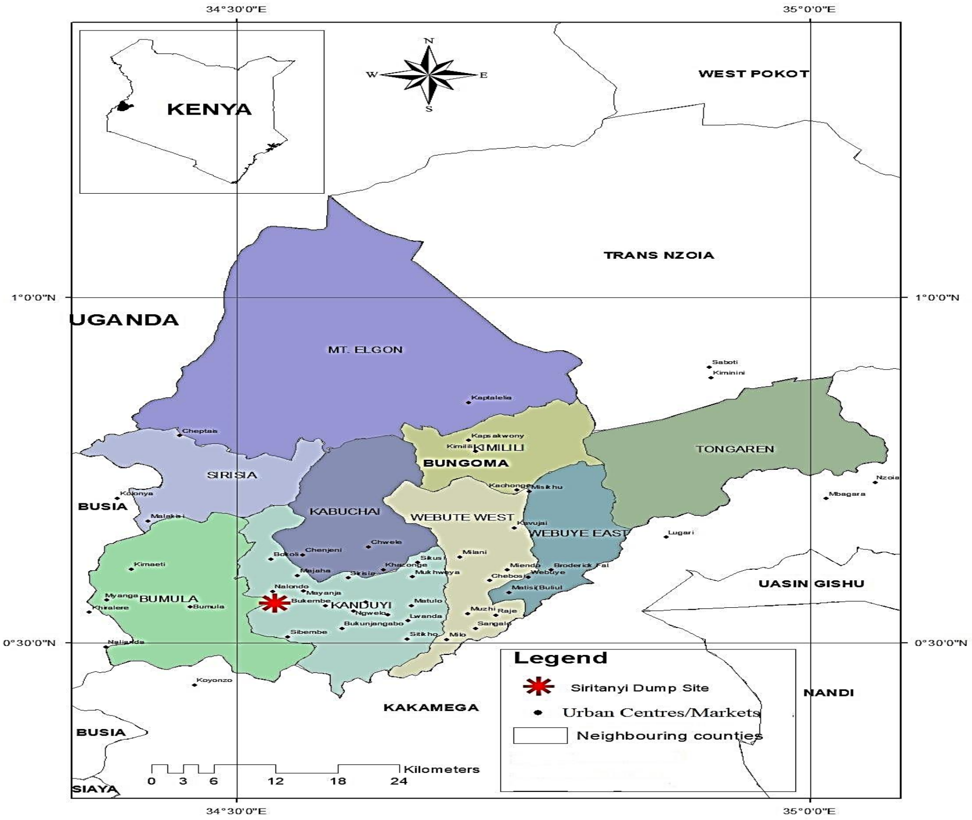
The solid waste collection, processing and disposal costs are critical in developers' practitioners' environment and health sector priorities, including maintaining clean air, soil and water, particularly in urban settings (Gichamo & Gökçekuş, 2019). Moreover, appropriate solid waste management helps mitigate greenhouse gases (Bhada-Tata and Hoornweg, 2016) and land and water pollution (Reyna-Bensusan, 2018). The solid waste sector is a major source of emissions that contribute to climate change, especially methane and black carbon (Gichamo & Gökçekuş, 2019). Methane emissions in the solid waste sector come from the anaerobic decomposition of organic waste. Emissions contributing to climate change come from various sources throughout the different stages of solid waste management, including collection, recycling, transportation, treatment and disposal (Atta et al., 2020).

In terms of their total contribution to climate change, these emissions equate to roughly 2 per cent of all greenhouse gas (GHG) emissions globally (Climate Watch, 2019). Cities produce an ever-growing amount of solid waste due to the ever-increasing urban population. Globally, the World Bank estimates that the amount of municipal solid waste generated by urban areas is growing even faster than the rate of urbanisation (Kaza and Yao, 2018). The urban population in Africa was projected to grow to 1.2 billion in 2050, making Africa the continent with the highest urban population growth (UNDESA, 2022).

Method

The study was carried out in Bungoma County in the western region of Kenya. It covers an area of 2,069 square kilometres and has a population of about 1.671, according to the 2019 census (KNBS, 2019). The area experiences two seasons of rainfall, mainly orographic: the long rainy season and the short rain season, which occurs in March and continues in July, while short rains start in August and up to October. Annually, there is a variation in the amount of rainfall from between 1250 mm and 1800 mm, which is heaviest in April and May. In the first season, the rains are distributed between 1500-1200mm, and the distribution in the second season is 430-1200mm, which is about 60% reliable. The average annual temperature ranges between 21-23^{0}C. The months between April and July seem to have the lowest temperatures, while December to February has relatively higher temperatures. The altitude of the County ranges from over 4,321m (Mt. Elgon) to 1200m above sea level.

Figure 1: A map of Bungoma County, showing various urban centres under study



Research Design

The study adopted both quantitative and qualitative approaches using a cross-sectional survey design. A multi-stage sampling procedure, which included stratifying the sampling area into urban and peri-urban, was used. Random sampling was applied to select residential areas to study, while snowball sampling was used to select individual homeowners and residents. In each, respondents were put in various strata.

Thus, it includes businesses or business enterprises, residential/household institutions, such as schools and colleges, and government and private institutions.

According to KNBS (2019), the population of Bungoma County was reported as 1,670,570, of which 812,146 were males and 858,389 females.

Krejcie and Morgan's (1970) formula was adopted to determine the sample size based on:

$S = X^2NP(1 - P) \div d^2(N - 1) + X^2P(1 - P)$

S = required sample size

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level where

N = the population size

P = the population proportion (assumed to be 0.50 since this would provide the maximum sample size)

D = the degree of accuracy expressed as a proportion (0.05)

As the population increases, the sample size increases at a diminishing rate and remains relatively constant at slightly more than 380 cases. The sample size for this study was 382 from the target population of 190,112 urban dwellers distributed by probability, as shown in Table 1.

Table 1: Distribution of respondents and sample population

Respondents	Frequency	Percentage (%)
Business community	174	45.55
Residential homes	174	45.55
Institutions	30	7.85
NEMA	1	0.26
Public Health	1	0.26
Environment, Water and natural resources	2	0.53
Total	**382**	**100**

NEMA, Public Health, and the Ministry of Environment are institutions whose information was collected through interview schedules; therefore, one or two was enough. Residents, business people, and institutions like schools had a more expansive universe, hence a larger number purposively allocated to them to get as much information as possible.

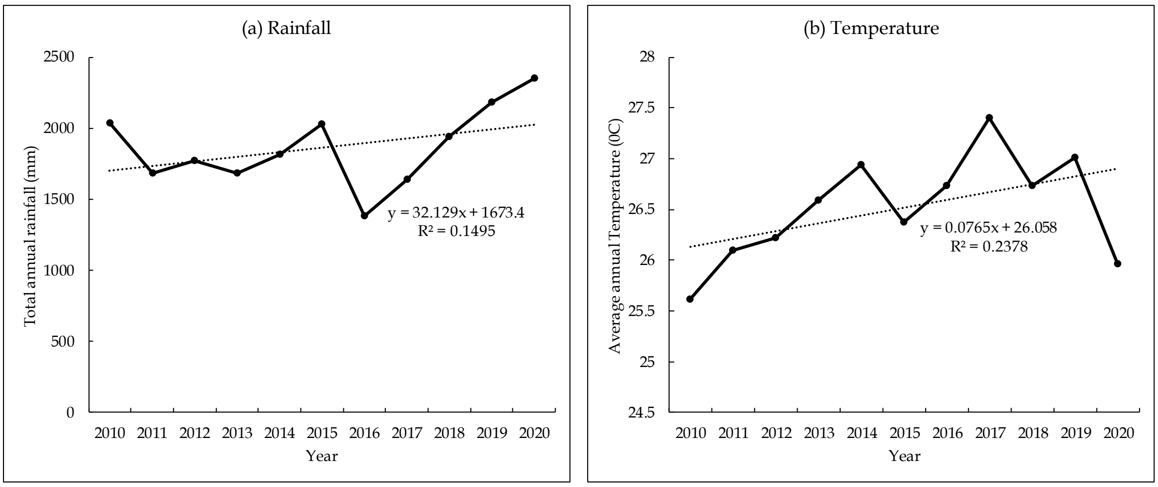
Observation, interviews, document analysis, and questionnaires were the main instruments used to collect data. Interview schedules were carried out with key informants from the Ministry of Environment, Water, Tourism and Climate Change, NEMA and Public Health. This instrument helped the researcher obtain information that could not be directly observed in this study. A total of 310 questionnaires were filled and returned after the study, representing 82.4%.

The data collected was analysed quantitatively using descriptive and inferential approaches; data from the questionnaire was coded and analysed using Statistical Package for Social Science (SPSS) version 28.0. Data collected was cleaned, edited, coded, and analysed descriptively using percentage, frequency, and measures of central tendency, including mean and standard deviation. The data was presented using tables, graphs, and pie charts. Pearson's Product Moment Correlation Coefficient was applied to determine the correlation between climate variables (rainfall and temperature) and waste generation. When Pearson's Correlation *r* is close to 1, it indicates a strong correlation between climate variables and waste generation. A positive

Pearson's *r* means that when one variable increases in value, the second variable also increases. Similarly, as one variable decreases in value, the second variable also decreases.

Influence of Climatic Variables on Solid Waste Generation

Figure 2: Time series of annual rainfall and Temperature data for Bungoma County showing linear trend line


(a) Rainfall
(b) Temperature

Analysis of rainfall and temperature was done from 2010 through 2022. This period was enough because the county government had established the necessary municipal solid waste management measures to support the study. The monthly values were reduced to a single value to understand the rainfall and temperature statistics. Data for temporal waste generation was obtained from the county government, Ministry of Environment, while climate data was obtained from the Kenya Meteorological Department Nairobi for both rainfall and temperature.

The average rainfall for Bungoma County was 1776mm. The highest rainfall was observed in 2010, 2015, 1019 and 2020, amounting to more than 2000 annually. On the other hand, 2016 and 2021 had lower than 1600mm annually. As indicated in Figure 2a, the study shows an increasing linear rainfall trend as denoted by positive slopes in the trend-line equation. The yearly trend-line analysis is presented as $R^{2=}$ 0.1495, which translated to a minimal change in temperature of 0.14 %. A positive slope on the trend line indicated that rainfall was increasing in the study area, although not in all the years.

The study revealed that Bungoma County experiences a mean temperature of 26.5°C. There was a gradual increase in temperature, rising from 26.5°C in 2010 to 27.4°C in 2017. The highest recorded temperature was 27.4°C in 2017, while the lowest was 26.5°C in 2010, as indicated in Figure 2b. The study area displays an increasing temperature trend as denoted by positive slopes in the trend line equation. The yearly trend line analysis presented R^{2} $^{=}$0.2378, translating to a 23.78% change. A positive slope on the trend line indicated the temperature was increasing in the study area, which could have affected the waste generation value chain.

Figure 3: Time series of waste generation, temperature and rainfall trends for Bungoma towns 2010-2022

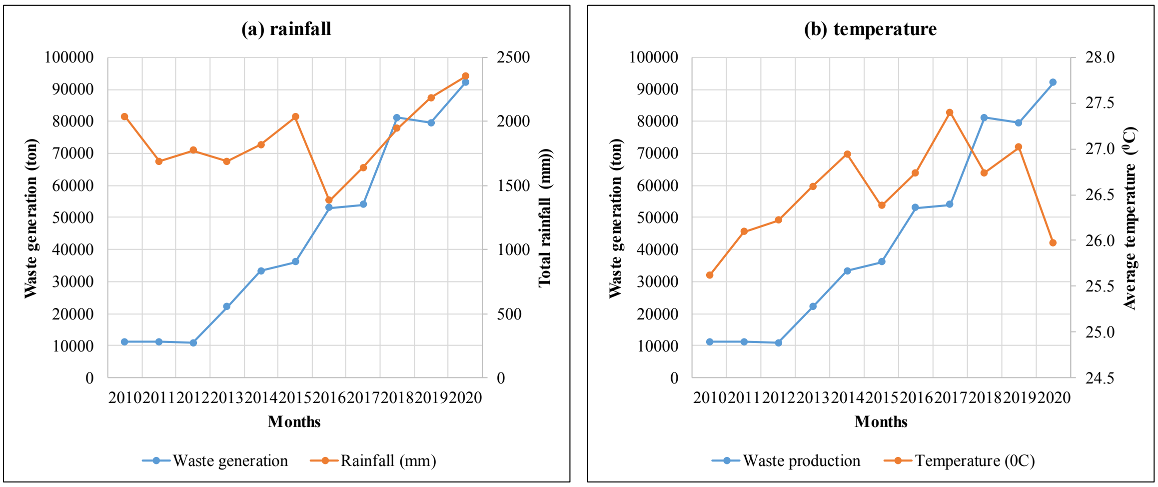


Figure 3a reveals that waste generation in the study area increased as rainfall increased, except in 2016 when it decreased. An increase in rainfall does not solely indicate that there will be an increase in waste generation since other confounding factors may also be at play.

Results in Figure 3b show an increase in temperature, which causes an increase in waste generation. The trend lines show that from 2010 to 2017, as the temperature increased, there was also an increase in the volume of waste generated. However, from 2019 to 2020, the temperatures dropped, but waste generation still rose.

Observed changes in solid waste Generation due to Rainfall and Temperature Patterns

In the study area, 45.7% of the respondents had observed the increased generation of waste during the wet season, 29.2% had observed the shifting waste composition, 20.7% had observed reduced production, and 4.4% had not observed any changes in waste generation as a result of rainfall changes effect. Regarding temperature, our findings show that 42.9% of the respondents have experienced an increase in waste generation due to an increase in temperature, 37.7 % have experienced shifting waste composition, and 15.2% reduced production of solid waste. In comparison, 3.9 % have yet to experience any change in solid waste generation. Results imply that changes in rainfall and temperature patterns have contributed to changes in waste production, which could mainly be agricultural waste, as confirmed by the previous findings, where an increase in rainfall led to a surplus of agricultural production, which translated to the production of large volumes of agricultural waste.

Table 2: Solid waste Generation due to Rainfall and Temperature Patterns (N=310)

	Rainfall	**Temperature**
	F	**F**
Increase production	142(45.7)	133(42.9
Reduced production	64(20.7)	47(15.2)
Shifting waste composition	90(29.2)	117(37.7)
No change	14(4.4)	12(3.9)

Respondents' perception of the effect of rainfall and Temperature on urban solid waste generation

Temperature

Results show that respondents strongly agreed that they had observed increased degradable waste due to high composting rates (43.5%), 32.2% agreed, 5.8% were unsure, 10.3% disagreed, and 8.1% strongly disagreed. Other respondents strongly agreed that they had observed increased agricultural waste due to increased growth and harvests (46.8%),17.4 % agreed, 9% were not sure, 6.4% disagreed %, and 20% strongly disagreed., Waste degradation and gas generation had (30.6%) who strongly agreed,35.5 agreed,5.8% were not sure,12.3 disagreed and15.8% strongly disagreed. Food waste due to spoilage (53.5%) strongly agreed, 22.6% agreed, 5.5% were unsure, 6.4% disagreed, and 11.9% strongly disagreed. A higher percentage of responses agreed and strongly agreed that temperature affected urban solid waste generation.

Findings imply that temperature change causes food spoilage and eventual food waste. High temperatures can increase the speed at which food deteriorates and spoils. The warmer it is, the faster microorganisms, enzymes, moulds, and yeast can grow. Some food products, like tomatoes, mature faster during warmer temperatures, resulting in excessive production and agricultural product waste. Temperature change has also increased the rate of waste degradation and gas generation in the dumpsite, which is an environmental health hazard.

Rainfall

The findings show that respondents had different responses on the effect of rainfall on solid waste generation. Results show that 55% strongly agreed that plastic waste increased due to waterlogged drainage channels. Fifty-one per cent strongly agreed that increased leachate was due to water supply damage, 58% strongly disagreed that there was increased e-waste due to damage of electronic devices by electricity fluctuations, 56% strongly agreed that increased degradable waste was due to high composting rates, 49% agreed that increased agricultural waste was due to increased growth and harvests, and 40% agreed that there was an increase in food waste due to spoilage. Findings imply that during the rainy season, there are high composting rates, leading to an increase in degradable waste. Plastic waste leads to blockage of drainage patterns, which destroys culverts and drainage systems. Agriculture waste increases due to a surplus in agriculture, increasing agricultural waste. e-waste is minimal because Bungoma County urban centres do not link to conurbations, hence minimal e-waste. People also tend to keep their e-waste as valuables due to the urban centres' peri-urban characteristics.

Figure 5: Perception of respondents on effects of Rainfall in Relation to Urban Solid Waste Generation (N=310)

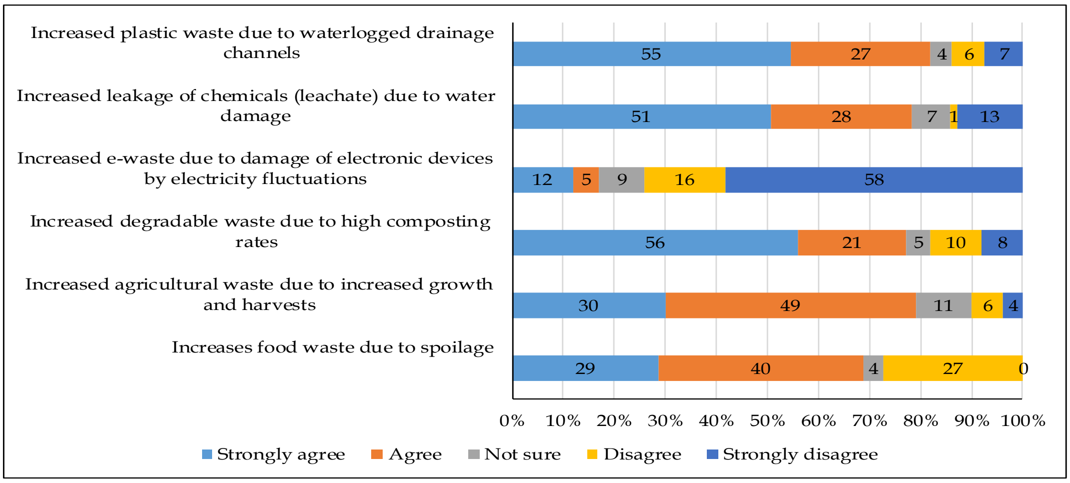


Table 3: Types of Waste Generated During Rainy Season (N=310)

Types of solid waste generated during the rainy season	**Frequency**	**Percentage**
Plastic waste	112	36.1
Organic waste (garden waste)	278	89.7
E-waste (batteries and electronic devices)	48	15.5
Hazardous waste e.g. chemicals	22	7.1

Results show that 89.7% of the respondents opined that organic waste is often generated during the rainy season, 36.1% opined that plastic waste increases during the rainy season, 15.5% indicated that e-waste is generated during the rainy season, and 7.1% indicated that hazardous waste is generated during the rainy season.

Interview schedules had responses, too. These are vital informants. Example: The key informants added that:

> *Rainfall and temperature changes have affected solid waste generation. More waste is generated when temperatures are high, particularly in plastic bottles and sugarcane waste. This is because when people are dehydrated during the dry season, they quench their thirst. The public drink more bottled water while others consume sugarcane. During the wet season, there is more agricultural waste due to a surplus in agricultural production. The excess agricultural products are thrown away on open grounds and in the market. Changes in rainfall increase drought, which is brought about by long dry seasons (Key Informant 1, 3).*

Conclusion

Findings imply that during the rainy season, there are high composting rates, leading to an increase in degradable waste. Plastic waste led to the blockage of drainage patterns, which destroyed culverts and drainage systems. Agriculture waste increases due to a surplus in agriculture; hence, increased agricultural waste is minimal because Bungoma County urban centres do not link to conurbations, hence minimal e-waste. People also tend to keep their e-waste as valuables due to the urban centres' peri-urban characteristics. Findings imply that temperature change causes food spoilage and eventual food waste. High temperatures can increase the speed at which food deteriorates and spoils. The warmer it is, the faster microorganisms, enzymes, moulds, and yeast can grow. Some food products, like tomatoes, mature faster during warmer temperatures, resulting in excessive production and agricultural waste. Temperature change has also increased the rate of waste degradation and gas generation in the dump site, which is an environmental health hazard. There is a need to embrace recycling and reuse at household and institutional levels. The county government should provide more bins at all urban centres and upcoming markets for waste collection. A comprehensive awareness program on waste management, especially using bins to categorise and segregate waste, could be implemented.

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