FORUM GEOGRAFI
ISSN: 0852-0682 | E-ISSN: 2460-3945
HTTPS://JOURNALS.UMS.AC.ID/INDEX.PHP/FG/

Research article

Spatial Differentiation of the Land and Nutrient Footprints for Kampala: Implications for Urban Food Sustainability

Asaba Joyfred*, Paul Isolo Mukwaya, Shauib Lwasa, Yazidhi Bamutaze, Fredrick Omolo

Department of Geography, Geo-informatics and climatic Sciences, Makerere University, P. O Box 7062, Kampala, Uganda

*) Correspondence: asabajoyfred@yahoo.com

Citation:
Joyfred, A., Mukwaya, P. I., Lwasa, S., Bamutaze, Y., & Omolo, F. (2024). Spatial Differentiation of the Land and Nutrient Footprints for Kampala: Implications for Urban Food Sustainability. Forum Geografi. 38(2), 138-152.

Article history:
Received: 02 Agustust 2023
Revised: 03 April 2024
Accepted: 04 April 2024
Published: 16 May 2024

Abstract

Rapid urban growth, together with an increase in urban food demand and rural-urban food flows, effectively transfer the urban footprint to the surrounding cities. In Uganda, where fast urban growth is evident, data on the resultant foodprint is sparse. To bridge this gap in knowledge, this paper quantitatively analyses the flows of the rural-urban cooking banana (matooke) to Kampala, Uganda, and the embedded land and nutrient footprints. Food freight surveys involving interviews with food truck drivers and field measurements were used to obtain data on quantities of banana flow to ten purposively sampled city markets. The results confirm that 88.5% of Kampala's banana inflows are sourced from the Ankole sub-region. Disaggregation of the flows by season revealed a 52% fall in banana supplies to the city during the wet season. The calculated annual land footprint associated with the city's banana inflows was 15,268 hectares. The hot spots for NPK nutrient mining are in the Ankole region, including mean daily losses of 362.29±29.13Kg (K), 104.66±8.42Kg (N) and 4.03±0.32Kg(P). The ANOVA results exhibited significant differences ($P<0.05$) in the cooking banana land and nutrient footprints between the source regions and concerning the dry and wet seasons, except for the Rwenzori, Kigezi, and Bunyoro sub-regions pertaining to the land footprint and Buganda, Tooro, and Bunyoro as regards the nutrient footprint. These results emphasise the intense rural nutrient mining that is associated with urban food consumption. Thus, to guarantee sustainable matooke production, there is a need to establish waste diversion strategies that enable nutrient recycling back to rural farms.

Keywords: Urban Footprints; Urban Foodshed; Land Footprint; Nutrient Footprint.

1. Introduction

Humankind has become a predominantly urban species over the past few decades, as the world has experienced a process of rapid urbanisation. In 1950, only 30% of the world's population was urban, however currently, the majority of people, approximately 55% of the world's population, resides in urban settlements. This percentage is projected to grow to 70% by 2050 (FAO, 2019). Africa is the world's fastest urbanising continent. Between 1950 and 2015, the continent's urban population increased by roughly 2000%, from 27 million to 567 million people (Heinrigs, 2020). By 2050, roughly 56% of Africans will live in urban settlements (Vearey, Luginaah & Shilla, 2019).

This unprecedented growth in the global urban population has brought with it a rise in urban food demand and a reduction in urban agricultural land (FAO, 2021). This leaves cities with limited spaces intended for food production (de Bruin *et al.*, 2021). Essentially, contemporary cities produce only a fraction of the food they consume (Hemerijckx *et al.*, 2023), making them immensely dependent on complex, large-scale food supply chains that originate from distant places outside city boundaries (Karg *et al.*, 2022; Zou, 2019; Benis, 2018). This external sourcing of food effectively transfers the environmental load associated with urban food consumption to the food source regions (Stelwagen *et al.*, 2021). Hence, this conceals the negative effects that arise from people's dietary choices (Bosire, 2016), thereby creating a metabolic rift between urban food consumers and their food source regions (Goldstein, Birkved & Fernandez, 2017). To city dwellers, food has become abstract, produced out there in the hinterlands and imported into the city. Extremely few people have any concrete knowledge of the origins of their food, how it reaches the city, and the associated environmental load (Vanham, 2017). Currently, given that the bulk of the global population reside in cities, documenting how much and what food enters cities and the attendant footprint is fundamental to achieve urban sustainability (Guibrunet & Sánchez, 2023).

To illustrate the environmental pressure associated with urban dependence on external food sources, the urban footprint is employed (Goldstein, 2017). Quantification of the urban footprint entails the application of composite indicators that reflect resource appropriation and the pollution flows associated with urban food consumption. Included in these are the urban land and nutrient footprints, which are consumption-based indicators that measure the total amount of land and nutrients employed domestically and externally to produce the food consumed by the urban population. The land and nutrient foodprints are sophisticated indicators that are effective in quantifying the extent to which a specified region is dependent on external land resources (Bosire, 2016). Land appropriation regarding urban food production and the attendant nutrient mining from rural landscapes represents a significant obstacle to achieving sustainable production and consumption (SDG 12) in both developed and developing nations (Lin *et al.*, 2016).

While a handful of previous studies have documented urban food flows and the accompanying environmental load (Aleksandrowicz *et al.*, 2016; Anielski, 2010; Billen *et al.*, 2008; Borucke *et al.*, 2013; Castellani *et al.*, 2017; Fischer *et al.*, 2017; Paitan &Verburg, 2019; De Cunto *et al.*, 2017; Goldstein, Birkved & Fernandez, 2017; Papangelou, Achten & Mathijs, 2020), most of these studies have ultimately focused on large cities in the high income, highly industrialised and data rich countries of the Global North (Guibrunet & Sánchez, 2023). Consequently, cities in the Global South that are characterised by unique socio-technical conditions are disregarded. Granting, these foodprint studies employ coarse resolution aggregated data or household survey data (Schreiber, *et al.* 2021), these data do not adequately reveal the detailed in-country spatial variations in the rural-urban food origins and the associated foodprints, specifically in the vast areas of Africa that are characterised by unique socio-technical conditions. This paucity of comprehensive fine-scale spatial resolution data, which relates the food consumed in the city to specific source locations, restricts accurate determination of the urban foodprint. Consequently, the practical utilisation of foodprint analyses concerning urban food planning in developing countries is exceptionally challenging (Godar *et al.*, 2015). This basically explains why, despite the convincing link between food and the environment, and regardless of the fact that the city is the space and place where demand for food is highest, previously, footprints have received only superficial consideration in regard to urban policy and planning (Wiskerke, 2015).

In Uganda, where rapid urban growth of 5.2% per annum is evident (UBOS, 2021), the scale of the rural-urban food flows and deep rooted footprint, have not been systematically investigated. Notwithstanding that knowledge of the locality of food sources regarding urban food supply is recognised as central in supporting urban food systems resilience and sustainability (Karg *et al.*, 2016); to date, no specific study has been conducted to quantify the rural-urban food flows in the country, the actual geographic areas from which food consumed in the city is sourced and the embedded environmental load. This gap in knowledge pertaining to urban foodprints in the country, represents a failed opportunity to address the significant urban environmental pressures associated with urban food consumption. With the projected increase in the proportion of the country's urban population from the current 27% to 50% by 2050 (UBOS, 2021), the urban land and nutrient footprint imposed on food source regions is expected to increase substantially. Hence, in the absence of the necessary comprehensive urban food planning, this could significantly compromise food production across the country and threaten urban food sustainability and rural livelihoods.

To mitigate this pending threat, there is need to ascertain the scale of urban food consumption and the attendant foodprint. In this study, we quantified the rural-urban flows for cooking banana (Musa spp. AAA-EA), determined the specific food origin regions and analysed the land and NPK nutrient footprints established in the flows. Cooking banana is a major crop for approximately 57.5% of Ugandans and the most consumed staple food in Central Uganda with per capita consumption of 220-400kg per annum (Calkins, 2021). Similarly, matooke dominates production among the five key crops in the country with a total annual production of 11.1 million metric tonnes (MT) and yield of 15.4 MT per hectare (UBOS, 2022). Given the reported strong association between banana production and significant losses of nitrogen, phosphorus and potassium (NPK) nutrients (Kongkijthavorn, 2017; Nalunga *et al.*, 2015; Apanovich & Mazur 2018; Tumuhimbise *et al.*, 2020), tracing Kampala's matooke inflows to places of origin is critical in pinpointing the dominant nutrient mining hotspots in the city's foodshed. This analysis reveals the potential food supply bottlenecks and vulnerabilities associated with urban food supplies and could assist city authorities to plan for urban food sustainability in a more integrated way, with regard to the level of the city's dependence on external food sources.

2. Research Methods

2.1. Description of the Study Area

For the purpose of this study, Kampala, Uganda's capital city, was purposively chosen as a representative sample, to highlight the rural-urban food flows and the associated land and nutrient footprints. The city is located at 0°18′ 49″ N and 32° 34′ 52″ E, on the northern shores of Lake Victoria (Figure 1). It is currently composed of five political and administrative divisions, specifically Central, Nakawa, Kawempe, Rubaga, and Makindye, covering a surface area of 189.3 Km^2 (Kampala Capital City Authority (KCCA), 2019). However, over time, the city has exponentially expanded in all directions, notably along major roads and existing towns, forming the Kampala

Metropolitan Area covering 941.2 Km^2 (KCCA, 2014). As it is one of the fastest growing African cities (Hemerijckx *et al.*, 2023), with an annual population growth rate of 4.03% and a current population of 1.75 million people, Kampala is the country's economic hub, accounting for roughly 80% the country's industrial and commercial activities and 65% of national GDP (KCCA, 2014; KCCA, 2019). If the city's growth pattern is maintained, Kampala is projected to become a mega city with a population of more than 10 million people by 2040 (World Bank, 2015). Intrinsically, Kampala's rapidly increasing population, coupled with the continuous decrease in agricultural land due to built-up land expansion, make it a representative sample of the many rapidly growing cities in Sub-Saharan Africa. Therefore, it is a suitable choice to study the urban foodprint imposed on food source regions, in developing countries.

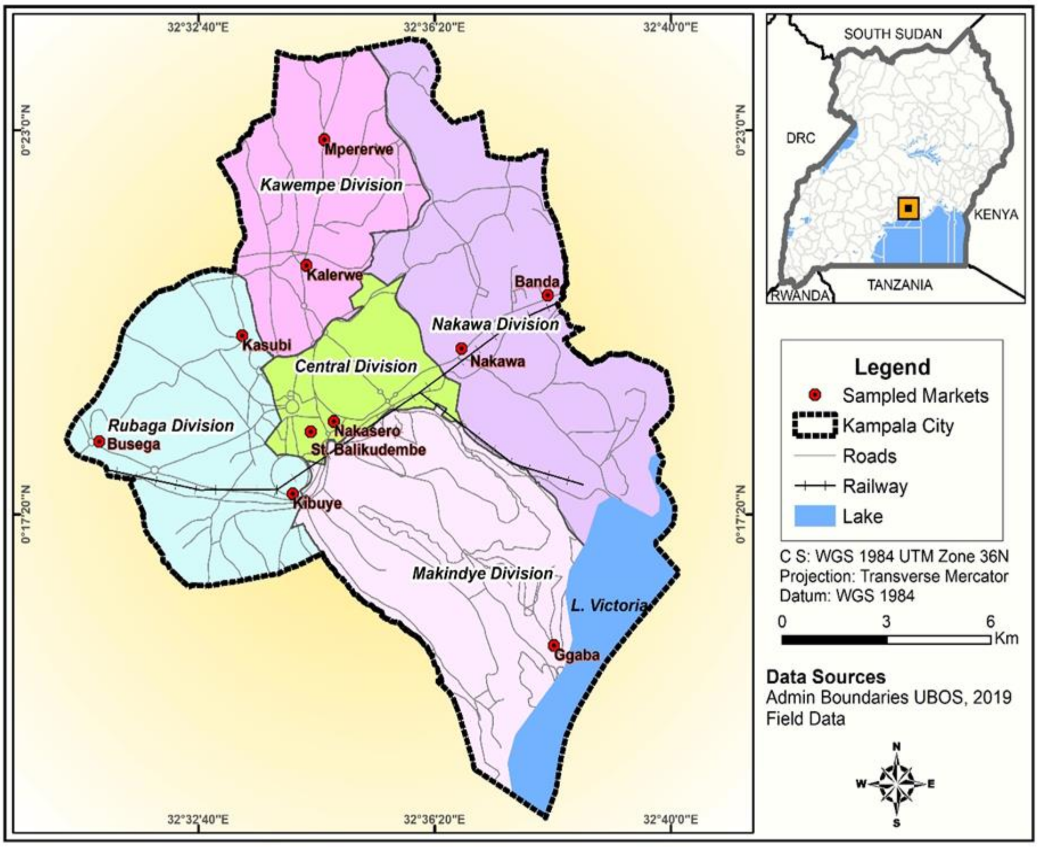

Figure 1. Map Illustrating the Location of Sampled Markets in the Five Divisions of Kampala.

2.2. Study Design

A survey design was adopted in this study. Given the lack of secondary data detailing urban food consumption in the country, the study followed a bottom-up, consumption based approach to quantify the rural-urban matooke flows for Kampala and the associated land and nutrient footprints. To generate comprehensive data on the food flows, interviews with food truck drivers and field measurements were employed. This data was subsequently utilised to estimate the land and nutrient food footprints with respect to cooking banana consumed in the city wherever these impacts occur.

2.2.1. Sample Design

Given the significance of mass in environmental footprint analysis, cooking banana, a non-seasonal crop that is cultivated in a wide range of ecological zones, was purposively selected for study. The choice of this food type was based on the fact that it is the most consumed staple food Central Uganda with a per capita consumption of 255 kilograms (fresh weight) per person per year (FEWS-NET, 2017). As a vital source of carbohydrates, vitamins A, B6 and C, together with nutrient K all year round, the cooking banana is a key component in both urban food security and agricultural sustainability throughout the country (Dotto, Matemu & Ndakidemi, 2018). It is also the most cultivated crop countywide, grown by 75% of all Ugandan farmers (Tumuhimbise *et al.*, 2020), with an annual production rate of 6.5 million metric tons (UBOS 2020). The dominance of matooke over other staple foods in Uganda makes it an appropriate choice as regards analysing the urban foodprint.

To quantify the city's cooking banana inflows, ten main food markets amounting to 52% of the grade one markets in Kampala were purposively chosen, with two markets selected from each of the five city divisions. These included Kalerwe and Mpererwe markets in Kawempe division, Busega and Kasubi in Lubaga, St. Balikudembe and Nakasero in Central, Kibuye and Ggaba in Makindye, in addition to Nakawa and Banda in the Nakawa divisions (Figure 1). The selection of only main markets in this study was established to avoid the double counting that would arise owing to food transfers from the large to smaller markets within the city. Each truck driver delivering matooke to the selected markets for the two months formed the study sample. A total of 1703 truck drivers were interviewed.

2.3. Quantification of the Rural-Urban Flows of Cooking Banana

To quantify Kampala's cooking banana inflows, food freight surveys were conducted at the 10 purposively sampled city food markets. Data on quantities of rural-urban matooke flows and source regions was collected from the matooke truck drivers delivering food to the markets for a period of two months, specifically July and October 2021. The choice of these two months representing data collection was meant to obtain variations in urban food supplies between the peak and lean seasons. The reported cooking banana supply peak seasons in Uganda are June to August, and December to February which is the period directly after the harvest, while the lean season is March to May and September to November (FEWS-NET, 2017). The total amount of matooke inflows from a specific region was ascertained by multiplying the average weight for a bunch or bag of matooke by the total number of matooke bunches and bags delivered to the sampled city markets for a period of two months. To ensure the accuracy of the information provided, data pertaining to quantities of matooke flows was collected in local units of measurement familiar to the truck drivers, specifically bunches and/or bags of matooke. These were subsequently converted to standard metric units of quantity (kilograms and metric tonnes), based on the field measurements that were completed using a platform digital weighing scale, model-A12, with a maximum capacity of 300 kilograms (Plate 1). The result was then extrapolated over a period of one year to denote the annual matooke inflows into Kampala. The total quantity of matooke food flows to Kampala was therefore ascertained as Equation 1.

$$Pi = (Sm \times Aw) \tag{1}$$

Where :

P_i : is the total quantity of the matooke inflows from a specified region in metric tons (MT)

S_m : is the number of bunches/bags of cooking banana delivered to the sampled markets in two months.

A_w : is the average weight of a bunch or bag of cooking banana in kilograms. The results were then converted to metric tons (MT).

Figure 2. Researcher Taking Measurements of Matooke Bunches and Bags at Nakawa Market in Kampala.

2.4. Quantification of the Land Footprint Associated with the Rural-Urban Flows of Cooking Banana

Cropland footprint is calculated based on food crop supply and yields of the region of origin (de Ruiter *et al.*, 2017). Essentially, for the purpose of this study, the land footprint for the matooke inflows to Kampala, was calculated as the area of land required to produce the given quantity of matooke flows. This was achieved by dividing the quantity of matooke flows by the local region yields for the crop. The equation (Equation 2) was adopted from Borucke *et al.* (2013) and employed in this study.

$$\mathrm{L}F = \sum_{i}^{n} \left(\frac{Pi}{Yw,i} \right) \qquad (2)$$

Where :

LF	:	is the total land required to produce a specified amount of matooke flows
Pi	:	is the consumed amount of each food type i in tons per year, which in this case is the estimated amount of the rural-urban matooke flows from a specified region.
Yw,i	:	is the yield for food type i (matooke) in metric tonnes per hectare.

In this study, regional yields as opposed to national or globally standardised yields were exploited. These were extracted from the Uganda Annual Agricultural Survey, 2018 (UBOS, 2020). To ensure accurate estimation of the land footprint for Kampala, yields for the specific food source subregions were utilised. This is primarily for the reason that yields or land intensities vary widely across regions, even within the same country.

2.5. Quantification of the Nutrient Footprint Associated with the Rural-Urban Flows of Cooking Banana

In this study, the three main nutrients, specifically nitrogen, potassium and phosphorous were chosen. The choice of NPK nutrients is based on the fact that they are reported to be the most susceptible to mining via banana extraction from the field (Dotto, Matemu & Ndakidemi, 2018). The nutrient footprint which is the total quantity of nutrients embedded in the rural-urban matooke flows was then ascertained by multiplying the amount of nutrients extracted from the farm per unit of fresh cooking banana, as shown in Equation 3.

$$\mathrm{T}_{\mathrm{nutrient}} = \sum_{i}^{n} (Qn * Qi) \qquad (3)$$

Where :

$T_{nutrien}$	:	is the total quantity of nutrients imbedded matooke flows from a specified region in tons.
Q_n	:	is the quantity of matooke from a specific region delivered to the sampled markets over a period of two months
Q_i	:	is the quantity of nutrient embedded in a unit quantity of matooke. In this study, the nutrient concentrations embedded in a unit of matooke are adopted from the study undertaken by Kongkijthavorn (2017). To be exact, for every 1 metric ton of harvested cooking banana, 2.6 kilograms of nitrogen, 9 kilograms of potassium and 0.1 kilograms of phosphorus are lost from the system.

2.6. Data Analysis

QGIS was used to develop food flow maps illustrating the spatial variations in the cooking banana flows from the different source regions of Uganda. This provided an understanding of hotspots in terms of which specific areas of the city's hinterland are associated with the largest food withdrawals. Data collected was analysed using R software version 4.2.2, for statistical analysis of variance (ANOVA). The one-way ANOVA was run to test whether there were significant differences in the land and nutrient footprints among the different food source regions.

3. Results and Discussion

This section presents the results of the cooking banana-related land and nutrient footprint. In the following, we initially present the quantified rural-urban food flows for Kampala (in metric tons) and the embedded land footprint. Next, the nutrient footprint associated with the food flows is reported. Lastly, we discuss the implications of the quantified urban land and nutrient footprints for sustainable urban food planning.

3.1. The Rural-Urban Flows of Cooking Banana

One of the objectives of this study was to quantify the rural-urban flows in relation to cooking banana consumed in Kampala. Essentially, data on the regional and seasonal distribution of the banana flows to Kampala is presented in 3.1.1 and 3.1.2.

3.1.1. Quantification of the Regional Cooking Banana Flows to Kampala

Kampala consumes considerable quantities of cooked banana. The mean daily cooking banana inflows to the city amounts to 323.06 metric tons, equivalent to 117,917 metric tons annually. Data on the regional sources of the city's banana food supplies (Table 1), reveals that roughly 88.5% of the banana inflows into the city markets originate from Western Uganda, 76.4% of which is from the Ankole sub-region. The Rwenzori, Tooro and Bunyoro regions contributed only 12.1% of matooke supplies to Kampala. Notwithstanding its close proximity to Kampala, only 11.5% of matooke inflows produced by Central Uganda. Thus, Kampala is considerably dependent on its distant rural countryside of Western Uganda for its supplies of fresh cooking banana.

Table 1. Regional Distribution of Cooking Banana (Matooke) Flows to Kampala

Region of Origin	Sub-Region of Origin	Total Matooke Flows (MT)	Mean Daily Matooke Flows (Mean±se)	Sd	Percentage of Total Flows
Western Uganda	Ankole	14,831.65	239.22±12.64	99.5	76.39
	Bunyoro	43.67	4.37±0.8	2.54	0.22
	Kigezi	234.70	6.18±0.67	4.12	1.21
	Rwenzori	351.14	8.56±1.02	6.56	1.81
	Tooro	1,725.96	28.77±2.13	16.53	8.89
Central Uganda	Buganda	2,229.54	35.96±3.82	30.09	11.48
	Total	19,416.66	323.06		100.00

The ANOVA results (Figure 2) confirm that there were significant differences between the regions of Ankole and Buganda Tooro in the quantities of matooke supplied to Kampala. No significant differences were observed among the Rwenzori, Kigezi and Bunyoro sub-regions.

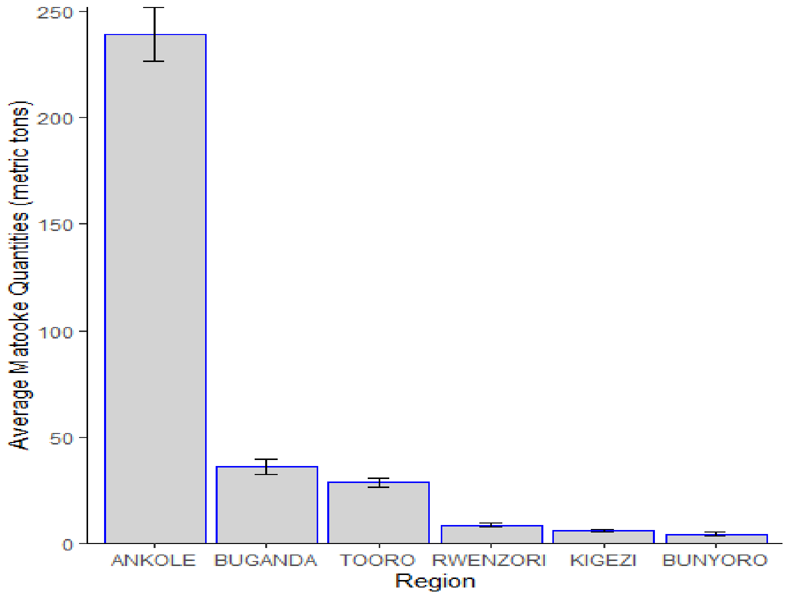

Figure 3. Regional Variations in Cooking Banana Supplies to Kampala

Disaggregation of the cooking banana flows per source district, demonstrates that Kampala's banana supplies are sourced from a combined total of 39 districts in Western and Central Uganda (Figure 4). Nonetheless, despite the diversified distribution of the city's banana source districts, a disproportionately large amount of cooking banana flows to the city originates from a handful of districts in Western Uganda. In actual fact, 65% of the total cooking banana supplies to Kampala are from the three districts of Isingiro (27.8%), Mbarara (23.4%) and Ntungamo (13.8%), in the Ankole sub-region, Western Uganda. Gomba district, Central Uganda's largest supplier of cooking banana to Kampala only accounts for 7.2% of inflows. This is despite the fact that the region is traditionally recognised as being ecologically more suitable for banana production than much of Western Uganda. This substantial reliance by Kampala on Western Uganda concerning its banana cooking supplies implies the transfer of the accompanying land and nutrient footprints to these distant hinterlands in the countryside.

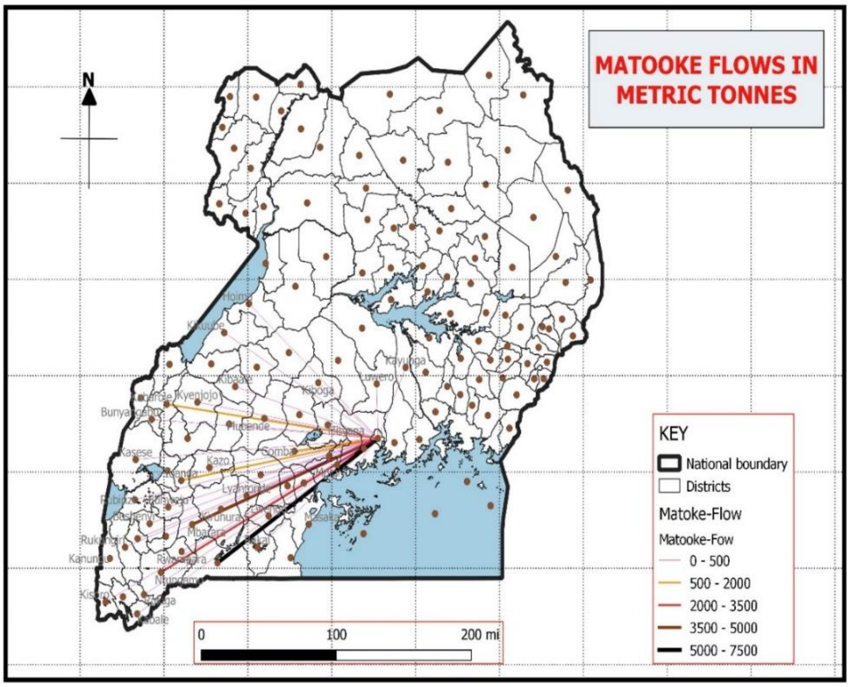

Figure 4. Quantities of Cooking Banana Flows to Kampala from the Source Districts.

3.1.2. Seasonal Variations in the Rural-urban Cooking Banana Flows

Kampala's cooking banana supplies significantly fluctuates depending on the season. Generally, banana supplies to Kampala plummeted by 52% during the wet-lean season (Table 2). Of the quantified total matooke inflows to the city, 13,089.06 MT (67%) were supplied in the dry-peak season (June-August), while the wet-lean season (September to November), accounted for 6,327.61 MT (33%). The central region registered the largest reduction in the rural-urban cooking banana flows between the dry and wet season (71.5%), followed by the Ankole sub-region (51.4%). Kigezi registered the lowest reduction in regard to inflows (7.8%). In Bunyoro however, a slight increase in the banana flows of 24.8%, was noted during the wet season.

Table 2. Seasonal Variations in Cooking Banana Flows to Kampala.

Sub-Region of Origin	Season	Total Quantity of Matooke Flows	Mean ±se	Percentage Change
Ankole	Dry	9,982.97	322.03±9.01a	
	Wet	4,848.68	156.41±3.87e	51.43
Buganda	Dry	1,734.71	55.96±3.88b	
	Wet	494.83	15.96±1.13f	71.47
Tooro	Dry	1,011.55	33.72±2.42c	
	Wet	714.42	23.81±1.61f	29.37
Rwenzori	Dry	218.32	11.49±1.18cd	
	Wet	132.82	6.04±0.67g	39.16
Kigezi	Dry	122.08	6.78±0.88dg	
	Wet	112.62	5.63±0.40g	7.75
Bunyoro	Dry	19.43	4.86±0.60dg	
	Wet	24.24	4.04±0.96g	24.76
Total	Dry	13,089.06		
	Wet	6,327.61		51.66

ANOVA was run to determine whether there were significant variations in cooking banana flows to Kampala between the wet and dry seasons. The results (Figure 3), explain that there were significant differences in banana supplies between the dry and wet seasons in the sub-regions of Ankole, Buganda, Tooro and Rwenzori (Figure 5). These regions registered significant reductions in banana supplies in the dry season. Additionally, Matooke flows to Kampala from the sub-regions of Kigezi and Bunyoro did not significantly differ with season.

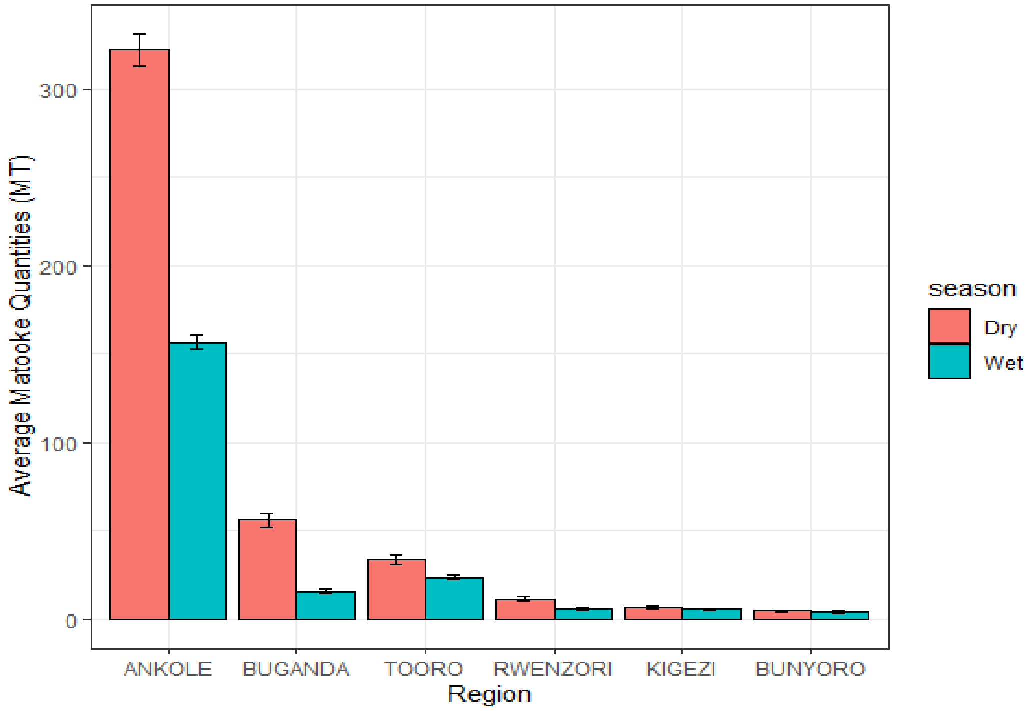

Figure 5. Seasonal Variations in Cooking Banana Flows

These seasonal variations in matooke inflows to Kampala during the dry and wet seasons are confirmed by the FEWS-NET (2017). This details a general reduction in matooke production throughout the country during the wet season from September-November and March-May. Conversely, this is followed by surplus production in the dry season from June-August and December-February. This decrease in urban matooke supplies in the wet season can be attributed to the reported poor accessibility owing to the muddy roads in the rural countryside and the growth cycle of the cooking banana crop.

Table 3. The Land Footprint Associated with the Rural-Urban Matooke Flows

Sub-region	Season	Total Footprint (Ha)	Annual Footprint (Ha)	Mean ±se	sd
Ankole	Dry	623.9355	7117.5	19.5±0.98d	5.54
	Wet	302.4078	3562.4	9.76±0.33a	1.86
Buganda	Dry	141.0333	1660.75	4.55±0.45e	2.48
	Wet	40.40691	474.5	1.3±0.13b	0.74
Tooro	Dry	71.74101	872.35	2.39±0.24f	1.33
	Wet	50.66781	616.85	1.69±0.16b	0.88
Rwenzori	Dry	15.48386	295.65	0.81±0.12fg	0.54
	Wet	9.419862	156.95	0.43±0.06c	0.3
Kigezi	Dry	7.630077	153.3	0.42±0.08g	0.34
	Wet	7.03898	127.75	0.35±0.03c	0.15
Bunyoro	Dry	1.378111	124.1	0.34±0.07g	0.14
	Wet	1.718858	105.85	0.29±0.09c	0.21
Total		1,272.86	15,267.95		

3.2. The Land Footprint Associated with the Rural-Urban Matooke Flows

The total amount of cropland used domestically to produce Kampala's matooke supplies was calculated based on the total banana flows per region and the attendant crop yields in each region (Table 3). The calculated total matooke land footprint required to supply the 10 sampled markets in Kampala was 1,272.86 hectares, converting to an annual land footprint of 15,268 hectares. The Ankole sub-region situated in Western Uganda, with a land footprint of 926.3 hectares, accounts for 72.8% of the total matooke land footprint for Kampala. Only 181.4 hectares (14%) of the city's matooke land footprint is from the central region of Buganda.

The ANOVA results (Figure 6) revealed significant differences in the matooke land footprint among the source regions except for Rwenzori, Kigezi and Bunyoro. Essentially, the cooking banana land footprint for Kampala is concentrated in the rural countryside of Western Uganda which controls the city's matooke food supplies. These findings relate to Nalunga *et al.* (2015), who note that, due to the geographic shift as regards cooking banana production from Central Uganda, roughly 65% of land devoted to cooking banana production in the country is currently located in Western and South Western Uganda.

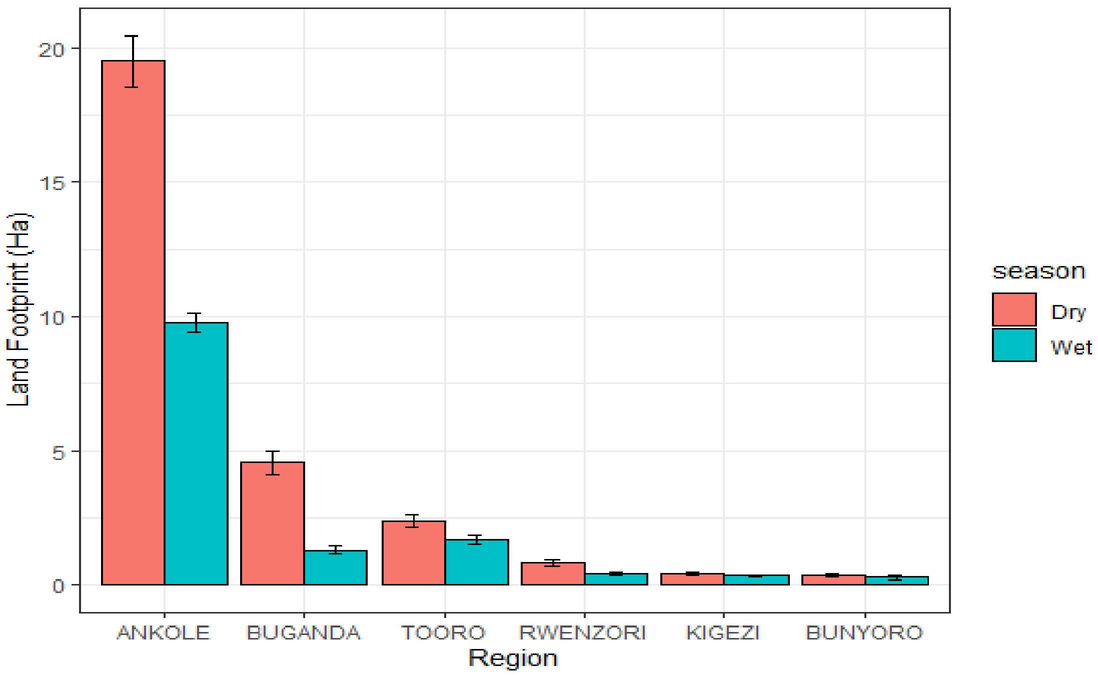

Figure 6. Regional and Seasonal Variations in the Matooke Land footprint for Kampala

3.3. The Nutrient Footprint Imbedded in the Rural-urban Matooke Flows to Kampala

To ascertain the scale of the rural farm nutrient losses associated with rural-urban matooke flows to Kampala, the nitrogen, phosphorous and potassium (NPK) nutrients incorporated in the banana flows were quantified and analysed (Table 4). From the results, potassium is the largest nutrient embedded in the banana flows to the city with calculated mean daily losses of 232.38±15.5Kg. This is followed by nitrogen (67.13±4.5Kg) and phosphorous (2.58±0.2Kg).

Table 4. Mean NPK Nutrient Losses embedded in the Rural-urban Cooking Banana Flows

Nutrient	Mean ±se	Sd	min	max
N	67.13±4.49	104.28	1.75	739.77
P	2.58±0.17	4.01	0.07	28.45
K	232.38±15.55	360.99	6.07	2560.74

The hot spots concerning the NPK nutrient mining associated with the cooking banana supplies to Kampala are in the Ankole sub-region with mean daily losses of 362.29±29.13Kg (K), 104.66±8.42Kg (N) and 4.03±0.32Kg (P), respectively. This was followed by Buganda, Tooro, Rwenzori, Kigezi and Bunyoro. The least nutrient losses were in the sub-regions of Bunyoro and Kigezi (Figure 7).

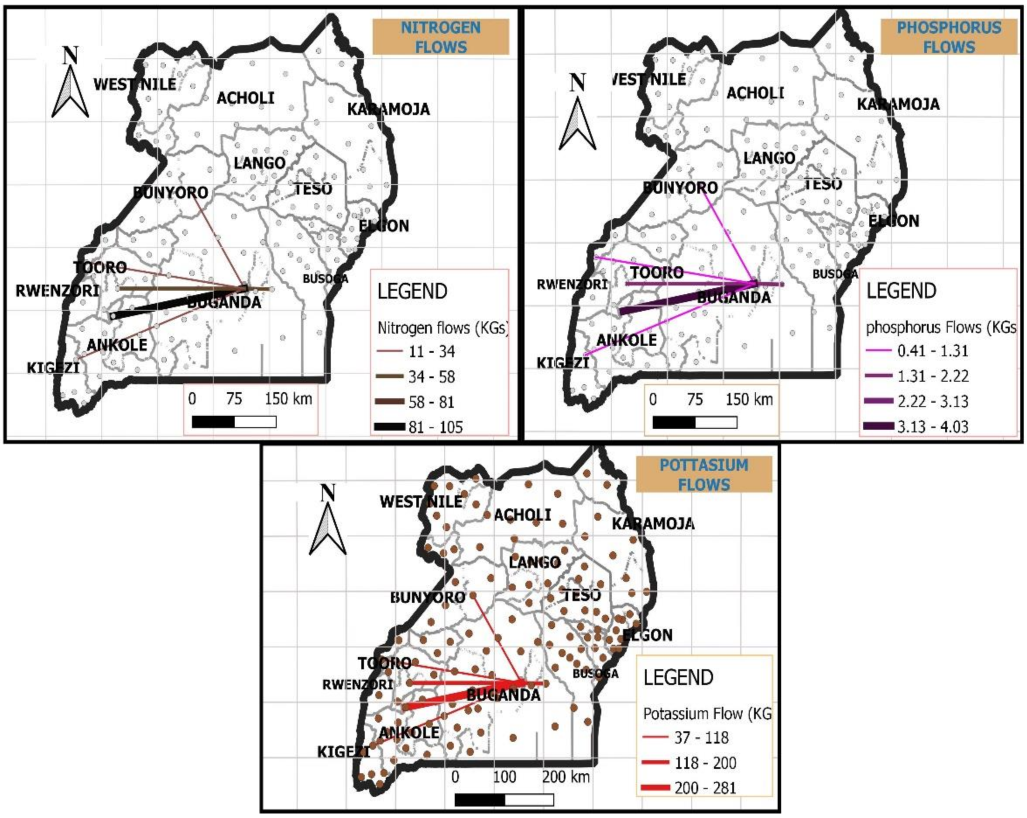

Figure 7. Regional Nitrogen (N) Phosphorus (P) and Potassium (K) Nutrient Flows.

There are significant differences in NPK nutrient losses among the regional sources of banana consumed in Kampala, except between the sub-regions of Buganda and Tooro, as well as Bunyoro and Kigezi (Table 5 & Figure 7). Thus, the hotspots for nutrient losses associated with Kampala cooking banana consumption are located in Western Uganda.

Table 5. Quantity of Nutrients Embedded in Matooke Flows (Kgs)

Nutrients	Region	Quantity of	Mean ±se	sd
N	Ankole	26,897.81	104.66±8.42d	134.91
	Buganda	5,186.54	37.86±4.61c	53.93
	Tooro	2,890.51	36.59±3.37c	29.94
	Rwenzori	683.71	26.3±3.78b	19.26
	Bunyoro	85.71	10.71±1.81a	5.12
	Kigezi	439.82	13.74±1.89a	10.71
P	Ankole	1,034.53	4.03±0.32d	5.19
	Buganda	199.48	1.46±0.18c	2.07
	Tooro	111.17	1.41±0.13c	1.15
	Rwenzori	26.3	1.01±0.15b	0.74
	Bunyoro	3.3	0.41±0.07a	0.2
	Kigezi	16.92	0.53±0.07a	0.41
K	Ankole	93,107.82	362.29±29.13d	466.99
	Buganda	17,953.42	131.05±15.95c	186.69
	Tooro	10,005.61	126.65±11.66c	103.65
	Rwenzori	2,366.70	91.03±13.08b	66.68
	Bunyoro	296.69	37.09±6.26a	17.71
	Kigezi	1522.46	47.58±6.55a	37.06

These results are consistent with the findings obtained by Nalunga *et al.* (2015) and Apanovich & Mazur (2018) who assert that nitrogen and potassium are lost in large quantities through banana harvesting and export from production areas. Given that the return of dead leaf, dead pseudo stems and banana peels is essential for the maintenance of nutrient levels within the banana cropping system, banana export from rural areas to urban centres increases nutrient mining. This results in a continuous loss of nutrients from the farms that accumulate in pools in cities, from which recycling back to the rural farms is scarcely viable. Kongkijthavorn (2017) reports that 26 kg of nitrogen and 90 kg of potassium are depleted from the soil with every 10 Mg ha-1 yield of banana. According, this export of nutrient resources from rural landscape soils to feed increasing urban populations, represents a significant obstacle to achieving sustainable food production. Irrespective of the insufficient levels of on-farm fertiliser application, these rural-urban nutrient flows are liable to exacerbate the already low and decreasing banana yields in the main producing areas (Tumuhimbise *et al.*, 2020).

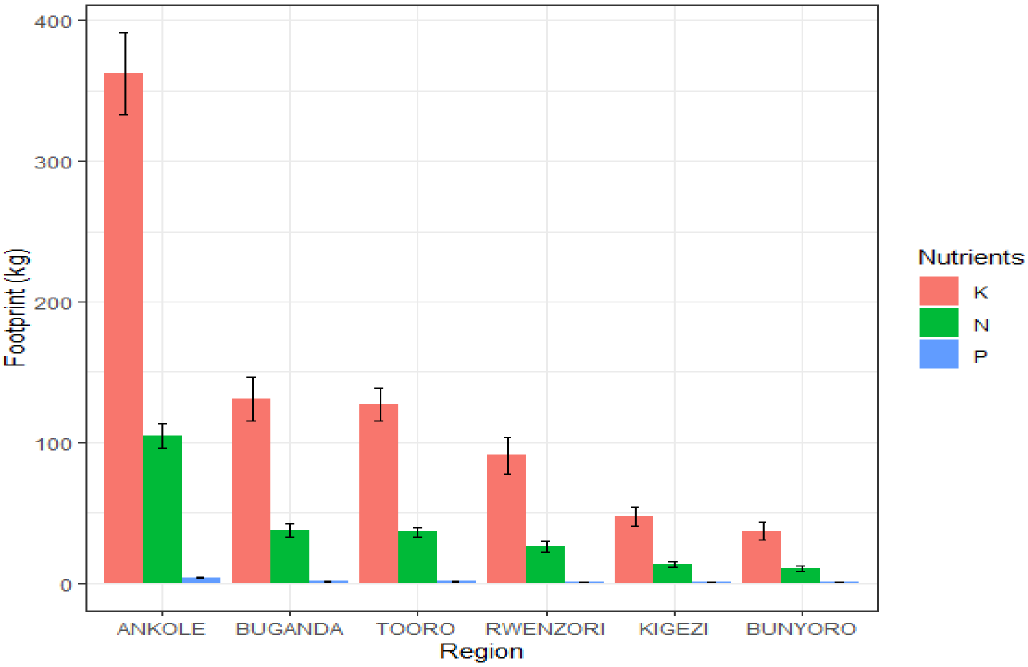

Figure 8. Regional Variations in NPK Nutrient Flows.

3.2. Discussion

3.4.1. The Spatial and Temporal Variations in Cooking Banana Supplies to Kampala

The majority of the city's matooke inflows are predominantly sourced from three distal districts, specifically Isingiro, Mbarara and Ntungamo. Notwithstanding that Central Uganda where Kampala is located, is traditionally considered more ecologically suitable for banana production in contrast to much of Western Uganda (Nalunga *et al.*, 2015), the region contributes only a very small proportion of the city's banana supplies. The dominance of Kampala's cooking banana supplies by Western Uganda is consistent with the findings obtained by previous studies that point to a persistent decline in matooke yields in the traditional matooke growing region of Central Uganda since the 1960s (Wairegi *et al.*, 2010). This decline in yields coupled with an increased urban food demand due to a rapidly growing urban population generated a geographic shift in relation to cooking banana production, to Western and South Western Uganda (Kongkijthavorn, 2017; Tumuhimbise *et al.*, 2020). Nonetheless, the concentration of the city's cooking banana sources in a handful of districts is a threat to sustainable urban food supplies. Shocks in anyone of these three district implies severe banana shortages in the city. Basically, it is vital to emphasise and support intensified cooking banana production in the city's surrounding districts to ensure more diversified banana supply chains that could safeguard Kampala against food supply shocks. Diversified food sources enhance systems resilience given place based risk factors as climate change and fertility decline.

On account of the distant origins of cooking bananas, Kampala's residents and planning authorities are unable to establish where the bananas frequently consumed in the city originate from and their associated environmental load. This external food sourcing disconnects the city dwellers from their food producing regions and protects them from the environmental consequences that arise from their dietary choices (Goldstein, Birkved & Fernandez, 2017) and complicates efforts to spearhead sustainable food consumption production. This partly explains why foodprints are conspicuously missing in Kampala's land use planning. This is a threat to urban food sustainability. Per se, it is essential for urban food planning to incorporate the intrinsic relationships among stakeholders in the city and its distal connected food source regions. According to de Bruin, food from local and regional sources as well as strong connections between the city and its hinterland are perceived to be key in supporting resilience and the sustainability of the urban food system. The emphasis should be on the city-region food system as a holistic and integrative planning framework comprising the urban and its entire foodshed.

The distant countryside sources that dominate Kampala's cooking banana supply chains suggest that the bananas travel over extensive distances by trucks to reach the urban consumers. Previous studies reveal that food transportation and the associated food miles consume large quantities of fossil fuel, thereby releasing greenhouse gases that contribute to global climate change. Thus, as part of their sustainability agenda, authorities in Kampala need to promote matooke production in the city's surrounding hinterland as a way to reduce the distance matooke is transported to reach consumers. Similarly, it is necessary to encourage investment in more efficient transportation systems, primarily railways that are better suited to transporting the bulky fresh matooke bunches and bags.

3.4.2. The Seasonal Variations in Cooking Banana Supplies to Kampala

The seasonal variations in cooking banana supplies to Kampala reveal a supply deficit during the wet season. A previous study by Nalunga *et al.* (2015) observed a decrease of practically 50% in banana supplies to Kampala during the wet (lean) season. This arises from the fact that the bananas that are delivered to the city in fresh form, have an exceedingly short shelf life under room temperature. Basically, the surplus from the increased supply during the dry-peak season cannot be stored for sale during the wet-lean supply season. This deficit in the banana flows is predominantly responsible for the reported persistent hikes in cooking banana food prices during the wet season (FEWS-NET, 2017). Assert that during the cool rainy off-peak season, cooking banana becomes less perishable due to the slow ripening rate. The prolonged banana ripening process enables farmers to retain the bananas for a longer duration, thereby selling them at higher prices in contrast to the lean supply season. Consequently, the wholesalers and market vendors also increase matooke prices to compensate for the increased trading costs when supplies are lower. Conversely, Lee (2023) contends that this seasonality in cooking banana supplies also generates a minor shift in market power in favour of the farmers during the lean wet season and the whole sellers during the peak supply dry season.

Intrinsically, to stabilise the supply and price of urban banana cooking, there is an urgent need to invest in banana processing into more durable products. Given that banana flows to Kampala from Bunyoro region marginally increased during the lean season, this region presents an alternative for increased cooking banana supplies during this period of scarcity.

3.4.3. The Land and Nutrient Footprints Embedded in Cooking Banana Flows to Kampala

From the results, it is evident that a disproportionate size of Kampala's cooking banana land footprint is located in its distant hinterland in Western Uganda. This is consistent with the findings of Ochola *et al.* (2022) who note that since 1958, roughly 60% of the national increase in banana cultivation has been in Western Uganda. The concentration of the city's matooke land footprint in Western Uganda implies the conversion of land previously allocated to the cultivation of traditional staples and grazing. Given that bananas in this region are grown as a monocrop, the conversion of grazing pasture land to banana production has implications for soil fertility.

The continuous rural-urban cooking banana flows to Kampala result in significant nutrient mining from rural farmlands. Previous studies have determined that nutrient depletion is a significant problem that is responsible for the reduction in banana yields. The continuous harvesting of bananas and their transportation to urban markets, results in the net removal of nutrients from banana stands. Moreover, the constant NPK nutrient mining and depletion associated with the rural-urban matooke flows is a threat to the sustainability of banana production in the source regions. The nutrients lost on the rural farmlands finish up in pools in the city from which recycling back to the rural farms is unviable. The nutrient mining, notwithstanding the current insufficient levels of on-farm fertiliser application in the country, is likely to exacerbate the already low and diminishing yields in the country's main banana producing areas and threaten urban food security (Tumuhimbise *et al.*, 2020). In this regard notes that declining soil fertility is the foremost constraint to agricultural production and hence a significant cause of food insecurity in Uganda. Thus, to ensure sustainable matooke production for urban food security, there is a need to engineer waste diversion strategies that enable nutrient recycling back to rural farm lands. This could include deliberate investment in value-addition processes in the banana source regions with the aim of ensuring that banana waste is re tained in production areas and recycled back to the farms.

In addition, the immense loss of NPK nutrients through the rural-urban cooking banana flows indicates that soils need to be constantly replenished with nutrients to ensure sustained production. Seeing as inadequate supply and the high cost of fertilisers are acknowledged to be significant bottlenecks to fertiliser uptake by farmers in Uganda, it is vital to develop more economically feasible fertiliser recommendations that target the main nutrient deficiencies. The development of these recommendations requires tools to identify plant nutrient imbalances. The nutrient norms currently in existence for the diagnosis of nutrient imbalance in AAA-EA cultivars (cooking bananas), were based on data that was limited to the Kagera region in Northwest Tanzania and may not be applicable to Uganda. Following his nutrient balance calculations based on measurements on Ugandan cooking banana farms, Kongkijthavorn (2017) proposes a ratio of 1 N: 2.1-2.5 K fertilisers to offset nutrient losses that arise from banana harvesting and transportation off the farm. Nonetheless, according to Wairegi, this use of external nutrient inputs is only profitable in areas with promising farm gate prices. Specifically, those close to the city and with a robust crop response, may not necessarily be profitable in distant locations or those places with relatively poor fertiliser response, such as Eastern Uganda.

4. Conclusion

This study quantified the rural-urban flows of cooking banana to Kampala and the land and nutrient footprints represented in the flows. There is a noted concentration of the city's cooking banana supplies in a handful of districts in Western Uganda. This places the sustainability of banana supplies to the city at considerable risk, particularly concerning the occurrence of any environmental shocks that could compromise production in Western Uganda. Through its continuous extraction of cooking bananas from remote rural farmlands, Kampala imposes a significant land and nutrient footprint on its food source locations in the countryside, far beyond its administrative boundaries. The resultant land use conversions and nutrient depletion caused by nutrient mining on rural farms are a serious challenge to achieving sustainable food production and urban food provisioning and production. One strategy exploited to mitigate nutrient mining is recycling banana waste back to the farms from which food is sourced.

Kampala is substantially dependent on its distant rural hinterland for banana food supplies. Per se, management of the city's foodshed as regards food sustainability will require capitalising upon connectivity across the rural-urban continuum. This requires deliberate institutional and governance mechanisms to coordinate the designing and implementation of policies beyond urban sectoral and administrative boundaries. Thus, policies associated with urban agrifood systems, should enable the incorporation of local, regional and national agrifood system stakeholders in a bottom-up planning approach pertaining to sustainability.

As mentioned, Kampala experiences an acute shortage of banana supplies for cooking during the wet season. This is primarily because of the fresh nature and short shelf life of the rural-urban banana supplies. This shortage of banana supplies explains the sharp increase in cooking banana market prices during this season, which makes matooke unaffordable for the poor urban households. As such, it is necessary for city planning authorities to encourage diversified cooking banana production including urban and peri-urban banana farming to reduce the banana supply chain and the processing of the bananas into durable products. These would drastically reduce the cost of marketing the bananas and thus minimise shortages and price hikes during the lean supply season.

The urban foodprint analysis conducted in this study features the regions that are crucial for cooking banana production as hotspots regarding the urban footprint. These findings when combined with data on constraints and threats to agricultural production in the food source regions is valuable in assessing the city's level of vulnerability to external shocks including climate change and nutrient depletion related shocks. This is fundamental for designing appropriate interventions for resilient urban food systems with a focus on the most significant urban food supply regions. Sufficient knowledge of the scale of the urban foodprint can support urban planners to devise strategies to increase food sourced from local producers within the greater Kampala Metropolitan area.

In this study, with a specific focus on the environmental consequences associated with rural-urban food flows, we exploited data collected from urban markets to quantify the urban foodprint for cooking banana consumption. Essentially, the study does not account for cooking banana obtained by urban household from sources other than the city markets. Future research on urban foodprints in the country should consider incorporating food sourced from household farms and supermarkets in urban foodprint calculations.

Acknowledgements

The authors gratefully acknowledge the anonymous reviewers who provided valuable comments.

Author Contributions

Conceptualization: Joyfred, A., Mukwaya, P. I., Lwasa, S., Bamutaze, Y., & Omolo, F; **methodology**: Joyfred, A.; **investigation**: Joyfred, A., Lwasa, S.; **writing—original draft preparation**: Joyfred, A., Omolo, F; **writing—review and editing**: Joyfred, A., Mukwaya, P. I., Lwasa, S., Bamutaze, Y., & Omolo, F; **visualization**: Alikhanov, B. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

Authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

Funding

This research received no external funding

References

Aleksandrowicz, L., Green, R., Joy, E.J.M., Smith, P., & Haines, A. (2016). The Impacts of Dietary Change on Greenhouse Gas Emissions, Land Use, Water Use, and Health: A Systematic Review. *PLoS ONE,* 11(11): e0165797. doi: 10.1371/journal. pone.0165797

Anielski Management Inc. (2010). *Environmental Footprinting for Agriculture in Alberta: Literature Review and Analysis.* Report prepared for Environmental Stewardship Division of Alberta Agriculture and Rural Development.

Apanovich, N., & Mazur, R. E. (2018). Determinants of seasonal food security among smallholder farmers in south-central Uganda. *Agriculture & food security*, 7(1), 1-10. doi: 10.1186/s40066-018-0237-6

Benis, K., Gashgari, R., Alsaati, A., Reinhart, C., i Garcia, J. M., Gaxiola, I. E., ... & Kay, A. (2018). Urban Foodprints (UF)–Establishing baseline scenarios for the sustainability assessment of high-yield urban agriculture. *WITPRESS LTD*, 13(2), 349-360. doi: 10.2495/dne-v13-n4-349-360

Billen, G., Barles, S., Garnier, J., Rouillard, J., & Benoit, P. (2008). The food-print of Paris: Long- term reconstruction of the nitrogen flows imported into the city from its rural hinterland. *Regional EnvironmentalChange*, 9(1):13–24. doi: 10.1007/s10113-008-0051-y

Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J. (2013). Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecological Indicators*, 24, 518–533.

Bosire, C. K. (2016). The water and land footprint of meat and milk production and consumption in Kenya. Implications for Sustainability and food security. *PhD Thesis, University of Twente, Netherlands*. doi: 10.3990/1.9789036542463

Calkins, S. (2021). Food as medicine: Making 'better bananas' in Uganda. *The Sociological Review*, 69(3), 560-579. Doi: 10.1177/0038026121100905

Castellani, V., Fusi, A., & Sala, S. (2017). Consumer Footprint. *Basket of Products indicator on Food, EUR 28764 EN, Publications Office of the European Union, Luxembourg, 2017*, ISBN 978-92-79- 73194-5, doi:10.2760/668763, JRC 107959

de Bruin, S., Dengerink, J., & van Vliet, J. (2021). Urbanisation as driver of food system transformation and opportunities for rural livelihoods. *Food Security*, 13(4), 781-798. doi: 10.1007/s12571-021-01182-8

De Cunto, A., Tegoni, C., Sonnino, R., Michel C., & Lajili-Djalaï, F. (2017). Food in cities: study on innovation for a sustainable and healthy production, delivery, and consumption of food in cities. *European Union, Luxembourg*. ISBN: 978-92-79-66947-7

Dotto, J., Matemu, A., & Ndakidemi, P. (2018). Potential of Cooking Bananas in Addressing Food Security in East Africa. *The Nelson Mandela AFrican Institution of Science and Technology*, 13(4), 2222-5234. doi: 10.12692/ijb/13.4.278-294

FAO. 2021. The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point (SOLAW 2021). *Synthesis report 2021 Rome*, 1-82. doi:10.4060/cb7654en.

FEWS NET, (2017). *Uganda Staple Food Market Fundamentals. Famine Early Warning Systems Network*. East Africa, Kampala Uganda.

Fischer, G. Tramberend, S. van Velthuizen, H. Wunder, S. Kaphengst, T. McFarland, K… Giljum, S. (2017). *Extending land footprints towards characterizing sustainability of land use*. Institute for Ecological Economics Vienna University of Economics and Business: Welthandelsplatz 11020. Vienna Austria.

Godar, J., Persson, M.U., Tizado, E. J., Meyfroidt, P. (2015). Towards more accurate and policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of production to consumption. *Ecological Economics, Elsevier*, 112, 25-35. doi: 10.1016/j.ecolecon.2015.02.003

Guibrunet, L., & Sánchez Jiménez, A. (2023). The current and potential role of urban metabolism studies to analyse the role of food in urban sustainability. *Journal of Industrial Ecology*, 27(1), 196-209. doi: 10.1111/jiec.13361

Goldstein, B. P. (2017). *Assessing the edible city: Environmental implications of urban agriculture in the Northeast United States.* DTU Management.

Goldstein, B. P., Birkved, M., & Fernandez, J. (2017). Surveying the Environmental Footprint of Urban Food Consumption. *Journal of Industrial Ecology*, 21(1), 151-165. doi: 10.1111/jiec.12384

Hemerijckx, L. M., Nakyagaba, G. N., Sseviiri, H., Janusz, K., Eichinger, M., Lwasa, S., ... & Van Rompaey, A. (2023). Mapping the consumer foodshed of the Kampala city region shows the importance of urban agriculture. *npj Urban Sustainability*, *3*(1), 11. doi: 10.1038/s42949-023-00093-1

Heinrigs, P. (2020). Africapolis: understanding the dynamics of urbanization in Africa. *Field Actions Science Reports* 21(22), 18-23. doi: 10.1787/b6bccb81-en

Karg, H., Bouscarat, J., Akoto-Danso, E. K., Heinrigs, P., Drechsel, P., Amprako, L., & Buerkert, A. (2022). Food flows and the roles of cities in West African food distribution networks. *Frontiers in Sustainable Food Systems*, 6, 857567. doi: 10.3389/fsufs.2022.857567

Karg, H., Drechsel, P., Akoto-Danso, E., Glaser, R., Nyarko, G., & Buerkert, A. (2016). Foodsheds and City Region Food Systems in Two West African Cities. *Sustainability*, 8(12), 1175. doi: 10.3390/su8121175

KCCA. (2014). *Laying the Foundation for Kampala City Transformation. Kampala City Strategic Plan*. Kampala city Council Authority. Kampala Uganda.

KCCA. (2019). *Kampala City Statistical Abstract, 2019*. Kampala, Uganda.

Kongkijthavorn, S. (2017). *Towards sustainable banana production in Central Uganda: Assessing four alternative banana cropping systems (dissertation)*. Farming Systems Ecology Group, Wageningen University: Netherlands.

Lee, H. (2023). Overview of the Current Status of Uganda's Banana Sector: Formalizing the Matooke Sector may not be the Best Policy Option. *The Open Agriculture Journal*, 17(1).

Lin, H. C., Huber, J. A., Gerl, G., & Hülsbergen, K. J. (2016). Nitrogen balances and nitrogen-use efficiency of different organic and conventional farming systems. *Nutrient Cycling in Agroecosystems*, 105(1), 1-23. doi: 10.1007/s10705-016-9770-5

Nalunga, A., Kikulwe, E., Nowakunda, K., Ajambo, S., & Naziri, D. (2015). *Structure of the cooking banana value chain in Uganda and opportunities for value addition and post-harvest losses reduction*. RTB-Endure technical report.

Paitan, C.P., Verburg P. H. (2019). Methods to Assess the Impacts and Indirect Land Use Change Caused by Telecoupled Agricultural Supply Chains. A Review. *Sustainability*, 11(4), 1162. doi: 10.3390/su11041162

Ochola, D., Boekelo, B., van de Ven, G. W., Taulya, G., Kubiriba, J., van Asten, P. J., & Giller, K. E. (2022). Mapping spatial distribution and geographic shifts of East African highland banana (Musa spp.) in Uganda. *Plos one*, 17(2), e0263439. doi: 10.1371/journal.pone.0263439

Papangelou, A.,Achten,W. M. J.,&Mathijs, E. (2020). Phosphorus and energy flows through the food system of Brussels capital region. *Resources, Conservation and Recycling*, 156, 104687. doi: 10.1016/j.resconrec.2020.104687

Schreiber, K., Hickey, G. M., Metsonc, G.S. Robinsona, B. E., MacDonald G.K. (2021). Quantifying the foodshed: A systematic review of urban food flow and local food self-sufficiency research. *Environmental Research Letters*, 16(1), 1-19. doi: 10.1088/1748-9326/abad59

Stelwagen, R. E., Slegers, P. M., de Schutter, L., & van Leeuwen, E. S. (2021). A bottom-up approach to model the environmental impact of the last-mile in an urban food-system. *Sustainable Production and Consumption*, 26, 958–970. doi: 10.1016/j.spc.2020.12.039

Tumuhimbise, R., Barekye, A., Talengera, D., Akankwasa, K., Nowakunda, K., Asasira, M., ... & Karamura,E. (2020). Assessing new banana genotypes for relevant traits: Implication for variety selection. *Agricultural Sciences*, 11, 1017-1032. doi: 10.4236/as.2020.1111066

UBOS. (2020). *Statistical Abstract 2020. Uganda Bureau of Statistics.* Kampala, Uganda

UBOS. (2021). *Uganda National Household Survey 2019/2020*. Uganda Bureau of Statistics Kampala, Uganda

UBOS. (2022). *Annual Agricultural Survey 2020*. Uganda Bureau of Statistics Kampala, Uganda

Vanham, D., Gawlik B.M., & Bidoglio, G., (2017). Cities as hotspots of indirect water consumption: The case study of Hong Kong. *Journal of Hydrology*, 573, 1075-1086. doi: 10.1016/j.jhydrol.2017.12.004

Vearey, J., Luginaah, I., Magitta, N. W. F., Shilla, D. J., & Oni, T. (2019). Urban health in Africa: a critical global public health priority. *BMC public health*, 19(1), 1-4. doi: 10.1186/s12889-019-6674-8

Wairegi, L. (2010). Management practices and opportunities in the East African highland banana (Musa AAA-EA) production in Uganda. Retrived From https://edepot.wur.nl/151966

Wiskerke, J. S. (2015). *Urban food systems.* In Cities and agriculture Routledge.

Zou, T. (2019). Urban Metabolism and the UM-US-SC Nexus. *Asian Journal of Social Science Studies*, 4(4), 53-78. doi: 10.20849/ajsss.v4i4.671