Cost and affordability of recommended diets in Rwanda using [near] real-time market data

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Abstract

Improving access to nutritious foods and affordable healthy diets is crucial for reducing malnutrition. Current data show that healthy diets are unaffordable for most consumers in lower-income countries, but annual estimates obscure seasonal and spatial variations. This study presents the first costing analysis of Rwanda's new food-based dietary guidelines, highlighting spatial, temporal, and socioeconomic differences in recommended diet affordability. Using monthly market price data, the sub-national costs of recommended diets were assessed from April 2019 to March 2024. Findings indicate a 67% increase in costs from June 2022-October 2023, tracking inflationary, making diets unaffordable for 85% of Rwandans. Significant cost disparities were noted between rural and urban areas and regions bordering neighbouring countries, affecting the urban poor and those near the Democratic Republic of Congo. High-frequency monitoring of diet cost is feasible and can provide intelligence for policymakers to identify and address geographies or social groups most disadvantaged in accessing recommended diets.

Introduction

An estimated 2.3 billion people have insufficient access to nutritious food, with a similar number suffering some degree of food insecurity [1]. Malnourishment and food insecurity in Africa remain widely prevalent and are expected to worsen by 2030 [2]. Improving access to nutritious foods and healthy diets are key strategies in addressing malnutrition [3]. Healthy diets must be sufficiently diverse and balanced to protect against malnutrition, but also be affordable [4].

Systematic methods have been developed (e.g., [5, 6]) for costing healthy diets internationally (e.g., [1,3]) which have shown healthy diets to be unaffordable for 42% of the global population [3]. Local adaptation of these methods using national food-based dietary guidelines and sub-national food item prices datasets reiterate the unaffordable nature of healthy diets and their spatial and temporal dynamism in countries around the world [7, 8, 9,10, 11, 12, 13, 14], yet no such analyses exist for Rwanda.

Monitoring this dynamism through improved spatial and temporal disaggregation of data can improve our understanding of the responsiveness of dietary cost to expected (e.g., seasonal) and stochastic (e.g., conflict-induced) price shocks. The benefit of this monitoring is especially significant in countries where consumers spend the majority of their income on food and where lean seasons persist because items essential for good nutrition (e.g., fruits, vegetables) confer few calories and are commonly foregone when facing caloric insufficiency. In most of these countries, markets in both urban [16] and

rural areas [16, 17] are the primary source of food items [18, 19, 12]. High-frequency and spatially disaggregated data can provide timely insights to guide policymakers in protecting year-round access to a healthy and affordable diet for all consumers. The potential of such [near] real-time advisory is ever closer in low- and lower middle-income countries (e.g. [20])

In Rwanda, high-frequency, spatially disaggregated market price data is part of the government's efforts to improve nutrition and transform the country's food system [21, 22]. Food prices have been collected since 2017 across more than 60 markets on a daily basis, and are publicly available on the eSoko platform (www.esoko.gov.rw). The spatial and temporal richness of this dataset is an invaluable, yet heretofore underutilised resource and represents a unique opportunity for spatially explicit, high-frequency estimation of diet costs, a rarity even in high-income countries [23]. Rwanda is about to release its food-based dietary guidelines and food composition tables, but it does not have information about whether diets meeting its recommendations are available or affordable to consumers.

By deploying standardised methods for healthy diet costs [6] to the eSoko data and local dietary guidelines, we calculate the monthly cost of recommended diets at a sub-national level. The aim is to generate outputs which provide policymakers with timely information to formulate and target policies for improved nutrition and health outcomes.

Results

Cost of a recommended diet

Figure 1 presents the costs of recommended diets as a (i) national average in nominal local currency units (Rwandan Francs (RWF)); (ii) national average in real terms (constant RWF, with January 2022 as the base month and year); and (iii) constant U.S. dollars at PPP-adjusted exchange rates with the same base month and year. In nominal terms, the cost of a recommended diet was stable at around RWF 600 from 2019 to mid-2022 (**Figure 1a**). From June 2022, we observed 17 months of near-constant price rises, increasing costs by 67% to a peak of RWF 920 in October 2023. The peak was followed by five months of decline to RWF 807 in March 2024 (an 11% decline). When adjusted for inflation, the real costs of recommended diets (**Figure 1b**) peaked in January 2022 at RWF 672 and declined, near continuously, for 26 months to March 2024, where the cost was RWF 480. The real costs in PPP-adjusted dollars peaked in June 2019 at $2.06 and oscillated around $1.80 from early 2020 to December 2021, where a second peak was observed ($1.94). Since early 2022, these real costs have declined to $1.35 by March 2024, a ~30% decline (**Figure 1c**). The change in the real cost of a recommended diet in constant (Jan 2022) RWF terms was far less dramatic because the adjustment for inflation accounts for other consumption items that may not have been affected by domestic or international price shocks.

The annual average mean cost of the recommended diet in local currency (nominal and real RWF) and constant U.S. dollars at PPP-adjusted exchange rates are available in **Table S1**. In nominal terms, the costs of recommended diets increased from 2019 to 2024 by 38% in RWF and 23% in international dollars. In real terms, the cost declined by 28%. Year–on-year changes in diets were most extreme for the years 2022 and 2023, with 22% and 21% nominal increases, respectively. In real terms, the 13.6% decline from 2021-2022 was the largest annual change.

Figure 1. Cost of recommended diet in Rwanda in a) nominal local currency units; b) real local currency units; c) constant U.S. dollars at PPP-adjusted exchange rates . Error bars present one standard deviation.

For brevity, remaining analyses are presented only in nominal RWF terms because this is a single country study where internationally comparable prices are less relevant, while nominal prices (i.e., without adjustments for inflation) are more important because those are the prices observed and experienced by consumers on a regular basis and thus affect consumer decision-making in the short run.

Disaggregating costs across food groups (**Figure 2**) reveals the constituent drivers of diet cost. Decreases in total food group costs were observed for animal-source foods (-1.3%) and oils and fats (-11%) during the study period, as opposed to observed increases for fruits and vegetables (91%), legumes (68%), and starchy staples (84%). The relative cost contribution of animal-source foods declined from 32% to 22% of the total cost; fruits and vegetables increased from 19% to 26%; legumes increased from 13% to 15%, oils declined from 24% to 14% (subject to the caveats discussed in Methods (Healthy Diet Costs), and starchy staples increased marginally from 19% to 22%).

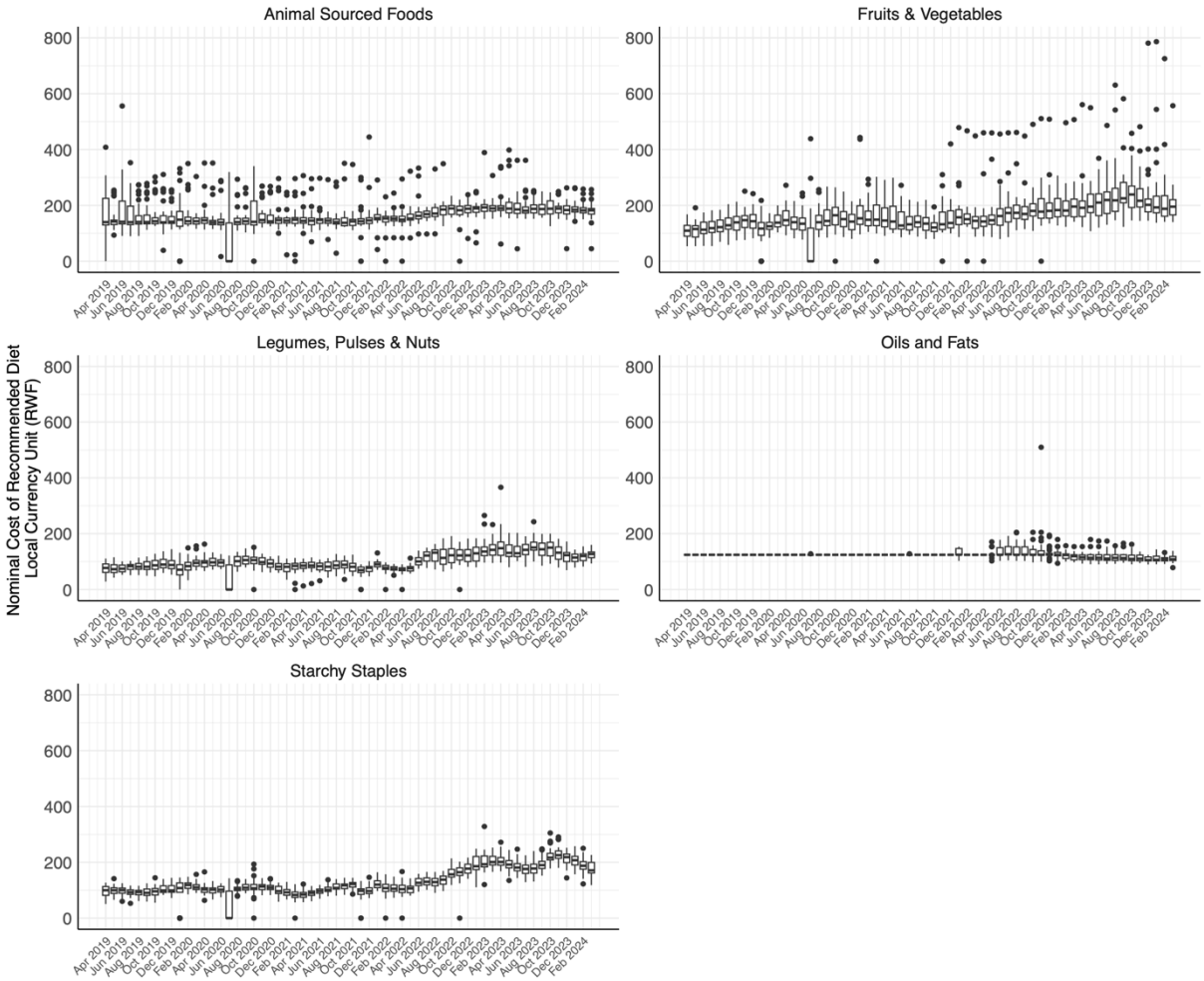

Figure 2. Cost of recommended diet disaggregated to constituent food groups. Boxes represent the 25th–75th percentiles of costs across Rwanda's 30 districts, with whiskers reflecting the 5th – 95th percentile of costs.

Cost seasonality

Rwanda has two main agricultural seasons: Season A (January-February) and Season B (June-July). Rwanda's lean seasons (April-May and October-November) correspond to the early growing periods for Rwanda's major crops. Thus seasonality is an important feature of food prices and diet costs in the country.

The seasonality of food group and total diet costs are presented as monthly deviations from annual trends (**Figure 3**). Positive (negative) values indicate periods when costs deviate above (below) the national average. Seasonality is most extreme in terms of total cost in October, aligning with the main lean season . In contrast, the total cost nadir (May) aligns with the end of the minor lean season. Starchy staples and legumes show the greatest seasonal deviations, with the peak costs of the former occurring in January and the latter in August. The cost nadir for most groups follows the harvest period and the months immediately following that period.

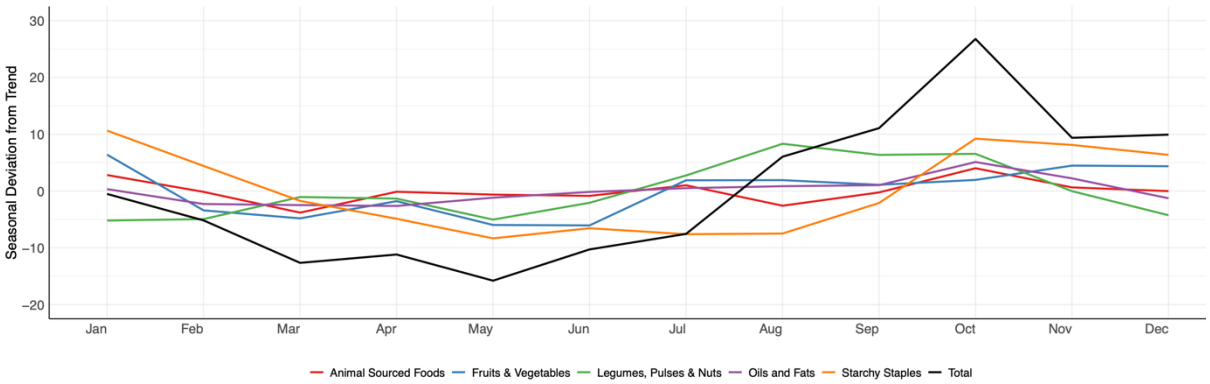

Figure 3. Seasonal deviation of the cost of recommended diets relative to national average, disaggregated by food groups. Lines present seasonal shifts from long-term trends, positive values representing when prices deviate above the trend, with negative values when prices deviate below it.

Spatial patterns of cost

Figure S1 presents the mean average total cost of a recommended diet in each of Rwanda's 30 districts (**Figure S1a**) during the 60 months of available data, with the standard deviation presented in **Figure S1b**. The average costs for the constituent food groups are also mapped (**Figure S1c-g**). The highest average dietary cost was recorded in Muhanga district (west of Rwanda's capital, Kigali) at RWF 859, with the lowest cost in Kayonza district at RWF 620 (east of Kigali, on the border with Tanzania). The spatial pattern of total dietary cost (**Figure S1a**) and deviation (**Figure S1b**) seems determined by fruits and vegetables (**Figure S1d**) and to a lesser extent animal-source foods (**Figure S1c**). Comparison of costs of recommended diets (**Table S2**) along the rural-urban continuum revealed they were significantly (10.5%) cheaper in rural districts (RWF 688), compared to urban (RWF 768).

Exploring these spatial features further with regression analysis shows that average diet costs in districts with international borders (**Figure 5**) deviate significantly from average costs in non-border districts (**Table 1**), and that these deviations closely mirror Rwanda's trade relations. Recommended diet costs in border districts from 2019-2024 were 1.6% cheaper than in non-border districts. Diets were significantly cheaper in districts bordering Tanzania (6.5%, p=0.009) and Uganda (3.4%, p=0.042), likely reflecting access to lower-cost food imports from both countries. Diet costs were 6.8% more expensive in districts bordering the DRC compared to non-border districts (p=<0.001 in all cases), reflecting Rwanda's lucrative exports in food items to DRC through both informal and formal markets. No statistically relevant differences were observed amongst those districts bordering Burundi, which is consistent with the relatively limited flows of food trade—either formal or informal—between the two countries.

Table 1. Impact of international borders on costs of recommended diets

International Border	Mean cost of recommended diet in RWF (SD)	Cost difference with non-borders (%)	P-value
Non-border districts	701.8 (153)	-	-
Border districts	690.4 (137)	-1.6	0.123
Burundi	690.8 (135)	-1.6	0.265
Democratic Republic of Congo	749.3 (117)	6.8	0.000***
Tanzania	656.3 (125)	-6.5	0.009**
Uganda	678.1 (144)	-3.4	0.042*

*p<0.05, **p<0.01, ***p<0.001

Affordability of recommended diet

Smoothed affordability trends for the recommended diet are presented as a proportion of daily wages (**Figure 4**). Trends are disaggregated for rural and urban wage earners across income quintiles. In **Figure S2**, we present a similar figure for sex and location (e.g., urban female). Overlayed on **Figure 4** are two proportions of wages used for food spending (100%, black dashed line; 52%, red dashed line). Recommended diets were unaffordable throughout the study period for low-mid earners (quintiles 1-3), based upon 52% of wages directed towards food purchases, a pattern maintained across sex and location groups. By late 2023/early 2024, wage earners in quintiles 1 and 2 would need to spend more than 100% of their wages on the recommended diet. This is most pronounced for low wage earners in urban areas, where the recommended diet would exceed 175% of their daily wage. Earners in quintile 4 would spend almost 52% of wages on the recommended diet. For Rwanda's highest earners (quintile 5), a recommended diet would consume almost 25% of their daily wages for rural workers and just under 20% for urban earners.

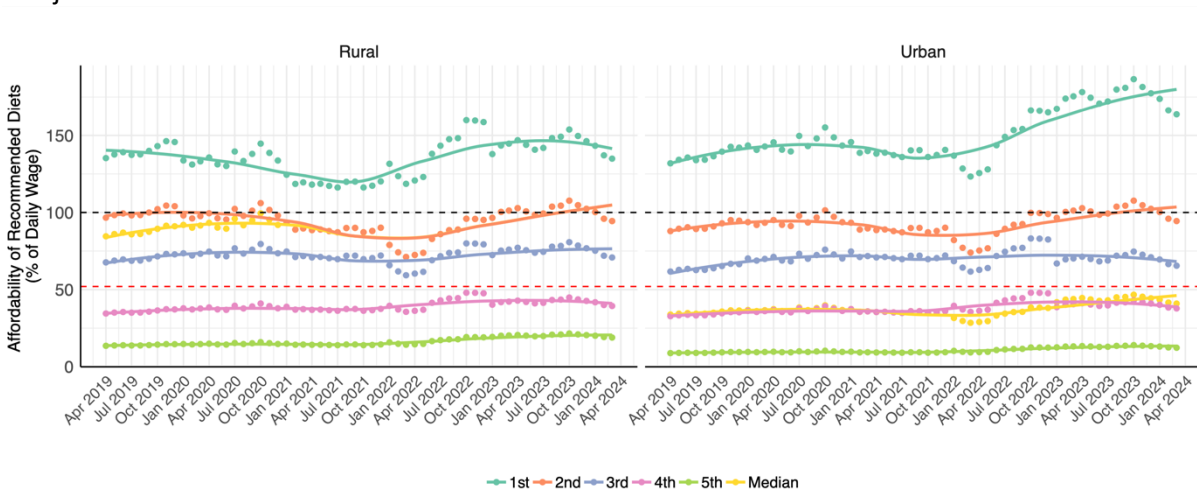

Figure 4. Affordability of recommended diets relative to median daily wage across wage quintiles, rural and urban wage earners. Black dashed line presented 100% of daily income and red dashed line 52% of income, a threshold used in international studies of the affordability of a healthy diet.

We also estimated the number of employed Rwandans who would be unable to afford the cost of the healthy diet, based upon their wages (**Table S3**). These numbers were estimated at the 52% rate of a daily wage (the red dashed line – **Figure 4**). In 2019, 32% of wage earners could afford the recommended diet, by late 2023 this had declined to 15%. This translates to 2.3 million wage earning Rwandans being unable to afford a recommended diet.

Discussion

We calculated sub-national monthly recommended diet costs for the period April 2019-March 2024, finding average nominal costs were stable up until May 2022, at around 600 RWF (~$1.85 international USD). Despite prolonged periods of lockdown, curfews, and border closures, limited cost fluctuations were observed during the peak of COVID-19 (2020-2021). Considering reported impacts of COVID-19 on global food prices (e.g. [24]), the diet cost stability in Rwanda might be an unexpected finding. However, costing using a food basket approach, where items could be replaced by cheaper options, likely dampened COVID's effects in our results. Mwambi et al. [10], using a similar approach, observed minimal impacts of COVID-19 on dietary costs. Also, given that the restrictions introduced to contain the spread of the COVID-19 had a dampening effect on consumption by limiting access to markets for both food producers and consumers, diet costs were subject to slight deflationary pressures [25].

Russia's invasion of Ukraine had a more evident impact on dietary costs. The invasion had (and continues to have) significant impacts on global supply chains, energy and commodity markets, global

inflation, and food prices [26, 1]. Our analysis shows that the initial shock did not trigger an immediate response in dietary costs, contrary to the near-instant spike in the FAO's Food Price Index, observed in March 2022. The shock, translated as inflationary pressures, reached Rwandan consumers by May-June of 2022. At its peak, food and beverage inflation neared 40% and remained above 20% until late 2023 [27]. These inflationary pressures translated to 17 consecutive months of recommended diet cost rises from June 2022, increasing by 67% to a peak of 920 Rwandan Franc ($2.58 international USD) in October 2023. Consumers not only observe the nominal costs of a healthy diet in RWF, they are also likely to build their expectations and make consumption decisions based on those costs.

These cost increases had tangible impacts on diet affordability, with recommended diets unaffordable even before the war's effects cascaded to Rwanda. Since late 2022, Rwanda's lowest income earners would need 150% of their daily wages to afford the recommended diet. At the same time, more than 60% of wage earners (~1.7 million Rwandans) were unable to afford recommended diets based upon their daily wages and a 52% distribution of income purchasing diets. The inflationary pressures of 2022-2023 catalysed a peak of unaffordability, with an extra ~600,000 Rwandans, accounting for 85% of all wage earners (2.3 million individuals), being unable to afford the recommended diet by mid-2023 at median daily wages. Only those individuals in the highest wage quintile could feasibly afford a recommended diet. These results align with FAO [28], where 82% of Rwandans were estimated to find healthy diets unaffordable, in 2021. More concerning is the implication in this analysis that wages would only support an individual and would not be sufficient for dependents. Considering dependents and informal wage earners, the number of Rwandans who find recommended diets unaffordable is likely far higher than we estimate.

Inflationary pressures have eased since October 2023, resulting in cost reductions and moderate easing of unaffordability. Still, the pace and scale in the changes in affordability is troubling, compounded by sluggish wage growth across the country [29]. Rwanda has not updated its minimum wage since 1973, standing at 100RWF (~$0.08 USD). Recent developments in Nigeria, where minimum wages are to be pegged to the cost of a healthy diet [30], could suggest a pathway for the Rwandan government to make their recommended diet affordable and progressively update the minimum wage. If such a policy pathway were to be piloted in Rwanda, it would need to consider the spatial, seasonal, and social differences in recommended diets and affordability.

Recommended diets were calculated to be significantly cheaper in rural areas, mirroring recent findings in other African countries [13]. Higher urban food prices have been found to not be offset by consummate higher wage [31], inhibiting urban affordability of healthier foods and diets [32]. In Rwanda, we found similar patterns. Wages for the lowest urban wage quintiles were 17% lower than equivalent rural wages, even higher urban earners only received 4-8% more than their rural counterparts (29). The problem of limited wage opportunities are compounded by higher (~10%) recommended diet costs in urban areas, suggesting probable issues of urban malnutrition, as reported in other global studies (e.g. [33]). Cohen and Garrett [34] found that poorer urban households' dependence upon markets makes them particularly vulnerable to market prices. Unlike their rural counterparts, they are less likely to offset affordability problems by producing their own food [35, 36]. These findings suggest the newly developed government dietary guidelines are unaffordable to most Rwandans and calls for deliberate action to increase affordability. Achieving this requires continued monitoring to evaluate whether actions taken have the intended impact, especially in urban settings.

Further spatial differences were observed along international borders, with recommended diets significantly cheaper in districts bordering Uganda and Tanzania and more expensive in districts bordering the DRC. As a landlocked country, Rwanda is heavily dependent on its neighbours for formal

[37] and informal food flows [38, 39]. Versailles [40] and Brenton et al. [41] estimate moderate cross-border market integration for Rwanda and its neighbours, offering opportunities for international vendors [38, 41]. Items coming via informal flows, not subject to duties and delays and limited formal storage infrastructure in border areas, may push down localised prices [42]. Versailles [40] noted that the least integrated markets in East Africa were for fruits and vegetables. We found fruits and vegetables to be cheapest near Tanzania and Uganda, indicating inflows of these products into Rwanda. Versailles [40] suggests that their perishability and seasonality limits market integration (e.g. [14]), which explains why these cheaper items are not traded further into the country increasing total domestic supply. The combination of trans-border flows, moderate market integration, and the perishability of fruits and vegetables likely explain our findings of cheaper recommended diets near the borders of Tanzania and Uganda, with this food group being the greatest contributor to total diet cost. In contrast, the opposite seems true on the DRC border, where fruits and vegetables and starchy staples are more expensive than in other districts, likely attributable to notable outwards flows to the DRC [39], where vendors receive premium prices which imposes pressure on prices on the Rwandan side of the border. These findings suggest a flow of goods from Uganda and Tanzania into Rwanda, driving down food prices along international transport routes. In districts bordering DRC, a price differential may provide opportunities for vendors, with the gravity of flows moving out of Rwanda into the DRC pushing up local prices of what remains in Rwanda.

As part of the growing commitment to food system-based policymaking by the Rwandan Government, we believe this research reinforces the benefits of the eSoko dataset, which should have greater prominence in policy efforts. It offers an invaluable, yet underutilised low-cost resource that captures real-time and spatially disaggregated data that can facilitate timely responses to real-world events. A clear demonstration of this is from an immediate response to Burundi's unilateral closure of the Rwanda-Burundi border. Within a few weeks of the closure, eSoko data were used to show limited price impacts in neighbouring and distant markets [43]. In addition, tracking movements like spatial variations (e.g., prices near borders) and seasonality can help craft policies to mitigate price fluctuations and generate seasonal and location specific response plans. Also, simultaneous high-frequency monitoring of wages would allow for detailed and real-time diagnostics of affordability across Rwandan society. The unique data could also form part of an early warning system, highlighting where prices spike, at-risk social groups, and potential impacts. This system could also be a benchmark for neighbouring countries to aspire to.

This study utilises a spatially and temporally rich dataset to analyse the cost of a recommended diet during a 60-month period (April 2019 to March 2024) in Rwanda. Findings reveal significant fluctuations in dietary costs, with nominal costs increasing 67% in less than 18-months, tracking inflation driven price rises caused by the Ukraine War. Our findings suggest the newly developed government dietary guidelines are unaffordable to most Rwandans, with up to 85% of wage-earners in the formal economy unable to afford recommended diets in 2023. We observed spatial deviations in price too, with prices increasing along the rural-urban continuum and based upon distance to international bordering crossings. This calls for deliberate actions (e.g. improving market access and transportation infrastructure in rural areas, local food production) to increase affordability, which requires continued monitoring to evaluate whether actions taken have the intended impact, especially in urban settings. High frequency collection of market price data is highly advantageous not only to provide insights into long-term historical trends, but also forming the foundation of monitoring system to flag markets or regions where prices are spiking or social groups that may be at risk of finding recommended diets unaffordable. The system deployed in Rwanda could be a benchmark for neighbouring countries to aspire to and implement similar studies.

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Methods

Data

Food Prices

Price data were collected from the online platform, eSoko (www.esoko.gov.rw), maintained by the Rwandan Ministry of Agriculture and Animal Resources (MINAGRI). It collates price information for more than 136 items (including food, feed, and agricultural inputs), with 106 being food items. Prices are recorded per kilogram or litre. We aggregated similar items into groups (e.g. varieties into a single food item), taking the median price from this aggregation. This aggregation reduced the data to 56 individual items (**Table S4**).

Price data are collected daily by the Government of Rwanda and are available as an average of wholesale, retail, and farm gate prices, recorded in Rwandan Francs (RWF). Data are collected at 67 markets, with at least one market in each of Rwanda's 30 districts (administrative level 2; **Figure S3**). We spatially aggregated market prices to district prices, taking a mean price if multiple prices are available for the same food item (**Table S4**) from different markets in the same district. As data collection was not performed simultaneously across markets, we aggregated to a monthly mean per district, generating monthly price data for the period April 2019 to March 2024.

Wages

Median monthly wage data were collected from the National Institute of Statistics Rwanda (NISR; [29]). Data were collected for the period 2019-2023, although data were unavailable for 2020 and 2024. Data for 2020 was interpolated from an average of 2019 and 2021. For 2024, 2023 data were used. The justification for this being that reported wage data were noted to be slow to change, with minimal changes expected in the first quarter of 2024. Wage data were collected as: a national average, average for women, average for men, and for income quintiles. The number of individuals per income quintile were also collected. Monthly median wages were converted to daily wages.

Price Conversions

To account for the temporal nature of the analysis, monthly food price and wage data were converted from nominal to real RWF using the monthly consumer price index (CPI) for food and non-alcoholic beverages produced by the NISR for April 2019-March 2024 [27]. The NISR's CPI reference (base) period is February 2014, this was converted to January 2022 so that the reference month and year fell within the analysis period for ease of interpretation. Further, to ensure this study is comparable with similar global studies and datasets (e.g. [28]), nominal and real prices were converted to international dollars using the World Bank's annual purchasing parity conversion factors for 2019-2022 [44]. The 2022 conversion factor was used for 2023 and 2024 data as these data were yet to be released at writing.

Healthy Diet Costs

To calculate the monthly costs of a recommended diet across the districts of Rwanda, the methodology developed by Herforth et al. [6] was adopted. This method computes the least-cost diet that fulfils minimum food group serving and diversity requirements for a healthy diet basket. The

forthcoming Rwandan national food-based dietary guidelines (FBDGs) were used to define the dietary parameters (**Extended Data Table 2**). The Rwandan FBDGs were sourced from FBDG materials provided at a validation workshop convened by the Rwandan Ministry of Agriculture and the FAO in late 2021. The FBDGs recommend a healthy diet made up of 11 food items, split across five food groups (number of food items, **Extended Data Table 2**).

Table 2. Rwandan food based dietary guidelines adapted for healthy diet construction.

Food Groups	Number of Food Items	Recommended Amount per Group (grams/day)	Recommended Amount per Item (grams/day)
Animal sourced foods	2	111.19	55.60
Starchy staples (cereals, roots, and tubers)	2	441.75	220.88
Fruits and vegetables	5	429.53	85.91
Oils and fats	1	51.25	51.25
Legumes, pulses, and nuts	1	203.06	203.06

Each of the 56 food items available in the price data (**Table S4**) were grouped into the 5 food groups (**Extended Data Table 2**). For each food item, an estimate of the edible portion was generated as a proportion (0-1). Edible portions were sourced from the USDA [45] and complemented by author knowledge in cases where foods were not listed. The proportion was then used to calculate the cost per edible portion with prices per gram and item (**Extended Data Table 2**) generated from this edible amount (kilogram or litre). Using price data, we calculated the cost per gram of each available food item (edible amount), in each district, at each month. We then calculated the cost of the required amounts for each food items, using the per gram costs, multiplied by the recommended amount values from **Table 1**. For example, for animal sourced foods, we calculated the cost of 55.6g of each available animal sourced item, per district and month.

The costs of the recommended amount per item were then ordered from cheapest to most expensive, with the cheapest items per group food group selected, based upon the required numbers. For example, for fruits and vegetables, the five lowest-cost items were selected. The same item could not be selected multiple times to ensure diversity per group. This process was repeated for each food group. The costs per group were then calculated, with the total of these values used to generate the cost of a recommended diet in a given district and month. This was repeated in all 30 districts, for each of the 60 months analysed (April 2019 – March 2024).

Data for oils and fats were not consistently available before June 2022. Rather than truncate the analysis, a median average price of oils and fats was calculated using data from June 2022-March 2024 (123 nominal RWF). This value was applied in months and districts where oil and fat price data were unavailable before June 2022. This adjustment made the costs of oils and fats constant until mid-2022.

Seasonality

Previous studies have highlighted seasonal patterns of food prices (e.g. [7,8]). Important for understanding variations in affordable diets, we explore seasonal effects on food prices by decomposing the time series price data into three fundamental components: trend, seasonality, and remainder using the 'forecast' package in R [46]. Harmonic regressions were used to estimate a smooth trend in the time series. This harmonic-based approach has been used by others to better understand seasonality in dietary cost trends. Using this approach, the seasonal trends for each food group and the total diet cost were calculated, along with peak and nadir months.

Spatial Analysis

Spatial patterns were analysed across districts, the rural-urban continuum, and districts that border Rwanda's neighbours. The first dimension consisted of mapping costs across districts. The second

required the determination of the predominant settlement type in a given district (**Figure S3**). To do this, the 2022 census data were used, where each interviewed household was categorised as urban or rural [47]. Districts with >50% of urban households were classified as urban, districts with <50% of urban households were classified as rural (**Figure S3**). The third dimension focuses on the regional movement of food items and how that may impact prices in districts bordering Rwanda's neighbours, compared to non-border 'interior' districts. Rwanda has 19 official international border crossings [48], connecting it with neighbouring Democratic Republic of Congo to the west, Burundi to the south, Uganda to the north, and Tanzania to the east (**Figure S3** – red lines). As a landlocked country, Rwanda is heavily dependent these border crossings for the movement of most imported goods, including many food items [37,38]. Linear regressions were implemented to identify if statistically relevant spatial differences are observable across these three spatial dimensions.

Affordability of a recommended diet

Using daily wage data (See Wage), disaggregated across sex and wage quintile, we estimated the affordability of diets across these disaggregated groups by estimating the proportion of a daily wage that would be required to purchase a healthy diet. We calculated this at two levels: (i) where 100% of an individual's daily earnings are freely and uniquely available for purchasing food items for themselves, not accounting for dependents, rents, or other expenditures; and (ii) using the more realistic proportion of wages that may be directed to food purchasing, at 52% of daily wages [1]. We used both values to estimate the affordability of recommended diets and the number of wage earners who could afford the diet. This analysis was performed at the national level as wage data were unavailable at the district level.

Codes

All analysis were performed in R version 4.3.3 [49]. Replication code is available in the Supplementary Material.

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Supplementary Material

Table S1. Mean average annual cost of healthy diet and year on year change in costs in Rwandan Francs, nominal international dollars, and constant U.S. dollars at PPP-adjusted exchange rates. Standard deviations presented in brackets. Year on year percentage changes in mean cost also presented.

	Nominal Cost (Local Currency Unit -RWF)		Real Cost (Local Currency Unit _RWF)		Constant U.S. dollars at PPP-adjusted exchange rates	
Year	Mean (± SD)	Year on Year Change (%)	Mean (± SD)	Year on Year Change (%)	Mean (± SD)	Year on Year Change (%)
2019	599 (87)	-	631 (94)	-	1.99 (0.30)	-
2020	636 (85)	6.2	610 (81)	-3.3	1.82 (0.24)	-8.5
2021	610 (85)	-4.1	606 (84)	-0.7	1.84 (0.26)	1.1
2022	715 (106)	17.2	565 (85)	-6.7	1.59 (0.24)	-13.6
2023	871 (122)	21.8	504 (81)	-10.8	1.41 (0.23)	-11.3
2024*	828 (134)	-5.0	501 (88)	-0.6	1.43 (0.28)	1.0

*To date: March 2024

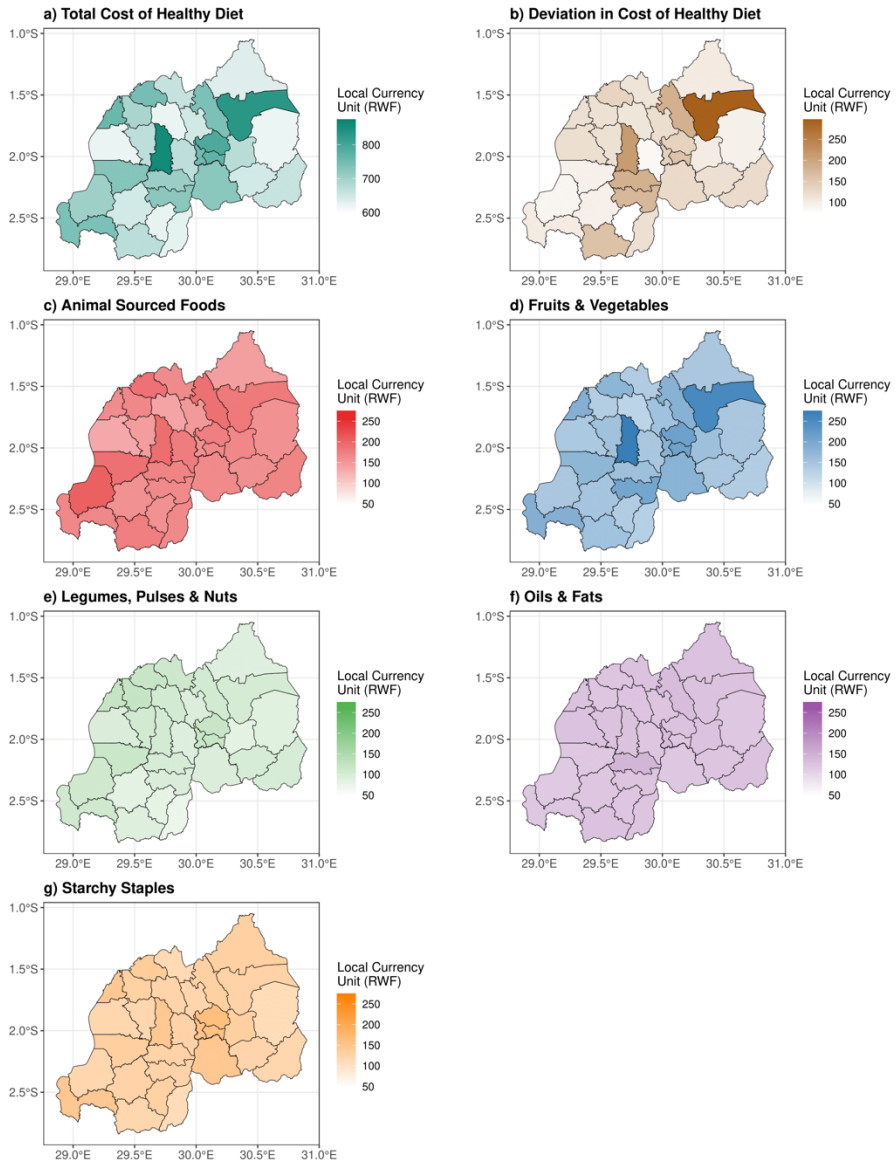

Figure S1. Cost of healthy diets across Rwandan districts: a) mean total dietary costs; b) the standard deviation of the total cost; c-g) the costs of the constituent food groups.

Table S2. Costs of recommended diet along the rural-urban continuum. Standard deviations in brackets.

	Mean cost of a recommended diet in RWF (SD)	P-Value
Urban	768.3 (139)	
Rural	687.6 (149)	0.000***

*p<0.05, **p<0.01, ***p<0.001

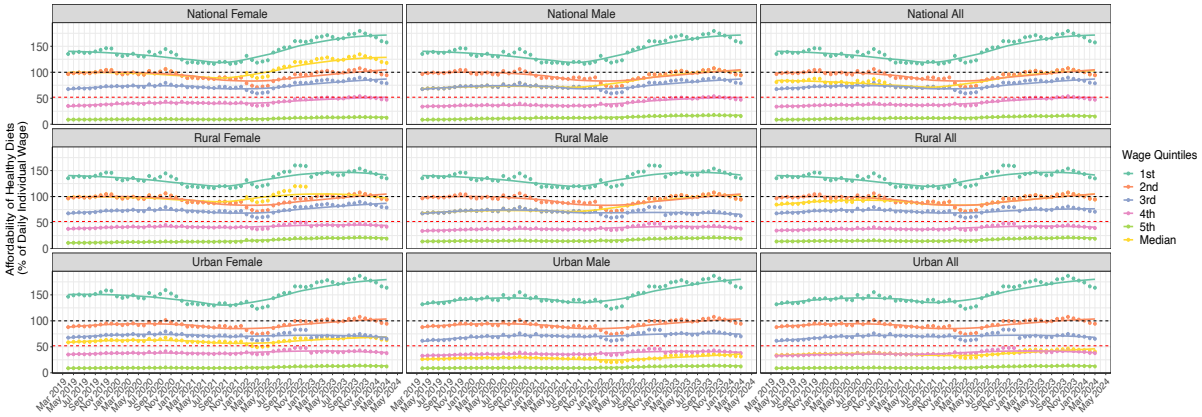

Figure S2. Affordability of healthy diets relative to median daily wage across wage quintiles for women, men, and a national average in rural and urban locations. Black dashed line presented 100% of daily income and red dashed line 52% of income, previously reported as amount of daily income spent on food.

Table S3. Estimated number of employed Rwandans who cannot afford a healthy diet.

Year	Number of Employed Individuals	% of Employed Individuals
2019	1,482,916	68
2020	1,566,307*	68
2021	1,649,698	68
2022	1,709,259	67
2023	2,307,971	85
2024	XXXXXXXX	68

*Interpolated estimates as no employment data available for 2020. + 2023 wage data used for 2024 (January-March).

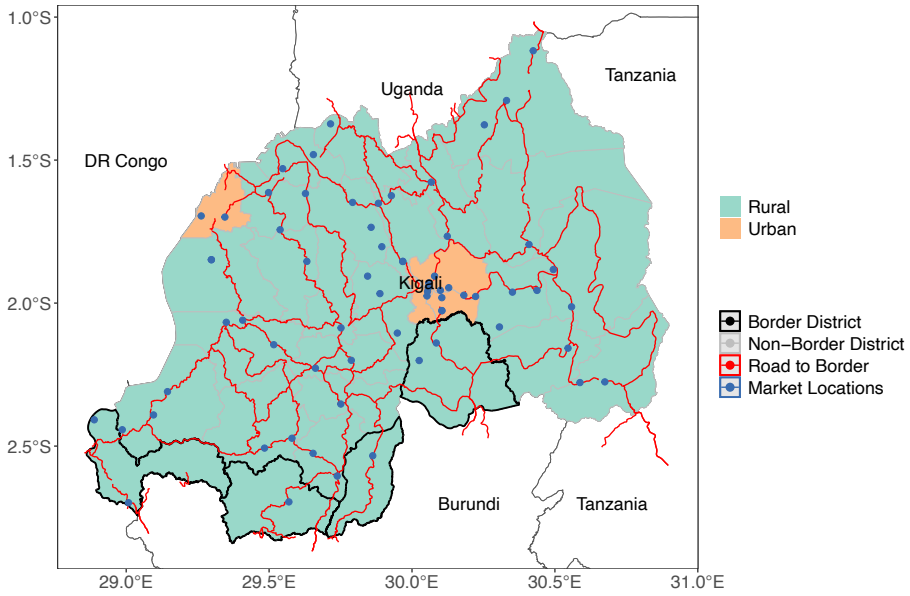

Figure S3. Rwanda and its neighbouring countries in Central Africa. Markets where price data are collected are presented in blue. Urban districts of Rwanda are presented in orange, with rural districts presented in green. All major roads of the country are coloured red, including all border crossings. Districts bordering neighbouring countries are framed in black, all other districts in grey.

Table S4. Retained food items from eSoko dataset.

Animal Source Foods	Fruits & Vegetables	Legumes, Pulses & Nuts	Oils & Fats	Starchy Staples
Chicken meat	Avocado	Beans	*Oil interpolation	Banana cooking
Chicken meat improved	Bananas ripe	Big beans	Palm oil	Cassava
Cow meat	Beetroot	Climbing beans	Sunflower oil	Cassava flour
Cow meat bones	Cabbage	Fresh beans		Irish potato
Cow milk	Carrot	Green beans		Maize
Egg	Cassava leaves	Groundnuts		Maize flour
Fish salted	Cauliflower	Peas		Maize flour imported
Fish sambaza	Celery	Small beans		Rice imported
Fish tilapia	Cucumber			Rice local
Fish tomson	Eggplant purple			Sorghum
Goat meat	Garlic			Sorghum flour
Honey	Gooseberry			Sweetpotato
Pig meat	Green pepper			Wheat
Rabbit meat	Guava			Wheat flour
Sheep meat	Lemon			
	Mandarin			
	Mangoes			
	Oranges			
	Papaya			
	Parsley			
	Passionfruit			
	Pineapple			
	Pumpkin			
	Red onion			
	Spinach			
	Strawberry			
	Tomatoes			
	Tree tomato			
	White onion			
	Yellow pepper			