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Urban consumption of meat and milk and its green and blue water footprints—Patterns in the 1980s and 2000s for Nairobi, Kenya

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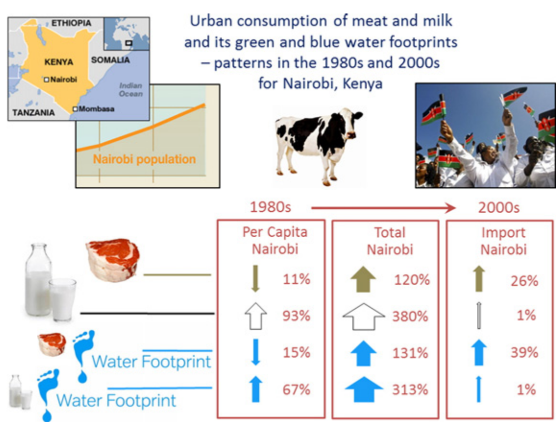
HIGHLIGHTS

- Consumption of meat and milk in Nairobi increased 2.2 and 5.0 times between the 1980s and 2000s.
- Total water footprints of meat and milk consumption increased 2.3 and 4.2 times, respectively.
- In the 1980s, water footprints of meat and milk consumption in Nairobi originated only from Kenya.
- In the 2000s, water footprint of meat consumption in Nairobi had a substantial foreign component.

GRAPHICAL ABSTRACT



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ABSTRACT

The problem: Various studies show that the developing world experiences and will continue to experience a rise in consumption of animal proteins, particularly in cities, as a result of continued urbanization and income growth. Given the relatively large water footprint (WF) of animal products, this trend is likely to increase the pressure on already scarce water resources.
Aim: We estimate, analyse and interpret the changes in consumption of meat and milk between the 1980s and 2000s for three income classes in Nairobi, the ratio of domestic production to imports, and the WF (the volume of freshwater consumed) to produce these commodities in Kenya and abroad.
Results: Nairobi's middle-income class grew much faster than the overall population. In addition, milk consumption per capita by the middle-income group grew faster than for the city's population as a whole. Contrary to expectation, average meat consumption per capita across all income groups in Nairobi declined by 11%. Nevertheless, total meat consumption increased by a factor 2.2 as a result of population growth, while total milk consumption grew by a factor 5. As a result, the total WF of meat consumption increased by a factor 2.3

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Nairobi
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and the total WF of milk consumption by a factor 4.2. The increase in milk consumption was met by increased domestic production, whereas the growth in meat consumption was partly met through imports and an enlargement of the footprint in the countries neighbouring Kenya.
Discussion and conclusion: A likely future rise in the consumption of meat and milk in Nairobi will further enlarge the city's WF. Given Kenya's looming blue water scarcity, it is anticipated that this WF will increasingly spill over the borders of the country. Accordingly, policies aimed at meeting the rise in demand for meat and milk should consider the associated environmental constraints and the economic implications both nationally and internationally.

1. Introduction

Urbanization is one of the three major processes driving the "livestock revolution" currently underway in many developing countries (Delgado et al., 1999). Advancing urbanization together with growing human populations and continued economic growth, engender rising food requirements and a change in dietary preferences towards more livestock intensive diets, consisting of more meat, milk and eggs (Crosson and Anderson, 1994; van der Zijpp, 1999; Ndambi et al., 2007). Not surprisingly, both the production and consumption of animal source foods (ASFs) in developing countries are projected to increase (FAO, 2016). The anticipated increase in ASF consumption will likely lower the prevailing high levels of undernutrition (FAO et al., 2015), which have been associated with inadequate consumption of protein (Ayele and Peacock, 2003; Narrod et al., 2011). Yet, despite the rising consumption of ASFs, there are major differences in consumption patterns among different income classes, with the middle and upper income classes consuming predominantly more ASFs, particularly from supermarkets (Thornton et al., 2007).

By 2014 about 54% of the global population was estimated to live in urban areas, compared to 30% in 1950. There is a huge difference in the level of urbanization between industrialized and developing countries, with around 75% living in urban areas in North America, Latin America and Europe, 48% in Asia and 40% in Africa. Up till 2050, the number of global urban dwellers is projected to increase by 2.5 billion and reach a total of 6.3 billion; 90% of this increase is projected to take place in Asia and Africa. When only the urban population in sub-Saharan Africa for the period 2015–2030 is considered, future prognoses indicate that the number of people transitioning from rural to urban life is estimated to increase by 115% in 15 years, from 170 to 360 million (UN, 2015).

Feeding urban populations requires large quantities of food to be transported into cities from surrounding areas (Liu et al., 2013). With progressing urbanization, urban centres develop tele-connectivity and a lengthening of food supply chains. Initially, agricultural products are supplied from only a few kilometres away. As urbanization continues, distances become larger, extending from local to national, to regional and finally to food imports from the global market. The highest degree of globalization is found in the most advanced countries, where urban areas are based on service and industrial sectors, which provide enough revenues to sustain long supply chains. In contrast, rural areas typically have lower population density and enough land per capita to produce food for both the rural inhabitants and adjacent and remote urban populations (Seto et al., 2012).

The environmental impacts of livestock production represent a major challenge and source of concern (Steinfeld et al., 2006; de Vries and de Boer, 2010; Gerber et al., 2013), and are expected to rise given the projected expansion of the livestock sector in developing countries in the coming decades (Alexandratos and Bruinsma, 2012b). There is thus a pressing need to safeguard ecosystems and natural resources in these countries, most of which are already experiencing considerable and varied pressures (Herrero et al., 2010; Herrero and Thornton, 2013). Following the fact that the majority of future consumers of livestock products will be urban dwellers, a deeper understanding of the link between urbanization and consumption of livestock products, on the one hand, and natural resource use and its environmental impacts, on the other, become increasingly important.

Consumption patterns and their associated socio-economic correlates have been widely studied and form the basis for projections of future demand for food (Delgado, 2003; Narrod et al., 2011; Msangi and Rosegrant, 2012). However, the relationships of these patterns to resource use, though highly intertwined, have only recently began to be intensively analysed (Gerbens-Leenes and Nonhebel, 2002; Rockström et al., 2007; De Fraiture et al., 2010; Falkenmark and Lannerstad, 2010; Molden et al., 2010; Fischer et al., 2011; Gerten et al., 2011; Mekonnen and Hoekstra, 2012), largely due to an increasing recognition of the growing scarcity of water and land, which severely constrains agricultural production (Costa, 2007; Molden, 2007; Hoekstra and Wiedmann, 2014). Most of these studies have mainly focused on understanding the environmental implications of food consumption in developed countries and their findings form the basis for recommendations to reduce environmental footprints. However, the results from these studies are seldom fully representative for developing countries. In Africa, studies of the relationship between resource use and consumption patterns have focused almost exclusively on crops (Chouchane et al., 2015; Pahlow et al., 2015). Consequently, there is an enhanced understanding of improved agricultural productivity of crops (Conceição et al., 2016) and its implications for natural resource demand.

An important aspect of the environmental implication of consumption that has attracted relatively little attention thus far is how urban growth and the associated increase in consumption of animal source foods (ASFs) affects natural resource appropriation in Africa. As a result, more focused studies into the relationship between resource use and consumption patterns in Africa are needed as a basis for developing sound strategies for limiting adverse environmental impacts of the rapidly expanding and changing consumption patterns.

This paper aims to contribute to advancing our understanding of consumptive water use linked to the consumption of animal sourced foods and its environmental consequences in an example developing country. More precisely, it focuses on Kenya and the linkages between the premier urban area in Kenya, Nairobi, and the use of water resources to produce the meat and milk consumed by its population. The metropolis of Nairobi functions as a financial, political and infrastructural hub for the East African region (Kearney, 2012). Its population increased from about 140,000 in 1950 to 3.9 million in 2015, raising the percentage of the total Kenyan population living in the capital city from 2.3% to 8.4% (UN, 2015). The fraction of Kenya's population living in the four largest urban areas during the same period increased from 4.3% to 12.2% (CBS, 2010), underscoring the rising importance of urban areas in Kenya (Obudho, 1997).

Nairobi City is highly segmented, with pockets of affluent neighbourhoods, with people spending at least 50 US dollars a day, surrounded by informal settlements dominated by urbanites living at, or below, the poverty line and spending about two dollars a day (Syagga et al., 2001; K'Akumu and Olima, 2007). This wealth inequality is reflected in the consumption of livestock products, with the poor households consuming far lower levels than their affluent counterparts (Gamba, 2005). Overall, about a quarter of the meat supply in Kenya is imported, with livestock from the neighbouring countries of Tanzania, Uganda, Somalia and Ethiopia constituting 22% of the total consumption (Muthee, 2006; Tempia et al., 2010). The rapid urban population growth in Nairobi and the associated changes in consumption levels of meat and milk make this city a good case for analysing temporal trends and spatial differentiation in consumption of animal source foods, and its associated water resource use.

The objective of this paper is to determine the sphere of influence exerted by the consumption of animal products in Nairobi City, by quantifying the per capita and total amount of meat and milk consumed by its residents (Section 2.2), assessing the fractions of these livestock products with domestic and foreign origins (Section 2.2), and comparing the patterns for the 1980s and 2000s to show temporal change (Section 3). The green and blue water footprints associated with meat and milk consumption are estimated (Section 2.3), contextualized in terms of their domestic and imported components, and viewed in relation to blue water scarcity in Kenya (Section 4). Thus, the study evaluates the geographic reach of Nairobi's externalized footprint.

2. Method

Fig. 1 shows the analytical steps followed in this study. We consider the change in urban population in Nairobi between the 1980s (1980–1989) and 2000s (2000–2009). The city's population is disaggregated into three income classes: low, middle and high. Meat and milk consumption quantities are estimated per income class. We consider meat from cows, goats, sheep and camels and milk from cows; we exclude poultry and pork as their reported quantities in the diets are very low (Gamba, 2005). We determine the per capita and aggregate green and blue water footprints associated with meat and milk consumption in Nairobi per income class per period (1980s vs 2000s). We distinguish between footprints within the country and outside, thus visualizing the foreign water dependency ratio. Finally, the blue water footprint of livestock production in Kenya is viewed in the context of blue water scarcity in the country.

2.1. Study area

Nairobi is situated at the southern tip of the Kenyan Highlands, an area of high agricultural potential. After Kenya's independence in 1963, Nairobi changed status from provincial Kenyan district to one of the eight administrative provinces. After the promulgation of the New Kenyan Constitution in 2010 the area became one of Kenya's 47 counties. Today, Nairobi County consists of nine districts, namely Kamukunji, Starehe, Makadara, Langata, Dagoretti, Westlands, Kasarani, Embakasi and Njiru. In addition to these administrative changes, the actual area of Nairobi has almost doubled during the last century, from 384 km^2 in 1910 to 695 km^2 currently.

2.2. Population and meat and milk consumption data (steps 1–5)

We use census data from 1989 and 2009 from the Central Bureau of Statistics of Kenya (CBS), recently renamed the Kenya National Bureau of Statistics (KNBS), as a proxy for the total population of Nairobi in the 1980s (1980–1989) and 2000s (2000–2009) (GOK, 2010). For each period we subdivide the number of inhabitants into three groups: high, middle and low income classes. For the 2000s, we extracted population data from Ledant (2011), whose estimates are based on the premise that the urban space is highly segregated according to levels of affluence. Ledant (2011) uses three analytical steps, including residential polygons, satellite data and household surveys, to generate sub-location polygons for seven income classes. To divide the population in the 2000s into the three income groups, we firstly used the residential polygons from Ledant (2011), satellite data and household surveys, to spatially delineate seven income groups into the sub-location polygons. Secondly, we aggregated these into the three prescribed classes: the first two low income groups in Ledant (2011) were classified as low, the next three were classified as middle and the last two were classified as high income. This new proportional representation was verified against the proportions reported by Odhiambo (2004). The two did not differ, thus confirming the applicability of the reclassification approach used. Fig. 2 shows the distribution of the population in Nairobi into three income classes as described above. To estimate the population size for the 1980s, we used the 1989 CBS census data at the sub-location level (the lowest administrative level used in the Kenyan census). To estimate the proportions of the three income groups, we applied the proportions for Nairobi estimated by Muwonge (1980).

We use a bottom-up approach to estimate the total amount of meat and milk consumed in Nairobi, i.e. the “food end-use” (Wirsenius et al.,

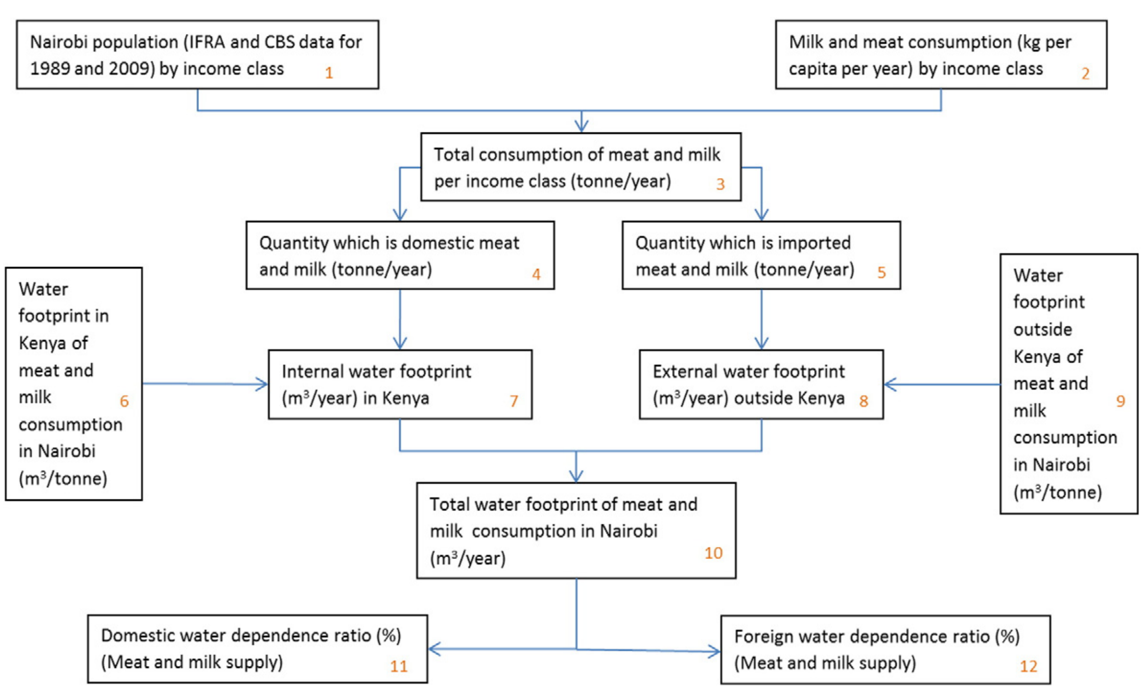

Fig. 1. The analytical steps followed in estimating the water footprint and sphere of influence of meat and milk consumption in Nairobi between the 1980s and 2000s.

2010). This refers to quantities purchased by consumers. The information about quantities of milk and meat consumed by different income groups in Nairobi in the 1980s and 2000s were collated from a wide range of sources (Shah and Frohberg, 1980; Ouma et al., 2000; Argwings-Kodhek et al., 2005; Gamba, 2005; Njarui et al., 2011). We linked the relative affluence to milk and meat consumption by assigning the quantities of milk consumed to the three income classes. Higher income levels are generally linked to higher consumption levels of ASFs, leading to larger environmental footprints. By disaggregating data by income class it is possible to account for variations in affluence and environmental footprints. Meat and milk consumption are summed across the livestock species considered. Thus, we assume that the preferences associated with individual residents are implicitly captured (Juma et al., 2010).

We assessed which fractions of Nairobi's meat and milk consumption come from domestic production and import based on the national ratio of total production to total import for these two product categories, taking data from various sources (Muthee, 2006; EADD, 2008; Tempia et al., 2010). This allows for an evaluation of the dependence of the city's consumption on national production versus imports. The precise sources of meat and milk consumed are determined from stock and supply routes for the live animals and unprocessed milk sold in the Nairobi markets, respectively.

2.3. Assessing the water footprint of milk and meat consumption (steps 6–12)

The water footprint of a product is the total amount of freshwater used to produce the good (Hoekstra et al., 2011). It consists of three components. The green water footprint refers to consumptive water use of rainfed soil moisture, the blue water footprint to the consumptive water use of groundwater and surface water, and the grey water footprint to the volume of water required to dilute pollution (Hoekstra et al., 2011). In this study we focus on water consumption, not water pollution, so we limit the analysis to green and blue water footprints.

A water footprint can have both a domestic and foreign component. For the urban consumption of meat and milk in Nairobi, the former refers to the consumptive freshwater use in Kenya to produce meat and milk for Nairobi's citizens while the latter refers to the consumptive water use in other countries to produce meat and milk consumed in Nairobi.

We use the bottom-up approach to estimate the green and blue water footprints of consumption WF_{cons} (m^3/yr) in Nairobi as follows:

$$WF_{cons} = \sum_{p} \left(C[p] \times WF^{*}_{prod}[p] \right) \tag{1}$$

where $C[p]$ is the consumption of product p by consumers in Nairobi (tonne/yr) and $WF^{*}_{prod}[p]$ the water footprint of this product (m^3/tonne). Since a quantity of product p consumed in Nairobi will generally originate in part from within the country and in part from other countries, the average water footprint of a product p consumed in Nairobi is calculated as in Mekonnen and Hoekstra (2011):

$$WF^{*}_{prod}[p] = \frac{P[p] \times WF_{prod}[p] + \sum_{n_e} \left(T_i[n_e, p] \times WF_{prod}[n_e, p] \right)}{P[p] + \sum_{n_e} T_i[n_e, p]} \tag{2}$$

in which $P[p]$ represents the production quantity of product p in Kenya, $T_i[n_e,p]$ the imported quantity of product p from exporting nation n_e,

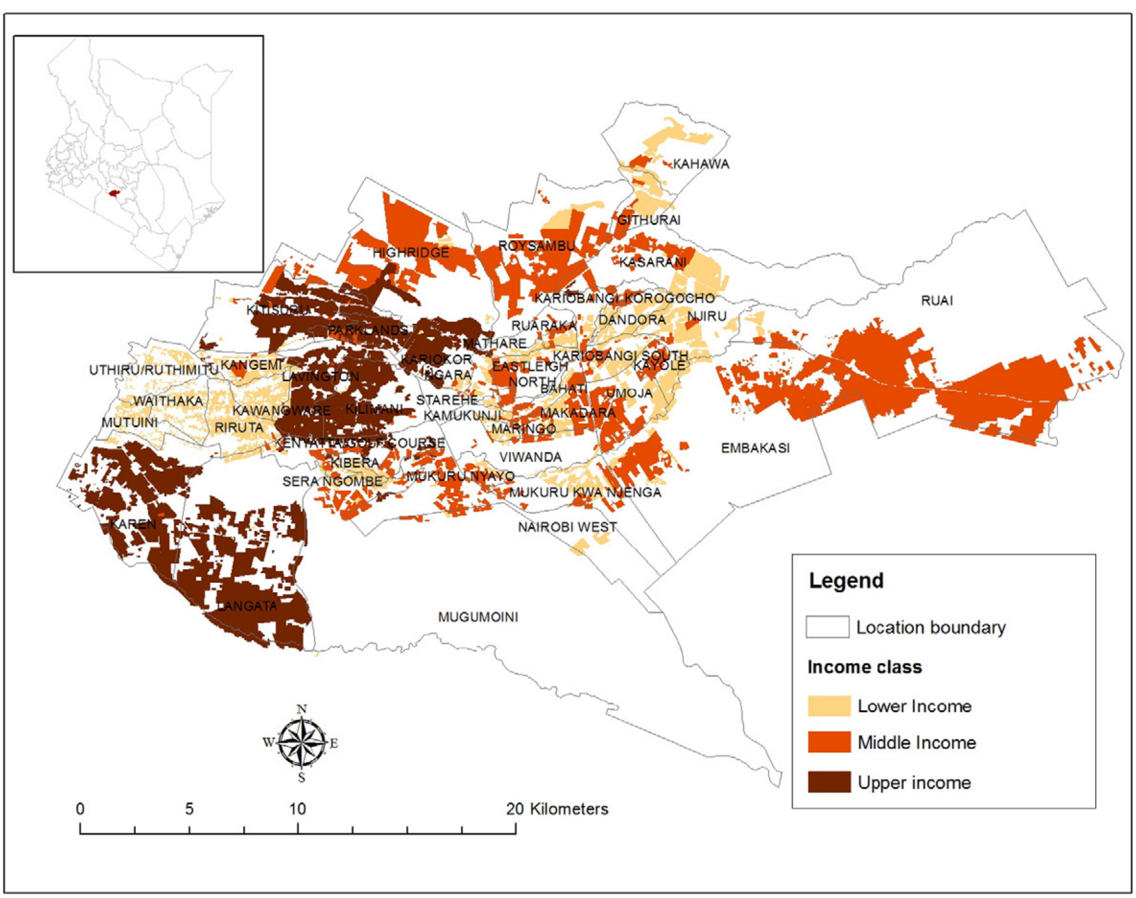

Fig. 2. Income-class distribution for Nairobi in the 2000s, across the nine districts of Nairobi by sub-location and residential type.
(Source: adapted from Ledant (2011)).

$WF_{prod}[p]$ the water footprint of product p when produced in Kenya and $WF_{prod}[n_e,p]$ the water footprint of product p as in the exporting nation n_e. The assumption made here is that the total consumption volume originates from domestic production and imports according to their relative volumes (Mekonnen and Hoekstra, 2012). This assumption would be problematic if huge price differentials or clear preferences existed between the meat and milk derived from the domestic and foreign sources and when this would affect Nairobi's buyer decisions differently than those in other parts of Kenya. We are not aware of any compelling evidence that this is the case.

For the water footprint of imported products ($WF_{prod}[n_e,p]$) we use the data from Mekonnen and Hoekstra (2012). For domestically produced products we used the weighted average of the water footprint from three production systems (arid, semi-arid and humid systems) from which the meat and milk consumed originate as described in Bosire et al. (2015) for both time periods. The main determinants of water footprint of meat and milk that we considered include the composition of the livestock feed, water use efficiency in feed crop production and the feed conversion efficiency of the animal. The main temporal trend in these systems is towards higher efficiency in the production of meat and milk in the humid system but a lower efficiency in the arid and semi-arid systems. This has lowered the water footprint per tonne of product in the humid system, but raised it in the arid and semi-arid systems. For the imported milk and meat, we use import proportions from Aklilu et al. (2002) for meat and from (EADD, 2008) for milk imports in the 2000s. We assume no imports for the 1980s, consistent with FAO estimates of meat and milk imports into Kenya in the 1980s (FAO, 2016).

The foreign water dependency of Nairobi's meat and milk consumption is defined as the ratio of the water footprint of Nairobi's meat and milk consumption outside Kenya to the total water footprint of Nairobi's meat and milk consumption. The domestic water dependency is calculated as the domestic divided by the total water footprint of Nairobi's meat and milk consumption.

3. Results

3.1. Population changes in Kenya and Nairobi between the 1980s and 2000s

Kenya's population increased by 70% between the 1980s and 2000s (Table 1). During this period the rural population grew by 38% and the urban population by about 240%. The population of Nairobi grew slower than the total Kenyan urban population, and increased by about 150%, from 1.3 to 3.1 million. In the 1980s, Nairobi represented one third of the national urban population; this was one fourth in the 2000s. Nairobi's middle-income class showed the greatest rate of increase, quadrupling its size between the 1980s and 2000s. The low-income class doubled, while the high-income class showed the lowest growth, about one and half times. Although all three income classes increased substantially between the 1980s and the 2000s, the residential settlement pattern associated with the three income groups in the 2000s (Fig. 2) was not much different from the 1980s.

3.2. Consumption of meat and milk in Kenya and Nairobi between the 1980s and 2000s

Between the 1980s and 2000s, per capita consumption of meat and milk in Kenya increased by 9% and 17%, respectively (Table 2). The rural population had consistently lower meat consumption per capita than the urban population. For the rural population, meat consumption per capita did not change discernibly, but for the urban population it increased. Overall, the total consumption of meat in Kenya increased over this period and the largest contributor to the increase in meat consumption in Kenya was the total urban consumption, which almost quadrupled. In contrast, the rural population's consumption of meat only increased by 38%.

However, in Nairobi, per capita meat consumption declined over this period. Among the income classes, the largest decline in meat consumption was in the high-income class. The doubling of meat consumption in Nairobi was mainly a result of population increases; most pronounced was the 255% increase in the total consumption of meat by the middle-income class.

Kenyan milk consumption per capita increased by 17%, in rural areas by 18% and in urban areas by 15%. Per capita consumption of milk was larger in rural than urban areas in both the 1980s and 2000s. For Nairobi, the consumption of milk per capita increased by 93% between the 1980s and 2000s. This increase was not even across all income classes: the middle income class more than doubled their per capita milk consumption, while the low income class increased their consumption by 74%.

Total consumption of milk in Kenya increased by 95%, and was mainly due to a quadrupling of the total urban population's milk consumption. Nairobi's consumption of milk increased five-fold between the 1980s and 2000s, with the highest increase, almost nine-fold, realized by the middle-income class. The high-income class increased their total consumption almost five-fold between the 1980s and 2000s, while the low income class increased their consumption three-fold.

Total supply in Kenya of both meat and milk increased between the 1980s and 2000s (Table 3). Though domestic supply of meat in the 2000s was 35% higher than in the 1980s, imports grew to account for 27% of the total supply in the 2000s. Domestic supply of milk in the 2000s was 97% higher than in the 1980s and milk imports only accounted for 1% of the total milk supply in Kenya in the 2000s.

Table 1
Population and meat and milk consumption in the 1980s and 2000s for Kenya and Nairobi City.

Consumer group	Population (thousand)		Per capita meat consumption (kg/yr)		Total meat consumption (tonne/yr)		Per capita milk consumption (kg/yr)		Total milk consumption (tonne/yr)	
	1980s	2000s	1980s	2000s	1980s	2000s	1980s	2000s	1980s	2000s
Kenya										
Rural	18,930	26,100	13	13	239,470	330,450	49	58	921,330	1,504,670
Urban	3700	12,500	18	21	69,050	263,990	42	48	155,630	599,390
Total	22,700	38,600	16	17	352,810	652,330	45	53	1,023,630	2,038,610
Nairobi										
Low income	950	2000	13	12	12,490	23,710	34	60	32,670	119,430
Middle income	240	950	24	21	5670	20,150	44	94	10,540	89,260
High income	60	170	29	25	1790	4170	66	126	4160	21,090
Total	1300	3100	22	19	27,400	60,340	48	93	60,550	290,980
Nairobi's share in Kenya	6%	8%			8%	9%			6%	14%

Table 2
Percentage changes in human population size, meat and milk consumption for Kenya and Nairobi between the 1980s and 2000s.

Consumer group	Change in population	Change in per capita meat consumption	Change in total meat consumption	Change in per capita milk consumption	Change in total milk consumption
Kenya					
Rural	38%	0%	38%	18%	63%
Urban	234%	14%	282%	15%	285%
Total	70%	9%	85%	17%	99%
Nairobi					
Low income	110%	−10%	90%	74%	266%
Middle income	300%	−11%	255%	112%	747%
High income	166%	−13%	133%	90%	407%
Total	149%	−11%	120%	93%	381%

3.3. Water footprint of milk and meat consumption per income group

3.3.1. Per capita water footprint of milk and meat consumption

Fig. 3 shows the water footprint of meat and milk consumption per capita per income class for the 1980s and 2000s. The 2000s had a consistently lower per capita water footprint associated with meat consumption than the 1980s, mostly because of a decline in the per capita consumption of meat in the 2000s across all income groups. The high-income group had the highest per capita meat footprint in both periods, which is consistent with the relatively high consumption of meat by this group.

In the 2000s, the water footprint of milk consumption per capita was larger than in the 1980s for all income groups, though the magnitude of the difference is not commensurate with the increased per capita consumption of milk. This is mainly due to an increased efficiency of milk production in the humid production system and the accompanying reduction in the weighted average water footprint in the 2000s.

The meat and milk water footprints were dominated by the green water footprint, which contributed 96% to the total water footprint for milk consumption and 98% for meat consumption.

3.3.2. Total green and blue water footprint of milk and meat consumption

The total green and blue water footprint of meat and milk consumption in the 2000s was larger than in the 1980s, due to the increased population of Nairobi. The largest total water footprint of consumption was that for meat consumption by the low-income group in the 2000s (Fig. 4). The middle-income group had the second largest water footprint recorded for meat consumption in the 2000s, whereas the high-income group had the smallest footprint for meat consumption in both the 1980s and 2000s, due to the comparatively small size of this income group. The total water footprint of milk consumption showed a similar pattern as observed for meat consumption, being largest for the low-income class. This is associated with the higher numbers for the low-income group in the 1980s and 2000s, as well as an increase in the per capita consumption of milk by this income class in the 2000s.

The total water footprint of meat consumption in Nairobi more than doubled between the 1980s and 2000s, while the total water footprint of milk consumption in Nairobi quadrupled (Table 3). The blue water footprint associated with meat consumption doubled between the 1980s and 2000s. The emergence of a blue water footprint of consumption of milk in the 2000s is associated with the inclusion of compounded and supplemental feeds in the livestock diets in this period. Nevertheless, the green water footprint was the largest component of the total water footprint in both the 1980s and 2000s because production of livestock feeds was primarily through rain-fed cultivation and rarely depended on irrigation.

Table 3
Domestic and imported shares of meat and milk in the 1980s and 2000s for Kenya.

	Meat supply (tonne/yr)		% Change	Milk supply (tonne/yr)		% Change
	1980s	2000s		1980s	2000s	
Domestic	352,810	476,200	35	1,023,630	2,018,220	97
Import	–	176,130	–	–	20,390	
Total	352,810	652,330	85	1,023,630	2,038,610	99
% change in import	–	27		–	1	

3.3.3. Domestic and foreign water dependence of meat and milk consumption in Nairobi

The domestic water dependence of meat consumption in Nairobi declined from 100% in the 1980s to 61% in the 2000s and the foreign water dependence rose from zero to 39% (Table 4). Milk consumption remained almost entirely dependent on domestic water resources. The proportion of the water footprint of Nairobi's meat and milk consumption to the total water footprint of meat and milk consumption in Kenya increased from 6.5% to 8% for meat and from 4.4% to 11% for milk between 1980s and 2000s.

4. Discussion

4.1. Consumption of meat and milk in Kenya and Nairobi

The average meat consumption per capita estimated for Kenya in this study is 17 kg per year for the 2000s, which is higher than the 13 kg per year reported by FAO (2016). The per capita beef/mutton/chevron consumption level of 17 kg per year for Kenya is much lower than in many other countries, like for example Australia, Brazil and the USA, estimated to 52 kg per year, 40 kg per year, and 37 kg per year, respectively. When poultry and pork are also included in the per capita meat consumption estimates, there is an even greater difference in the meat consumption estimates between Kenya and some other countries. With the addition of pork and poultry, meat consumption per capita is the highest at 120 kg per year in Australia, followed by 116 kg per year in the USA, and 92 kg per year in both Brazil and Canada. The inclusion of poultry and pork in the Kenyan average per capita meat consumption only adds a mere 0.8 kg to the annual consumption, which leaves per capita meat consumption in Kenya at about one fifth of the figures for the largest meat consumers.

In this study we have established that rural and urban consumption of meat and milk in Kenya show different developments between the 1980s and 2000s. While the urban meat consumption per capita increased, rural meat consumption did not change. In contrast to the increase in per capita meat consumption across all urban areas in Kenya, the per capita meat consumption in Nairobi declined, which may relate to the combination of general price increases in Nairobi and a decrease in overall livestock production in Kenya over this period (Gamba, 2005; Bosire et al., 2015).

The average meat consumption per capita in Nairobi is slightly higher than in Kenya as a whole and mimics the general rural-urban dichotomy of Kenya's meat consumption pattern. Per capita meat consumption in the low-income class was similar to the rural

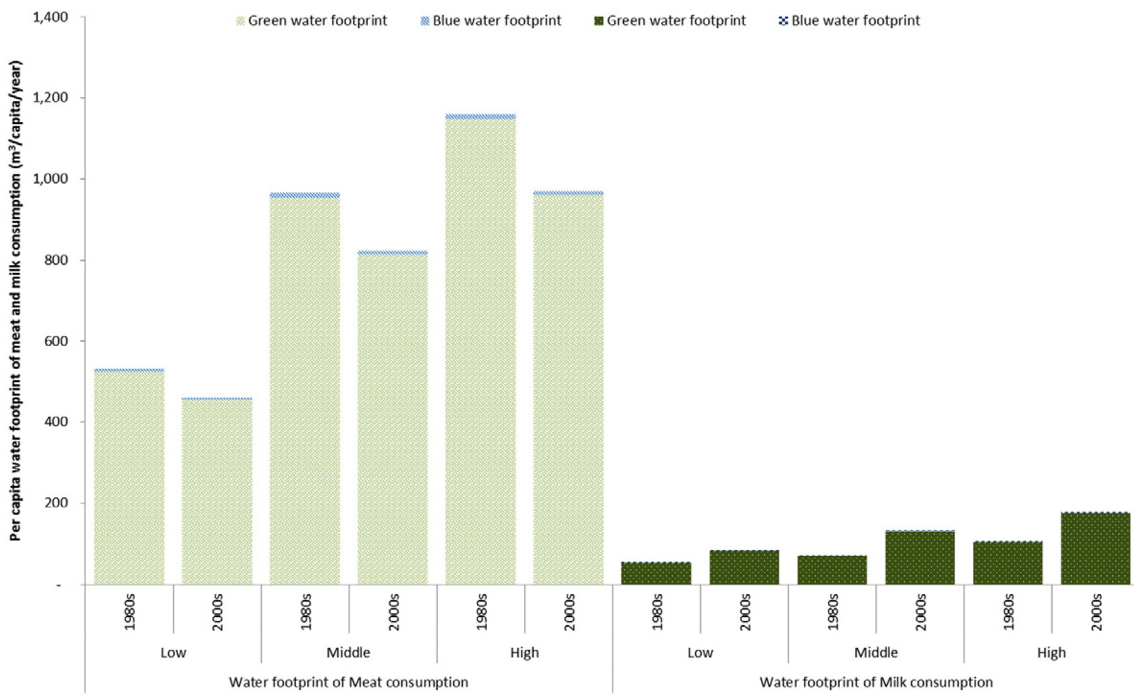

Fig. 3. The water footprint of meat and milk consumption per capita by low, middle and high-income class in Nairobi City, in the 1980s and 2000s.

consumption in both the 1980s and 2000s. This may be explained by the fact that recent migrants to Nairobi maintain their rural diets. Most rural migrants first settle into the low-income class residential areas and may maintain this residence throughout their stay in the urban areas. The largest annual per capita meat consumption is associated with the high-income group. This consumption level is about three times the average consumption of meat estimated for Africa, which is 9 kg per capita (FAO, 2016). When compared with the estimates for the neighbouring countries, the high-income class's annual per capita meat consumption is twice as high as the average consumption in Sudan and nearly four times higher than the average consumption in Ethiopia.

Price is a main driver of access to ASFs by Nairobi's residents, leading to the varied consumption patterns observed among the different income groups. Differences in the price and availability of milk and meat are determined by the level of processing and the livestock species from which they originate (Ouma et al., 2000; Gamba, 2005). The consumption of beef, in particular, provides clear evidence for differentiation along the affluence gradient as beef is one of the key livestock products consumed across all the urban income classes (Gamba, 2005). Among the various meat products produced in Kenya, beef ranks among the most common at about 77% of total production (Aklilu et al., 2002). Sheep and goat meat are not as widely consumed

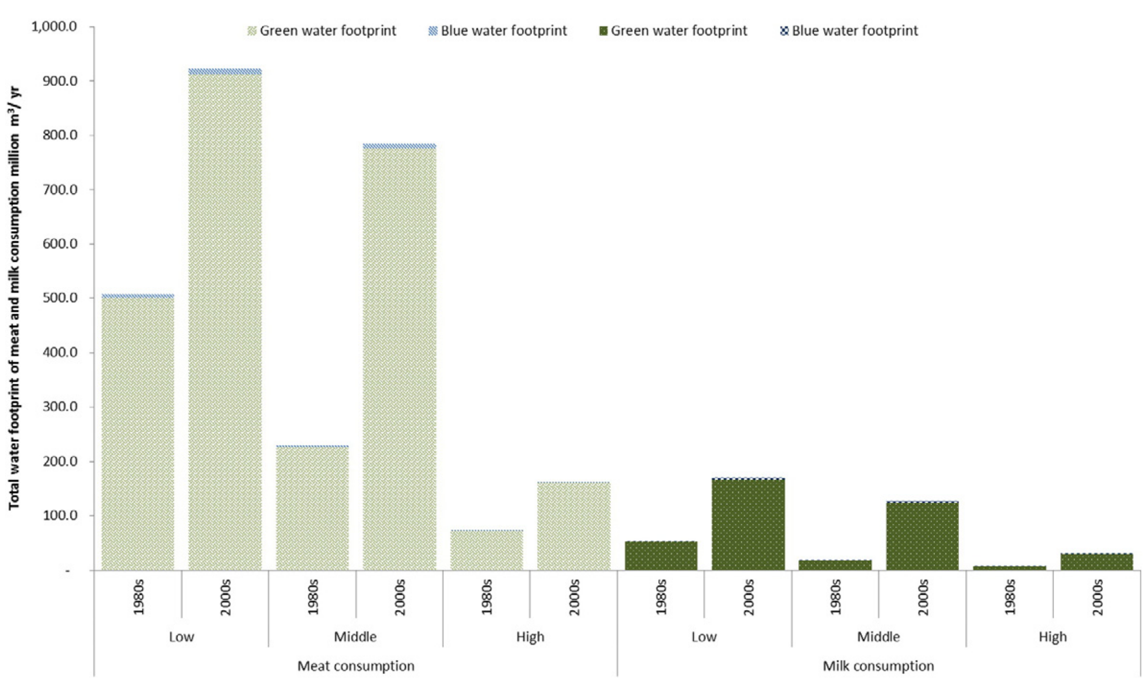

Fig. 4. The total water footprint of meat and milk consumption by low, middle and high-income class in Nairobi City, in the 1980s and 2000s.

Table 4
Total water footprint of Nairobi's meat and milk consumption in the 1980s and 2000s, specified into domestic and foreign components, and the associated dependence ratios.

Water footprint	Total water footprint of Nairobi consumption (million m^3/year)		Domestic water footprint of Nairobi consumption (million m^3/year)		Foreign water footprint of Nairobi consumption (million m^3/year)		Domestic water dependence of Nairobi consumption (%)		Foreign water dependence of Nairobi consumption (%)	
	1980s	2000s	1980s	2000s	1980s	2000s	1980s	2000s	1980s	2000s
Meat										
Green	810	1860	810	1130	–	730	100	61	–	39
Blue	10	20	10	10	–	10	100	65	–	35
Total	820	1880	820	1140	–	740	100	61	–	39
Milk										
Green	80	340	80	330	–	4	100	99	–	1
Blue	–	10	–	10	–	0	100	99	–	1
Total	80	350	80	350	–	5	100	99	–	1

and are mainly consumed by the middle and high-income groups as roasted meat, commonly referred to as “nyama choma” (Juma et al., 2010). Most low-income earners minimize their consumption of non-home prepared foods, at restaurants and kiosks, as this requires a shift to a price level only affordable to higher socio-economic levels (van 't Riet et al., 2003).

Milk consumption per capita in rural Kenya is about 10 kg per year higher than the urban consumption rate. This is mainly the result of access to milk and direct consumption at home. Urban consumption involves purchase, which may hinder access. Additionally, most milk in urban areas is consumed in the form of tea with milk, which reduces the consumption quantities (Njarui et al., 2011). The national milk consumption level of 53 kg per year per capita is much lower than the FAO estimate of 99 kg per year. This is partly a result of the difference in approach, with the current study using a bottom-up approach whereas the FAO uses a top-down assessment method. The average per capita milk consumption in Nairobi is however about twice as large as the national average milk consumption. This is indicative of the increase in consumption of animal source foods (ASFs) associated with urban growth. The purchasing power of Nairobi residents is also much higher than that in the other urban areas (Argwings-Kodhek et al., 2005) and may contribute to the larger consumption per capita. Compared to some of the large milk drinkers in the world, such as the USA (256 kg/yr/capita) and Europe (219 kg/yr/capita), the consumption in Nairobi by the low, middle and high income classes (60, 94 and 126 kg/yr/capita, respectively) is rather low (FAO, 2016). The gap in consumption between the high and low-income groups in Nairobi is quite large. This persisted from the 1980s to the 2000s and the low-income class still consumed milk at the rates characteristic of rural consumption. This finding is similar to that reported for milk and meat consumption in Kerala, India (Renuka et al., 2009). The consumption of milk associated with Nairobi is mainly due to good access facilitated by the close proximity to the milk production areas and to the fact that a large quantity of milk is consumed unprocessed, allowing for affordable pricing for all the income classes.

Total milk and meat consumption changes in Nairobi between the 1980s and 2000s are a function of population increase and changes in per capita meat and milk consumption. The 300% increase of the size of Nairobi's middle-income class contributed most to the increase in total meat and milk consumption. The low consumption level in the low-income class is associated with a high incidence of undernutrition and especially protein deficiency (Mboganie-Mwangi and Foeken, 1996; Black et al., 2013).

4.2. Sources of meat and milk consumed in Nairobi

The sphere of influence of Nairobi's meat and milk demand has grown with the increase in its population size since the 1980s. The growth in Kenya's GDP has not been rapid enough to lead to a dramatic increase in the demand for meat per capita (WB, 2015). Despite a stagnation in demand for meat per capita, there is a large increase in total demand because of the growing population and a significant increase in the quantities of meat imported from the neighbouring countries (Muthee, 2006; Tempia et al., 2010). The 22% increase in the import of live animals in the 2000s (Aklilu et al., 2002) was probably a response to the decline in supply of livestock in Kenya. The stock routes for live cattle, sheep and goats showed that the largest flow of these animals was directed towards Nairobi and Mombasa, with Nairobi receiving the bulk of this livestock import (Tempia et al., 2010).

In the 1980s, most of the ASFs and other perishable agricultural products consumed in Nairobi were sourced from farmers in the highland areas to the north and some ranches to the south of the city. On the contrary, cereals and other not highly perishable farm products were mainly ferried from rural areas as far away as western Kenya. Immigration of a large number of people from regions farther away from Nairobi increased the import of these cereals and vegetables (K'Akumu and Olima, 2007). Housing schemes such as the Umoja and Kariobangi schemes also pushed the dairy and ranching systems farther away from areas within the early boundaries of Nairobi, thereby increasing the average distance from which these products were sourced (Huchzermeyer, 2007).

Milk imports have not constituted a large proportion of the total consumption in Nairobi and Kenya as a whole. Milk imported from countries such as New Zealand, constitutes about 0.5% of the total milk supply to the Kenyan market, and is mainly in the form of powdered milk, that can be reconstituted into liquid milk by the processors (EADD, 2008), or sold in small packages, as small as 10 g, to low income groups (Olok-Asobasi and Sserunjogi, 2001). The imported milk is mostly used in the dry seasons. Sudan and Kenya jointly have the largest dairy herds in sub-Saharan Africa (Karanja, 2003), yet Sudan provides about twice the quantities of milk per capita, compared to Kenya. Adopting a more resource-efficient production of meat and milk would enable Kenya to reduce the reliance on external sources for ASFs. This is especially important in light of the contemporary and projected growth of cities in Kenya.

4.3. Influence of income on water footprint of milk and meat consumption in Nairobi

As expected, our results show that the water footprint of milk and meat consumption in Nairobi is linked to the socio-economic standards of the population. This finding reaffirms findings of other studies that have documented dietary changes in response to changes in income and those that have looked at resource use for countries with different income levels (Benjelloun, 2002; Delgado, 2003; Hoekstra and Chapagain, 2007). The water footprint in Nairobi changed as result of a combination of three factors: changes in total population, changes in consumption of milk and meat per capita and changes in the average footprint of production per unit of product (Bosire et al., 2015). The water footprint per unit of meat increased over time following the decline in efficiency and productivity. The water footprint per unit of milk, however, was reduced as a result of increases in productivity.

The differences in the per capita water footprint of milk consumption between the high, middle and low-income classes are slightly higher than the differences in the water footprints associated with meat consumption. The large difference in the water footprints between the high and low-income residents of Nairobi is due to a large difference between the quantities of milk consumed by the two income classes, which relates to differences in access. Overall, the relatively large water footprint associated with meat consumption is because meat generally has a large water footprint in comparison to milk (Bosire et al., 2015). In addition, the source areas for the local and imported meat are mainly classified as arid and semi-arid regions and the breeds of livestock reared are mainly indigenous, low meat yielding breeds.

4.4. The domestic and foreign water footprints of milk and meat consumption in Nairobi

Between the 1980s and 2000s there is a substantial increase in the total import of meat but only a very slight increase in the import of milk (Aklilu et al., 2002; EADD, 2008). This leads to a much larger growth in the domestic water footprint of Nairobi's milk consumption than in the domestic water footprint of the city's meat consumption. The increase in the domestic water footprint of milk consumption in Nairobi indicates a continued reliance on the domestic water resources for milk production despite an increase in the total milk consumption. This is made possible due to an improvement in the milk production over this period in Kenya. The domestic water footprint of meat consumption in Nairobi also increased between the 1980s and 2000s. We observe an increased reliance on foreign water resources to meet the increase in total meat consumption in Nairobi. The reliance on foreign water to meet the city's meat consumption is associated with a decline in livestock productivity between the 1980s and 2000s and partly explained by depressed investments in the livestock sector especially in the arid and semi-arid production systems (Bosire et al., 2015).

The green water footprint dominates both the domestic and foreign water footprint of Nairobi's meat and milk consumption in the 2000s. Generally, there is lower competition for green water than blue water resources. The externalization of the water footprint of Nairobi's meat and milk consumption to other countries, through imports, frees the domestic water resources to be used for other purposes than livestock production. It reduces the potential conflict arising from the use of limited domestic water resources towards livestock production rather than for food crop production. On the other hand, it increases dependence on foreign water resources, which are likely to become scarcer as well, particularly given that most imports come from neighbouring countries that face the problem of limited water resources as well.

4.5. Urban growth, the resultant water footprint increase and the implications for blue water scarcity

Any assessment of water footprints from increased food demand by urbanizing populations should take into account the availability of and potential competition for water with the other sectors of the economy. This is especially pertinent for developing countries, such as Kenya where the growth of urban areas is expected to accelerate following the establishment of county governments in 2013. Blue water scarcity can thus be expected to present a persistent and growing problem. Already, agriculture contributes as much as 86% to the total blue water footprint in Kenya (Table 5). The municipal and industrial sectors contribute only 13% and 1%, respectively. Although the blue water footprint constitutes a minor proportion of the current total water footprint of animal source products (given the much larger green water footprint), the blue water footprint of livestock production stands for as much as 31% of the total domestic blue water footprint. In the humid production system, which represents an area of increased efficiency and improved animal diets, where additional blue water consumption is associated with feed crops in the livestock diets, livestock production is responsible for >43% of the blue water footprint. In both the arid and semi-arid production system, livestock production contributes about 26% to the total blue water footprint. Blue water consumption here is restricted to drinking and servicing water.

Blue water scarcity in Kenya's production systems is classified significant to severe (Mekonnen and Hoekstra, 2016). The blue water scarcity is considered severe in the arid system, while the semi-arid and humid systems both exhibit significant blue water scarcity.

The domestic water footprint of milk consumption associated with Nairobi is mainly in the humid production system. This production system is classified as significantly blue water scarce. There are large competing claims to the blue water resources in this system that precludes the use of the blue water resources for cultivation of feed for milk production. Given the high level of blue water scarcity and the competing claims for water, there is a need to enhance water use efficiency in milk production and to consider alternative source areas for milk or less water-intensive protein sources than milk.

Meat is mainly sourced from the arid and semi-arid production systems, which jointly cover the largest area of Kenya. The severe blue water scarcity, large water footprint for livestock production in the arid system and increased total demand for meat may explain the strong rise in meat imports and foreign water dependence. Also in the case of meat production, water use efficiency needs to be increased or more water-efficient protein-rich meat alternatives could be considered.

5. Limitations and assumptions of the study

We have focused on the bottom-up approach to estimating consumption of meat and milk and not on the supply of food at the wholesale level as is often done. The approach we use allocates consumption

Table 5
The blue water footprint (million m^3/year) in the 2000s and blue water scarcity in three production systems in Kenya.

Production system	Blue water footprint of production (million m^3/year)						Livestock production share of total blue WF in Kenya	Avg. blue water scarcity
	Food-crop production	Feed-crop production	Livestock services	Household	Industry	Kenya total		
Arid	107.3	0	41.8	10.3	1.1	160.5	26%	3.51
Semi-arid	56.1	0	26.3	16.8	1.8	101.0	26%	1.86
Humid	46.3	17.0	34.1	19.7	2.1	102.2	43%	1.52
Others	0.8	0		0.1	0	0.9	0%	
Total	210.5	17	102.2	47	5	381.7	31%	

Sources: blue water footprint data from Hoekstra and Mekonnen (2012); blue water scarcity data from (Mekonnen and Hoekstra, 2016). Livestock production shares concern both feed and service water footprints. Scale for blue water scarcity: low blue water scarcity < 1, moderate blue water scarcity = 1–1.5, significant blue water scarcity = 1.5–2, and, severe blue water scarcity > 2.

quantities to different income groups. Our ability to estimate the consumption of meat and milk in Nairobi was limited by the large diversity of diets and the large sample sizes needed to have accurate estimates of the consumption of these products. To minimize potential biases in the estimated consumption of meat and milk, we relied on quantities documented by multiple household budget surveys (Shah and Frohberg, 1980; Argwings-Kodhek et al., 2005; Gamba, 2005; Njarui et al., 2011). We assumed that these data sources were representative of the diverse quantities consumed by the highly socio-economically segregated Nairobi population and both the rural and urban populations. We excluded poultry and pork from the study as the pertinent data were difficult to gather at this scale, there was no consistent analysis of consumption of these two products in the available literature, and the proportion of these two products in the diets was low according to existing data (Gamba, 2005). Consumption of poultry and pork are projected to increase in developing countries and so both sources of meat should be given consideration in future dietary analyses (Alexandratos and Bruinsma, 2012a; Herrero et al., 2013).

The diets are linked to incomes, yet there are often massive differences in incomes quoted by different studies, for example by Argwings-Kodhek et al. (2005) and Ledant (2011). The annual incomes for Nairobi residents reported by Ledant (2011), are much lower, merely US$ 691, than the over US$ 1440 reported for the high-income class by Argwings-Kodhek et al. (2005) (1 US$ = 69.44 KES at the 2009 exchange rate). Ledant (2011) acknowledges that responses by interviewees about their income amounts were often inaccurate. This discrepancy with the income classification done by the Central Bureau of Statistics of Kenya was corrected for in their methodology through the classification of residence types to more accurately reflect income classes, using such factors as monthly rental rates, type of material used for construction and area of land occupied by the residence. We assume that this correction negates the wide discrepancy in the incomes assigned to the various income classes.

The scale of the income class disaggregation was not similar for the 1980s and 2000s, further limiting the household-scale analysis of the changes associated with segregation patterns between the two periods. We thus focused on the sub-location level which is consistent for both periods from the census reports for Kenya for 1989 and 2009 and show no differences in the sub-location classification as low, middle or high income regions. We represent the urban income class segregation using the spatial scale of Ledant (2011), a baseline scale recommended for use in future consumption studies for Nairobi.

6. Conclusion

Between the 1980s and 2000s the population in Nairobi increased by 150%, from 1.3 to 3.1 million, which was twice the rate of the 70% population growth for entire Kenya. The rapid population increase in Nairobi is the main reason behind the increased consumption of both meat and milk during these decades, with 120 and 380%, respectively. This shows that across all income groups there was a marked relative shift from meat to milk. Out of the three income classes, it is the middle-income class that stands out with a total consumption increase of >250% for meat and 750% for milk. However, taking the rapid population increase into account, the per capita consumption displays a quite different pattern, with a per capita meat consumption decline of 11% and milk consumption increase of 17%.

The water footprints of total meat and milk consumption in Nairobi were fully met by domestic water resources in the 1980s. This had changed in the 2000s when the foreign water footprint of meat production was 39%. The reliance on foreign water resources to meet the consumption of meat may be viewed as a means to relieve pressure on the already scarce water resources in Kenya. At the national level, animal production by the 2000s contributes 30% to total consumptive blue water use in Kenya. This large contribution by livestock to the use of blue water will potentially increase with increased consumption of meat and milk unless measures are put in place to improve efficiency of livestock production.

Given the water scarcity levels in the areas of the three production systems, the Kenyan government should be cautious in formulating and implementing policies aimed at increasing the proportion of meat and milk in the diet. Careful consideration should be given to measures to improve the resource efficiency of meat and milk production and the potential of increasing import from other more resource-endowed countries.

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