Health & Place 75 (2022) 102809

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

Mapping food and physical activity environments in low- and middle-income countries: A systematised review

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ARTICLE INFO

Keywords:
Food environment
Physical activity environment
Built environment
Obesogenic environment
Low- and middle-income country
LMIC

ABSTRACT

This systematised literature review synthesised evidence on approaches to mapping food and physical activity (PA) environments in low- and middle-income countries (LMICs). Of the 60 articles included, 25 and 35 mapped food and PA environments respectively. All studies were cross-sectional with researcher-led data collection. Three types of mapping tools were identified – maps (n = 18), GPS (n = 10), and GIS (n = 37). Our findings point to a paucity of research mapping food and PA environments, overall and particularly subjective domains. We highlight a need for future studies that utilise innovative, inexpensive and participatory research methods to understand dynamic exposures to obesogenic environment features in resource-constrained contexts undergoing rapid urbanisation.

1. Introduction

The most rapidly growing cities globally are located in low- and middle-income countries (LMICs), with 56% of people living in LMICs projected to be living in urban areas by 2030 (United Nations, 2018). The rapid urbanisation in most LMICs has contributed to the unplanned transformation of urban areas to accommodate the ever-growing socio-economic and spatial needs of the population (Goryakin et al., 2017; Turner et al., 2020; Day, 2018). One such change is the emergence of urban obesogenic environments defined as social, economic and physical environment conditions that encourage weight gain leading to increased overweight and obesity incidence (Swinburn et al., 1999). Two key features of obesogenic environments are the increased physical presence and consumption of unhealthy foods, such as fast food and sugar sweetened beverages, and limited opportunities for the population to engage in physical activity (PA) (Kapoor and Anand, 2002; Ellulu et al., 2014). This may be through the promotion of motorised in place of active transport modes (walking and cycling) as well as the absence of physical spaces (sports fields and pedestrian pavements) to partake in physical activity. The impact of obesogenic environments on urban food consumption patterns and PA practices can be measured, in part, by the geographical mapping of specific features of obesogenic food and physical activity environments.

The term "food environment" broadly refers to the range of food sources and products accessible to an individual or community in their daily life. Specific features of the food environment are delineated across five domains: food availability – types of food physically available within a community, food accessibility – the ease of accessing available food when required, food affordability - pricing of food items relative to available financial resources, food accommodation - efficiency by which food sources adapt to individual and community needs, and food acceptability - personal views and opinions on food products available in their environment (Caspi et al., 2012). The availability and accessibility domains are commonly measured using objective geographical methods, such as maps, global positioning systems (GPS), and geographical information systems (GIS) (Caspi et al., 2012; Charreire et al., 2010) while food affordability, accommodation, and acceptability are typically measured by subjective methods such as individual or

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https://doi.org/10.1016/j.healthplace.2022.102809
Received 3 September 2020; Received in revised form 6 December 2021; Accepted 15 April 2022
Available online 1 May 2022
1353-8292/

group interviews, direct observation, and surveys.

The PA environment consists of exogenous built and natural environment features that either promote or impede PA across four domains: functional - infrastructure, such as pedestrian pavements, that provides space for physical activity, safety – features, such as traffic lights and streetlamps to improve pedestrian and cyclist safety, aesthetics - features that indirectly enhance the PA experience such as tree shading or street cleanliness, and destinations – the availability and accessibility of destinations such commercial hubs and recreational parks that support PA (Sallis, 2009, Brown et al., 2014, Durand et al., 2011, Pikora et al., 2003) The categorisation of features into each of these domains may differ contextually (Pikora et al., 2003). For instance, tree shading may be aesthetically pleasant and provide relief in one area, but may be perceived as reducing safety at night-time in a different context.

The mapping of food and PA environment features is required to understand the exposure of individuals and households to obesogenic environments. When integrated with mixed-methods survey data on food or PA behaviour, mapping data can provide useful insights that can inform the design and implementation of population interventions to improve healthy diet and PA behaviour. However, in order to accurately collate these data, there is a need to ensure that contextually appropriate methods are used for mapping. At present, evidence on the measurement of food and PA environments that shape individual habits is dominated by research from high-income countries (HIC) (Charreire et al., 2010; Brownson et al., 2009; Butler et al., 2011; Holsten, 2009). While useful, inferences from HICs are not always applicable in LMIC given the contexts of informality that characterise urban expansion in LMIC cities (Turner et al., 2020; Day, 2018).

To address this knowledge gap in urban health research in LMICs, we conducted a systematised literature review to synthesise existing evidence on approaches to mapping features of the food and PA environments in LMICs. This synthesis is critical to inform the use of appropriate research methodologies in future studies seeking to understand exposure to obesogenic environment features in LMICs.

2. Methods

The systematised review typology was used to explore the landscape of existing LMIC studies that have mapped features of the food or PA environment in order to identify the tools and techniques used for mapping. Systematised literature reviews apply a uniform and comprehensive search strategy across multiple databases to identify relevant literature (Grant and Booth, 2009). However, critical appraisal of study design, methods and outcomes is not required (Grant and Booth, 2009).

An initial literature search was conducted in PubMed (a MEDLINE database interface) and Google Scholar to identify key literature and inform the selection of relevant key words and search terms. The finalised search strategy included the following key terms "food" "physical activity", and "environment" as well as the names of 140 LMIC (as designated by the World Bank Group (The World Bank Group) (Supplement 1). The search terms were uniformly applied in three databases: Scopus (includes MEDLINE database content), Web of Science and EbscoHost. Based on the search, 8841 articles retrieved for review (between February and April 2020). Article title and abstracts were first imported into EndNote (Analytics, 2017) and subsequently uploaded onto Covidence (web-based online screening software) (Innovation, 2016) for screening.

Research articles were screened against the following inclusion criteria: the research study was published in a peer-reviewed academic journal, research study methods described the tools or techniques used to map either the food or PA environment, the research had been published by February 14, 2020 (when the search was conducted), and the study had been conducted in an LMIC as designated by the World Bank Group (The World Bank Group). There were no restrictions on publication language and retrieved non-English articles were translated using Google translate. Studies were excluded if they were not primary research studies, for example review studies or protocols, and if despite reporting on aspects of food or physical environment, they did not speak directly to the methods used to map the environment.

Research articles were independently screened by four independent reviewers in two stages - title and abstract, and full text screening. The reviewers discussed any screening conflicts as they arose until consensus was achieved. A Microsoft Excel template was used for data extraction.

3. Results

- **Search Results**

The PRISMA flow diagram (Fig. 1) demonstrates our search strategy and included studies.

- **Description of studies**

We found 60 cross-sectional LMIC studies, published between 2003 and 2020, that mapped food (n = 25) (Table 1) and PA environments (n = 35) (Table 2). Studies mapping features of the PA environment were conducted in 9 countries with most (n = 22/35) research studies being conducted in China (n = 11) and Brazil (n = 11) (Fig. 2; Table 2). One study mapped PA environments in 12 LMICs (Brazil, Colombia, China, and Mexico) and HICs (Australia, Belgium, Czech Republic, Denmark, New Zealand, Spain, the United Kingdom, and the United States of America).

The majority (60%; n = 15) of studies mapping food environment features were conducted in the Latin America and Caribbean countries (Brazil(n = 7), Mexico (n = 6), Guatemala (n = 2)) (Fig. 2 and Table 1). One additional comparative study was conducted in South Africa and Ghana.

Mapping of the community food environment was conducted by trained researchers using a combination of digital and analog tools, with the exception of one study that used a community-based participatory approach (Ahmed et al., 2019).

- **Mapping of features under each food or physical activity environment domain**

Each of the five food environment domains were mapped out in at least one LMIC study (Fig. 3). Food accessibility was the most examined domain (n = 23) followed by food availability (n = 14), and food affordability (n = 8). The majority of studies (n = 17/25) assessed more than two domains. Measures of food accessibility typically mapped the location and distance of food retail outlets relative to individual residential addresses. Food availability was measured through documentation of types of food sold in some of the retail outlets.

Over 80% (n = 30/35) of PA environment studies mapped the functional domain of the PA environment (Fig. 4). This includes features such as housing density, transport stop density and distance to recreational facilities.

- **Mapping tools used in LMIC studies**

We identified three types of mapping tools - maps (analogue and digital), GPS, and GIS - used to map food (Table 1) and physical activity (Table 2) environment features. Most studies used multiple tools simultaneously. We also observed the complementary use of environmental audit tools such as the Good and Services Inventory (GASI) (Soltero et al., 2017) and the China Urban Built Environment Scan Tool (CUBEST) (Su et al., 2014) to report on food and PA environment features that are not easily measured by objective mapping techniques.

o *Maps*

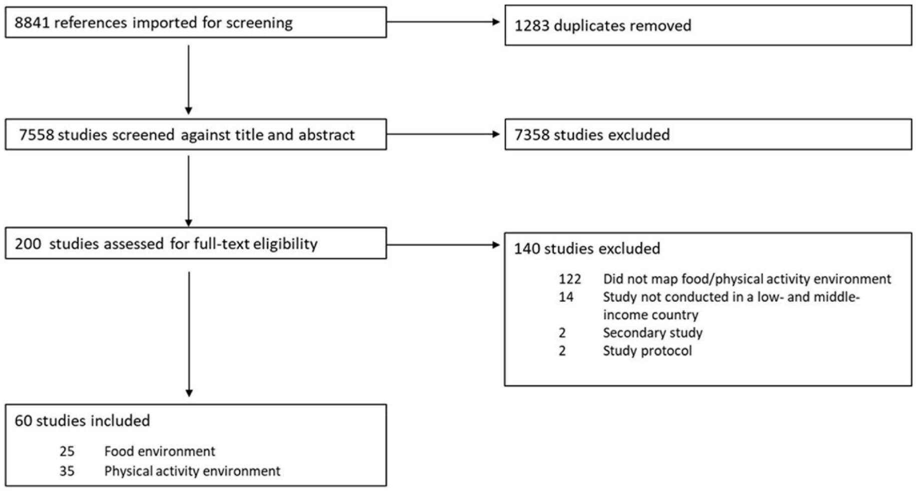

Fig. 1. PRISMA flow diagram.

Eighteen studies (30%) used maps to describe the spatial distribution of food and PA environments in LMIC countries. These maps were either aerial maps (printed or digitised) provided by city authorities or publicly accessible maps such as Google Maps (or Baidu Maps in China). Maps provided by city authorities were printed out by researchers and used for canvassing and geocoding the location of specified food or PA environment features. For instance, researchers in Almaty, Kazakhstan and Maputo, Mozambique walked around sampling sites with pre-printed maps, marking out locations of food retailers (Andrew et al., 2003; Gelormini et al., 2015). This information was subsequently digitised for further analysis using geographical software.

Web-based maps, Google Maps and Google Earth were used in 15 studies in Guatemala, South Africa and Hong Kong to geocode food store locations as well as to verify online geocoded addresses. Studies conducted in Brazil and Colombia used Google Maps and Earth platforms to identify and map exogenous PA environment features such as street connectivity and land-use mix for PA (Silva et al., 2015; Lamour et al., 2019; Arellana et al., 2020).

Notably, a study in Nairobi, Kenya used participatory mapping to capture the food vendor distribution in three communities (Kibera, Mathare and Mukuru) (Ahmed et al., 2019). This technique involved placing a digital camera inside a helium balloon to capture high-resolution aerial photographs at specified altitudes. These photographs were subsequently compiled to provide overhead imagery on the location and type of food vendors in the communities as well as their distribution relative to residential and social landscapes (Ahmed et al., 2019).

o *GPS*

We found 10 studies that used GPS tools to geocode exact locations of food and built environment elements (Bridle-Fitzpatrick, 2015, Dake et al., 2016, Liao et al., 2016, Patel et al., 2017, Marrocos Leite et al., 2018, Barquera et al., 2018, Kroll et al., 2019, Backes et al., 2019, Su et al., 2014, Jia et al., 2018). Hand-held GPS devices (mobile phones and GPS gadgets) were used to pinpoint the exact location of food retail outlets in Mexican, Ghanaian, and Indian studies. For the mapping exercise, researchers walked around neighbourhoods with GPS devices and geocoded food retail outlets either outside or inside the structure. In studies utilising the buffer network technique for characterising food environments, hand-held GPS devices were used first to geocode study participants residential addresses and map out the location of the accessible food retailers within a specified buffer. Complementary to GPS tools, studies also used photographs, Google Street View images and audit tools for georeferencing of outlets.

Two studies, both conducted in China, detailed the use of GPS in mapping PA environment features (Jia et al., 2018; Su et al., 2014). In one study, GPS units, along with the CUBEST audit tool, were used in the geocoding and georeferencing of street elements (including destinations, street connectivity and bicycle lane quality) in a 400 m buffer around neighbourhood administrative boundaries (Su et al., 2014). The second study mapped out individual exposure to neighbourhood greenness by geocoding residential addresses within a neighbourhood relative to publicly accessible green spaces (Su et al., 2014).

o*GIS*

The majority (62%; n = 37) of studies used GIS for mapping food and PA environment features. GIS utilises diverse information sources to gather, analyse and visualise spatial/georeferenced data. Nearly 60% (22/37) of these studies used information from city authorities such as Institute of Urban Planning of Florianopolis in Brazil (Corseuil Giehl et al., 2016), Praia Municipal Government in Cape Verde (Anciaes et al., 2017), and the National Institute of Statistics and Geography in Mexico (Salvo et al., 2014). Additional information was obtained from other mapping tools - Google (or Baidu) Maps and Street View, Google Earth, Open Street Maps, Open Street Map, and Satellite images. Additionally, georeferenced photographs and tabular information were also used in describing non-geographical characteristics such as food availability and street aesthetics.

The density and proximity to food and PA opportunities were mostly mapped using GIS. Density measures of food and built environment features were conducted across whole neighbourhoods or in buffer regions surrounding a geocoded central point. In the former, firstly the outer boundaries of neighbourhoods were mapped out in GIS, and then all environmental features of interest, such as number and location of food outlets, recreational infrastructure, transport routes and public greenspaces, were mapped within these boundaries. Buffer regions were either circular (n = 9) or network (n = 4) (Hino et al., 2011, 2014; Salvo et al., 2014; Jauregui et al., 2016) buffers.

In studies using circular buffers (Duran et al., 2016, Zhang and Huang, 2018, Marrocos Leite et al., 2018, Cervero et al., 2009, Gomez et al., 2010b, Da Silva et al., 2017, Florindo et al., 2019, dos Santos et al., 2019, Borchardt et al., 2019), a geocoded central point such as participant addresses, schools and metro stations were mapped out in GIS, and a radial buffer area demarcated around them. As seen in Tables 1 and 2, buffer radiuses varied ranged from 400 m up to 1.6 km. Reasons for selecting the radius length varied were based on previous literature or contextual factors. For example, in mapping neighbourhood food environments for children in Santos, Brazil, a 500 m buffer was selected

Table 1
Studies mapping food environment features in low- and middle-income countries.

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Yim et al., 2003 (Andrew et al., 2003)	Almaty, Kazakhstan	City-wide	City block	Analog maps	Food retailer location Available food products
Chacon et al., 2013 (Chacon et al., 2013)	Mixco, Guatemala	School	200m^2 circle area around school entrance.	Google Earth	Food store location Available snack foods
Battersby et al. 2014 (Battersby and Peyton, 2014)	Cape Town, South Africa	City-wide	Neighbourhood	Online store locator Google Maps GIS	Supermarket location
Peyton et al., 2015 (Peyton et al., 2015)	Cape Town, South Africa	City-wide	Neighbourhood	Online store locator Google Maps GIS	Supermarket location
Gelormini et al., 2015 (Gelormini et al., 2015)	Maputo, Mozambique	City-wide	Public transport bus stops	Maps (from Maputo Municipal Council (Conselho Municipal Cidade de Maputo) Field audits	Street food vendor location and operating hours Type of food products sold Food portion size Food price Food packaging
Chacon et al., 2015 (Chacon et al., 2015)	Mixco, Guatemala	School	200 m buffer around school compound	Google Earth In-store audit	Food kiosks in school Food store location and type Snack food advertisement Snack placement inside the shop
Bridle-Fitzpatrick 2015 (Bridle-Fitzpatrick, 2015)	Mazatlan, Sinaloa, Mexico	City-wide	Neighbourhood	GPS device On-site audit tools - Audit using Nutrition Environment Measure variations (NEM-S and NEM-R)	Food outlet density Available food products Food prices
Duran et al., 2016 (Duran et al., 2016)	Sao Paulo, Brazil	City-wide	1.6 km euclidean buffer around respondent's place of residence	GIS Environmental audit (“Obesogenic” Environment Study in Sao Paulo, Brazil (ESAO-SP))	Supermarket and fresh produce density and proximity
Dake et al., 2016 (Dake et al., 2016)	Accra, Ghana	Neighbourhood	Enumeration area	GPS	Location of out of home cooked foods, convenience stores and fruit/vegetable stall Type of food products sold
Barrera et al., 2016 (Barrera et al., 2016)	Cuernavaca and Guadalajara, Mexico	School	School	GIS GPS Satellite images	Location of mobile food vendors, food store, food establishments.
Liao et al., 2016 (Liao et al., 2016)	Beijing, Tianjin, Shanghai, Qingdao, Hangzhou, Shaoxing, Suzhou, Nantong, Zhenjiang, Chengdu, Xining and Harbin (12 cities), China	City-wide	Neighbourhood	GPS Environmental audit	Food stores and food service place's location Available food products
Soltero 2017 (Soltero et al., 2017)	Guadalajara, Puerto Vallarta, Mexico City, Mexico	School	800 m buffer around school compound	Analog maps Environment audit - Good and Services Inventory (GASI)	Food retailer type and location
Patel et al., 2017 (Patel et al., 2017)	Delhi, India	City-wide	1 km buffer around census enumeration blocks	GPS Google Earth GIS	Location of full service and fast-food restaurants
Costa et al., 2018 (Costa et al., 2018)	Belo Horizonte, Brazil	City-wide	1.6 km buffer around (Academia de Saude/ Health Academy Program) units	GIS (Municipal Secretariat Principal Collection Fund (georeferenced list of establishments), Belo Horizonte City Hall website (street markets)) Google street view On-site audit (Study of the Obedient Environment - ESAO-S).	Food establishment location Availability, placement, variety, price and advertising of fruit and vegetables Availability, variety, advertising of ultra-processed foods
Zhang et al. 2018 (Zhang and Huang, 2018)	Hong Kong, China	City-wide	1 km euclidean buffer around respondent's place of residence	GIS Google Maps	Location of grocery stores, convenience stores and fast-food restaurants. Density of food outlets
Marrocos Leite, et al. 2008 (Marrocos Leite et al., 2018)	Santos, Brazil	City-wide	500 m buffer around census tract centroid	GPS GPS	Food store location
Barquera et al., 2018 (Barquera et al., 2018)	Cuernavaca and Guadalajara, Mexico	School	100 m buffer around school compound	GPS Photographs	Food retailer location Food and beverage advertising
Gonzalez-Alejo 2019 (Laura Gonzalez-Alejo et al., 2019)	Mexico City, Mexico	City-wide	City	GIS (using data from National Institute of Statistics and Geography (INEGI) and the National Statistical Directory of Economic Units (DENUE))	Location of small-scale fixed food retailer, public fixed market, itinerant market, self-service stores
Kroll et al., 2019 (Kroll et al., 2019)	Cape Town, Kumasi, South Africa, Ghana	Neighbourhood	Neighbourhood	GPS	Food outlet type and location Variety of food sold

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Table 1 (*continued*)

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Mendes Camargo et al., 2019 (Mendes Camargo et al., 2019)	Sao Paulo, Brazil	City-wide	500 m buffer around census tract centroid	Maps In-store audit	Type of food retail outlets Available food products
Borges et al. 2019 (Borges and Jaime, 2019)	Sao Paulo, Brazil	City-wide	Neighbourhood	AUDITNOVA	Type of food establishment Available food products
Contreras Navarro et al. 2019 (Contreras Navarro and Ortega Velez, 2019)	Hermosillo, Mexico	City-wide	City	GIS (using data from INEGI geo-statistical system DENUE (Directorio Estadístico Nacional de Unidades Económicas))	Food outlet type
Backes et al., 2019 (Backes et al., 2019)	São Leopoldo, Brazil	Neighbourhood	400 m buffer around respondent's place of residence	GPS units Nutrition Environment Measure – Stores (NEMS) to audit within the store.	Food store location Available food products Food prices
Assis et al., 2019 (Assis et al., 2019)	Juiz de For a, Brazil	City-wide	Neighbourhood	GIS - (using data from the Secretary of Finance of Minas Gerais) GPS	Food retailer density
Ahmed et al., 2019 (Ahmed et al., 2019)	Nairobi, Kenya	Neighbourhood	Neighbourhood	Balloon mapping kit - Digital camera placed inside a helium balloon to take high resolution aerial photographs at a specified height.	Food vendor location

based on previous research from the UK reporting 500 m as a safe walking distance for children (Marrocos Leite et al., 2018). Likewise, Borchardt et al., 2019 selected a 500 m circular buffer when mapping out built environments in accordance with previous literature demonstrating this to be a reasonable distance covered by someone when walking moderately for 10 min (Borchardt et al., 2019).

The street network buffer technique was used in studies measuring the density of built environment features (Hino et al., 2011, 2014; Salvo et al., 2014; Jauregui et al., 2016). This method, which gauges the travel distance between two points along road networks, was used to map available recreational facilities within a 500 m walking distance from respondents' residential addresses in Curitiba, Brazil (Hino et al., 2011). Similar principles were applied in two studies conducted in Cuernavaca, Mexico (Jauregui et al., 2016). Considerations for network buffer area were also based on previous literature. For example, Salvo et al., (2014), selected a 500 m street network buffer (as opposed to the commonly used 1 km) to reflect the urban landscape in Mexico, where increased density and urbanisation mean that built environment features of interest occur in smaller buffer regions (Salvo et al., 2014).

We found only a few studies measuring the proximity or accessibility of food and PA destinations within individual buffers and whole neighbourhoods using GIS. In one Brazilian study, addresses of participants and supermarkets within a 1.6 km buffer were both geocoded and the Euclidian distance measured as a proxy for fresh produce accessibility (Duran et al., 2016). On the other hand, the proximity to nearby destinations was derived by following the walking route taken by randomly selected participants from the train station to their destination in Beijing, China (Sun et al., 2016).

- **Units of analysis and measurement**

Across the studies, food and PA environments in LMIC were analysed at city-wide (60%; n = 42), neighbourhood/district (18%; n = 11), and school (12%; n = 7) levels (Fig. 5).

oCity-wide

At the city level, environment features were mapped in different parts of the city to show variations in these environments. For example, a study conducted in Cape Town mapped the location and density of large chain supermarkets in different parts of the city to highlight disparities in food access and identified increased large chain supermarket density in high-income compared to low-income neighbourhoods (Battersby and Peyton, 2014; Peyton et al., 2015). A similar approach was also used in Mexican studies (Bridle-Fitzpatrick, 2015, Contreras Navarro and Ortega Velez, 2019, Laura Gonzalez-Alejo et al., 2019). In mapping the PA environment, a Romanian study mapped the spatial distribution and accessibility of publicly available green spaces across three types of residential built-up areas and found that a higher percentage of people living in collective housing (26%) had good access to green spaces compared to those in single-family housing (13%), and historical neighbourhoods (6%).

Twelve studies investigating food and PA features at the city-level used neighbourhoods as the unit of measurement (Battersby and Peyton, 2014, Peyton et al., 2015, Bridle-Fitzpatrick, 2015, Liao et al., 2016, Borges and Jaime, 2019, Assis et al., 2019, Gomez et al., 2010a, Zhang et al., 2014, Su et al., 2014, Morar et al., 2014, Corseuil Giehl et al., 2016, Anciaes et al., 2017). Using this approach, city neighbourhoods were stratified and sampled based on distinguishing characteristics, such as socio-economic status or spatial location to provide generalisations for city features. This approach is detailed in Florianópolis, Brazil with census tracts (neighbourhood proxy) in the city stratified based on the collective average household income for each tract (Corseuil Giehl et al., 2016).

Sixteen studies conducted a detailed analysis of food (n = 6) (Duran et al., 2016, Patel et al., 2017, Zhang and Huang, 2018, Marrocos Leite et al., 2018, Mendes Camargo et al., 2019, Costa et al., 2018) and PA (n = 10) (Cervero et al., 2009; Gomez et al., 2010a; Hino et al., 2011; Salvo et al., 2014; Hino et al., 2014; Jauregui et al., 2016; Lu et al., 2017; Da Silva et al., 2017; Florindo et al., 2019; Borchardt et al., 2019) environments by mapping out features in close proximity to study respondents' households. Using this method, households were geocoded, and relevant features mapped within a specified buffer. For instance, a 1.6 km radius was demarcated around respondents' household to map presence and location of fruit and vegetable retailers in Sao Paulo neighbourhoods. Increased density and proximity to these retailers was associated with regular (self-reported) fruit and vegetable consumption even among low-income individuals (Duran et al., 2016). Similarly, when measuring the PA environment, a Colombian study mapped out the presence and accessibility of built environment design features and destinations within a 500 m buffer from participant addresses to characterise the state of the PA environment across the city (Gomez et al., 2010b) Built environment features, such as public transport bus stops (Gelormini et al., 2015), train stations and street segments (Alfonzo et al., 2014; Silva et al., 2015; Hermida et al., 2019), were also used as nuclei for mapping city food and PA environments. For example, a Mozambican study used bus stops as nuclei points for mapping the location and type of street food vendors selling ready to eat food in

Table 2
Studies mapping physical activity environment features in low- and middle-income countries.

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Cervero et al., 2009 (Cervero et al., 2009)	Bogota, Colombia	City-wide	500 m and 1 km buffer around city block and census tract respectively	GIS (data from Cadastre Department of the City of Bogota)	Density Land-use diversity Design Distance to transit Destination accessibility
Gomez et al. 2010 (Gomez et al., 2010a)	Bogota, Colombia	City-wide	500 m around centroid of each neighbourhood	GIS	Public park density Street connectivity Presence of a cycling tracks Number of (bus) stations
Gomez et al. 2010 (Gomez et al., 2010b)	Bogota, Colombia	City-wide	Neighbourhood	GIS (data from Cadastre Department of the City of Bogota)	Housing density Land-use mix Park density Presence of a cycling tracks Number of (bus) stations
Hino et al., (2011) (Hino et al., 2011)	Curitiba, Brazil	City-wide	500 m buffer around respondent's place of residence	GIS (data from the Institute for Urban Research and Planning of Curitiba). GPS device	Population density Density of recreation infrastructure Accessibility to recreation facilities Density of traffic lights Slope of terrain
Hino et al., 2012 (Ferreira Hino et al., 2012)	Curitiba, Brazil	Neighbourhood	Census tracts	GIS (data from the Institute for Urban Research and Planning of Curitiba)	Walkability Index (derived from entropy, commercial density, residential density, and connectivity streets)
Zhang et al., 2014 (Zhang et al., 2014)	Zhongshan, China	City-wide	Neighbourhood	GIS (data from Zhongshan Municipal Bureau of Urban Planning)	Sidewalk density Population density Green space land use Bus-stop density Land-use mix
Su et al., 2014 (Su et al., 2014)	Hangzhou, China	City-wide	Neighbourhood 400 m buffer around administrative boundaries.	Street audit (China Urban Built Environment Scan Tool (CUBEST) GPS device	Access to commercial destinations Access to physical activity destinations Street connectivity Sidewalk quality Bike lane quality Aesthetic quality Safety from traffic
Morar et al., 2014 (Morar et al., 2014)	Timişoara, Romania	City-wide	Neighbourhood	GIS (data from Open Street Map, aerial imagery and plans from the 2012 National Agency for Cadaster and Land Registration, Planwerk S.R.L. and Vitamin Architects S.R.L.)	Access to green spaces. Distance to green spaces Number of green spaces
Salvo et al., 2014 (Salvo et al., 2014)	Cuernavaca, Mexico	City-wide	500 m and 1 km buffer around respondent's place of residence	GIS (data from Mexican National Institute of Statistics and Geography and the Land Use Registry Department of Cuernavaca.	Net residential density Proportion of commercial land use Street connectivity Land-use mix Number of parks intersecting the buffer Number of public transit (bus) routes Street network
Hino et al., 2014 (Hino et al., 2014)	Curitiba, Brazil	City-wide	500 m buffer around respondent's place of residence	GIS (Participant addresses, Institute for Urban Research and Planning of Curitiba).	Accessibility to selected built environment features Street network buffer Population density Density of public transport stops and stations traffic lights Land-use mix Street patterns Terrain slope
Alfonzo et al., 2014 (Alfonzo et al., 2014)	Shanghai and Hangzhou, China	City-wide	Street segment	Environmental Audit (Irvin-Minnesota Inventory-China IMI-C)	Micro-scale built environment features (sidewalks, street trees, benches, street width, curb cuts, or building facades). Density and building height Land-use mix Street connectivity Street form Presence, quality and access to parks, public spaces Pedestrian infrastructure and amenities Bike infrastructure and amenities Personal safety Traffic safety Aesthetics Recreational facilities
Adams et al., 2014 (Adams et al., 2014)	Multicounty*	City-wide	Smallest administrative unit (varied by country)	GIS	Net residential density Land-use mix Connectivity of the street network
	Sao Paulo, Brazil	City-wide	Street segment		

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Table 2 (*continued*)

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Silva et al., 2015 (Silva et al., 2015)				Google Maps Google Street View Street Audit Assessment - Observation	Type of road structure (flooring) Type of cross street Existence of sidewalks Irregularities on sidewalks Bus stops Crosswalks Traffic lights Streetlights Slope of the land The presence of green spaces (including public parks)
Liu et al., 2016 (Liu et al., 2016)	Shenzen, China	City-wide	Shenzen districts	Shenzen Greenway Map GIS (data from Shenzen Greenway Map)	Greenway density
Jauregui et al., 2016 (Jauregui et al., 2016)	Cuernavaca, Mexico	City-wide	500 m and 1 km buffer around respondent's place of residence	GIS (data from INEGI and the Land Use Registry Department of the City of Cuernavaca) GPS device	Residential density Land-use mix Intersection density Proximity to parks Proximity to transport stops
Sun et al., 2016 (Sun et al., 2016)	Beijing, China	City-wide	Metro station. Respondents trip from metro station to destination	Printed station map Baidu Maps Baidu Street View GIS	Participant walking route Destinations Number of floors in each building Street connectivity
Chen et al., 2016 (Chen et al., 2016)	Guangzhou, China	District	500 m and 1 km buffer around respondent's place of residence	GIS	Distance to community recreational facility
Corseuil et al. 2016 (Corseuil Giehl et al., 2016)	Florianópolis, Brazil	City-wide	Census tracts	GIS - (data from the Institute of Urban Planning of Florianópolis (IPUF)) Google Earth Google Street View	Land-use mix Street density Street connectivity Public open places Population density Percentage of street lighting Percentage of paved density Percentage paved streets and sidewalks
Sun et al. 2017 (Sun et al., 2017a)	Nanchang, China	City-wide	Train station approach area	Digital and printed maps China urban rail walking access scan tool - CWRWAST	Building density Land-use diversity Design (amenities, aesthetics, distance for building setbacks, wall on the sidewalk) Elements on the sidewalks (walking barriers, sidewalk width, completeness, connectivity, path materials) Road bedside sidewalk (road condition, maintenance, number of lanes, fence in the middle of the road, greenery in the middle of the road, width of the greenery, street parking, pedestrian crossing) Intermodal connection (number of bus stops, distance between the closest bus stop to metro, number of feeder bus lines, bus stop condition)
Lu et al., 2017 (Lu et al., 2017)	Hong Kong, China	City-wide	400 m buffer around housing estate	GIS (data from the Hong Kong government)	Land-use density Street connectivity
da Silva et al. 2017 (Mohnsam Da Silva et al., 2017)	Pelotas, Brazil	City-wide	500 m buffer around respondent's place of residence	GIS (Pelotas' streets network data from the Mobility and Management City Secretary) Google Maps	Street lighting Paved streets Sidewalks Trees existence Street garbage Open sewage
Anciaes et al., 2017 (Anciaes et al., 2017)	Praia, Cape Verde	City-wide	Bairro (neighbourhood)	GIS (data from the National Statistics Office of Cabo Verde and the Praia Municipal Government, and from previous studies.)	Availability of destinations for pedestrians Pedestrian space Proportion of formal pedestrian space Collision risk Crime Slopes Environmental risk (from flooding and landslides)
Jia et al., 2018 (Jia et al., 2018)	Bengbu, Anhui Province, China	Neighbourhood	Neighbourhood	GPS device Google Earth Satellite imagery (MODerate-resolution Imaging Spectroradiometer) GIS	Neighbourhood greenness (calculated using Vegetation Index (NDVI)
	Shanghai, China	School		Baidu Maps	

(continued on next page)

Table 2 (*continued*)

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Lin 2018 (Lin, 2018)			100 m, 200 m, 400 m and 800 m buffer around school 200 m and 400 m buffer around respondent's neighbourhood		Residential buildings Land-use (counts of restaurants and parks) Transportation facilities (total street network length, counts of intersections, bus stops, metro stations)))
Gu et al., 2018 (Gu et al., 2018)	Tianjin, Chongqing, Shijiazhuang, and Kunming, China	City-wide	City wide	Tencent street view imagery service	Pedestrian safety (sidewalks, bike lanes and crossing facilities) Pedestrian comfort (street width, the street–wall continuity ratio, and the percentage of streets with tree shade) Street network density Street crossing density Facility accessibility index
Reisi et al., 2019 (Reisi et al., 2019)	Isfahan, Iran	Neighbourhood	Street segment	Google Maps Street audit	Safety (lighting, crossing availability, potential vehicle conflict points, and sidewalk width) Obstructions (poles, signs, chairs along sidewalks) Support facilities (tactile paving, colour-contrast kerbing, kerb ramps, lane markings signage, landings on long ramps) Number of ramps for disabled people along the road and sidewalks Presence of trees and parks Recreational destinations Fixed furniture (presence of benches and other places to rest) Public toilets Number of transport stations
Lamour et al., 2019 (Lamour et al., 2019)	Sao Paulo, Brazil	Neighbourhood	Train station approach area	GIS (Digital City Map - Mapa Digital da Cidade) Google Maps Onsite street audits	Land-use diversity Pavement widths Street segments with parking spaces Public spaces Quality of streets
Hermida et al., 2019 (Hermida et al., 2019)	Cuenca, Ecuador	City-wide	Street segments	Open Street Map On-site street audit GIS	Street segment characteristics (including length, width, condition and surface, temporary and permanent obstacles, vegetation, furniture, bus stops, lighting and signage, parcel's front setback, number of doors and windows at the street level and presence of parking spaces) Land-use mix
Florindo et al., 2019 (Florindo et al., 2019)	Sao Paulo, Brazil	City-wide	500 m and 1 km buffer around respondent's place of residence	GIS (data from Municipal and State Government and National Economic Activity Classification database)	Bus stops Train and subway stations Parks Public recreation centres Bike paths Destinations
dos Santos et al. 2019 (dos Santos et al., 2019)	Curitiba, Brazil	School	500 m buffer around each school.	GIS (data from Curitiba City Institute for Urban Research and Planning (IPPUC)) Google maps Street audit (Microscale Audit of Pedestrian Streetscapes (MAPS)	Number of street crossings Number of dead Number of street segments
Dias et al., 2019 (Dias et al., 2019)	Porto Alegre, Brazil	City-wide	Distance from student's home to city parks	GIS (shapefile data from Municipal Department of Urbanism (SMUrb) of Porto AlegredRS)	Parks
Borchardt et al., 2019 (Borchardt et al., 2019)	Rio Grande, Brazil	City-wide	500 m buffer around respondent's place of residence	GIS (data from IBGE, satellite images, Secretariat of Finance, and Military Police)	Pedestrian security Population density Number of bus stops Public lighting Paved streets Sidewalks Trees Curbs Accessibility ramps Maintenance hole/down-take pipes Absence of open sewage Absence of accumulated garbage
Cubukcu et al., 2019 (Cubukcu et al., 2019)	Izmir, Turkey	City-wide	Zones	Foca Municipality Maps Google Earth	Street network characteristics Land-use mix
	Bandar Abbas, Iran	Neighbourhood			Total number of parks

(*continued on next page*)

Table 2 (*continued*)

Author, year	Setting	Unit of analysis	Unit of measurement	Mapping technique	Environment features
Aliyas 2019 (Aliyas, 2019)			1,500 km buffer around respondent's place of residence	Municipality Maps GPS device	
Arellana et al., 2020 (Arellana et al., 2020)	Barranquilla, Colombia	Neighbourhood	Street segments	Google Street View GIS	Sidewalk condition Traffic safety Security Comfort Attractiveness

* Adelaide, Australia; Ghent, Belgium; Curitiba, Brazil; Bogotá, Colombia; Olomouc and Hradec Králové, Czech Republic; Aarhus, Denmark; Hong Kong, a Special-Administrative Region of China; Cuernavaca, Mexico; North Shore, Waitakere, Wellington, and Christchurch, New Zealand; Pamplona, Spain; Stoke-on-Trent, United Kingdom; and Seattle and Baltimore, United States of America.

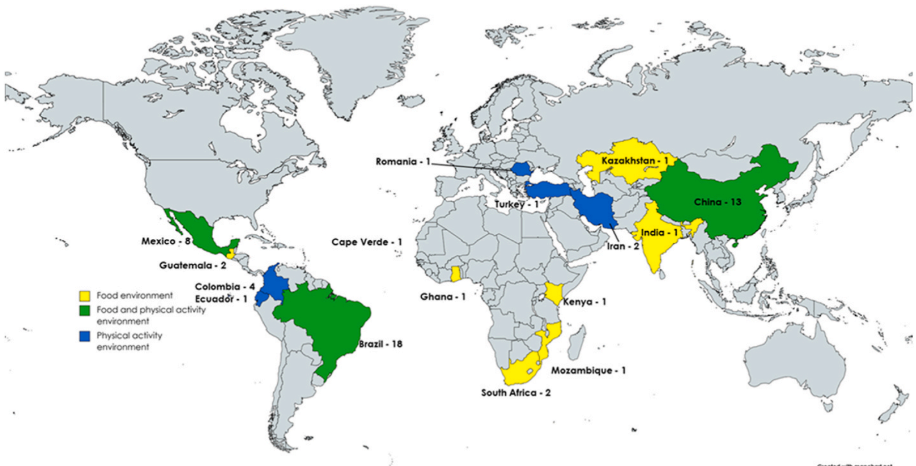

Fig. 2. Spatial distribution of LMIC research studies mapping food and physical activity environment.

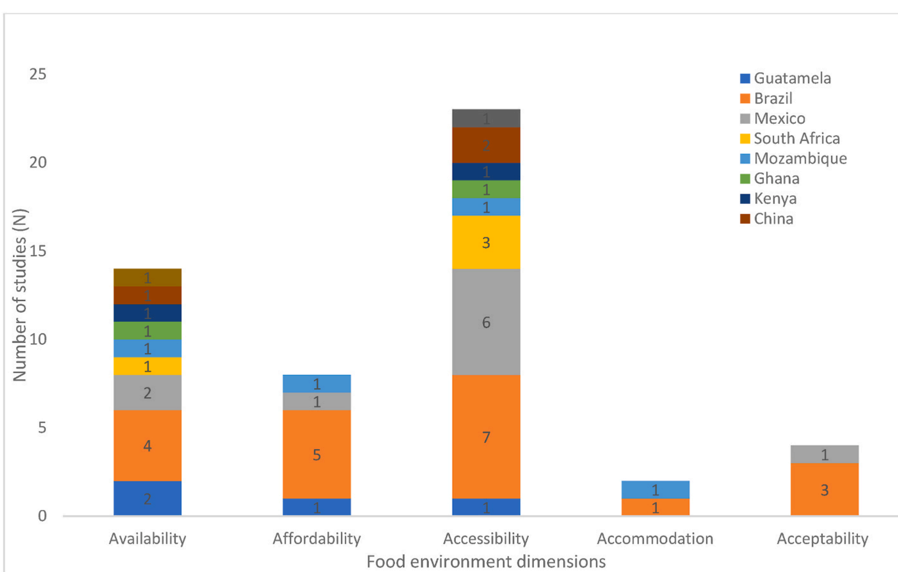

Fig. 3. Food environment domain by country.

KaMpfumu district neighbourhoods (Gelormini et al., 2015). Train station approach areas, in Beijing and Nanchang, China were also employed to map out the influence of built environment features in promoting walking access to and from train stations (Sun et al., 2016, 2017b).

oNeighbourhood and district

We found 11 studies mapping environments at the neighbourhood (n = 10) and district (n = 1) levels. Four studies mapped the neighbourhood food environment and seven mapped PA environments (Dake et al., 2016, Kroll et al., 2019, Backes et al., 2019, Ahmed et al., 2019, Ferreira Hino et al., 2012, Jia et al., 2018, Reisi et al., 2019, Lamour et al., 2019, Aliyas, 2019, Arellana et al., 2020, Chen et al., 2016). The units of measurement – whole neighbourhoods, buffer regions around participants' household and public features – were similar to those used

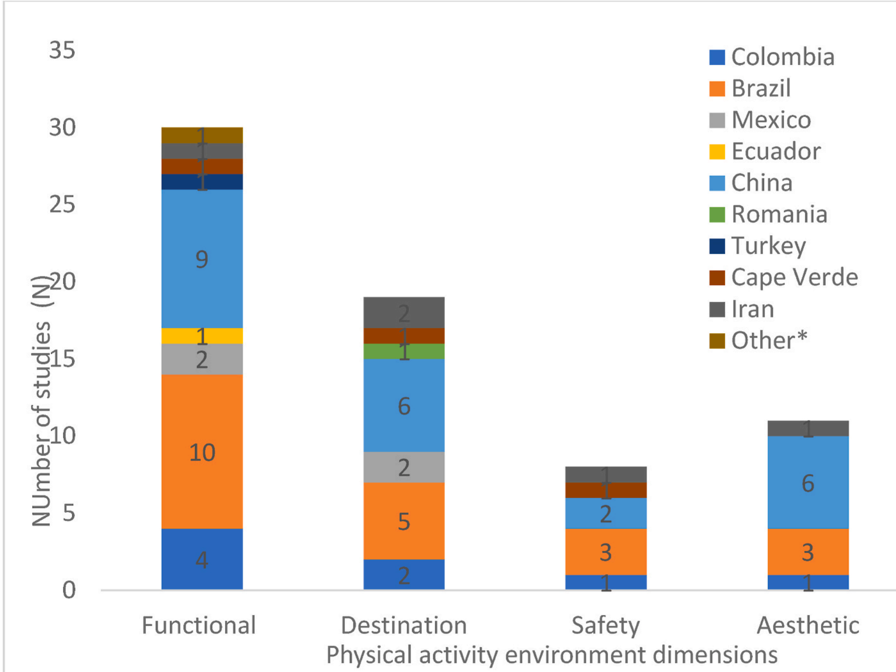

Fig. 4. Physical activity environment domain by country. *Multinational study conducted in 12 HIC and LMIC.

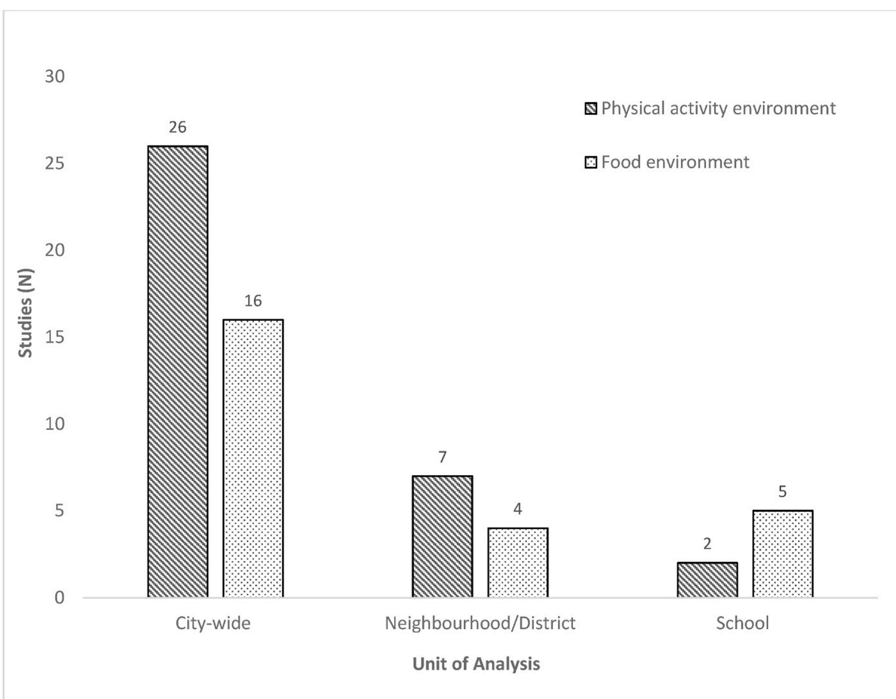

Fig. 5. Units of analysis used in mapping food and physical activity environments.

for mapping at the city-wide level. However, there were some inconsistencies in the demarcation and definitions of neighbourhoods across studies. In some cases, neighbourhoods were clearly defined based on both city geographical planning and social boundaries, as was the case for Khayelitsha (Cape Town, South Africa) and Ahodwo (Kumasi, Ghana) (Kroll et al., 2019). In other cases, like in São Leopoldo and Curitiba (Brazil), neighbourhood boundaries were not as clearly demarcated, prompting use of census tracts as neighbourhood proxies (Backes et al., 2019, Ferreira Hino et al., 2012).

oSchool

We found seven studies mapping the food and PA environment around schools in Guatemala, Mexico, Brazil and China (Chacon et al., 2013; Chacon et al., 2015; Barrera et al., 2016; Soltero et al., 2017; Barquera et al., 2018; Lin, 2018, dos Santos et al., 2019). Across all studies, environment mapping was conducted by trained researchers without child/adolescent participation in data collection. In all these studies, buffer regions ranging between 100 m and 800 m around the school compound were demarcated for mapping. For the food environment, there was an interest in the type and location of food retailers selling snack foods targeted at school-going children on their way to and from schools (Chacon et al., 2013, 2015). Two studies further mapped out the location of snack food advertisements around schools in Mixco, Mexico (Chacon et al., 2015; Barquera et al., 2018). For PA environments, features such as the number of street crossings, street segments, transportation stops, residential buildings and land-use mix were mapped out to infer the available opportunities for transport-related PA for students moving to and from school.

4. Discussion

In this review, we identified 60 LMIC studies that used maps, GPS and GIS to map food and PA environments. Complementary environment audit tools were used to collect data on non-geographic features. The majority (60%) of studies mapping the food environment were conducted in Latin America and Caribbean countries. Of the 35 studies mapping the PA environment, 66% were conducted in either China (n = 12) or Brazil (n = 11). All reviewed studies were cross-sectional and used digitised methods during data collection and analysis.

- Study design

The universal use of cross-sectional study designs echoes previous findings of limited longitudinal evidence in food and PA environment research (Lytle, 2009; Story et al., 2009; Minaker et al., 2016). This is a point of concern given that longitudinal studies provide stronger evidence for causal inference in addition to enabling investigation of the interlinkage between changing urban environments and trends in population food and PA behaviour (Pérez-Ferrer et al., 2019). This is ever more important for capturing rapidly evolving LMIC contexts where longitudinal (observational or natural experimental) studies could establish how rapidly changing food and PA environments impact community behaviour (Sun et al., 2014). Furthermore, longitudinal studies will need to utilise a mixed method approach that combines elements of geographical mapping and qualitative data collection to capture the interplay between the more studied objective food (availability, accessibility) and PA (functionality, and destination) domains and the subjective (acceptability, affordability, and accommodation; safety and aesthetics) domains (Lee et al., 2013; Short et al., 2007) (Turner et al., 2017, 2020). This is considering evidence from a recent review suggesting that, across 15 African countries, study participants overwhelmingly perceived individual factors (affordability) as influencing their food behaviour relative to physical environment factors (such as food availability and accommodation) (Osei-Kwasi et al., 2020). This finding contrasted with evidence from other LMIC contexts that showed proximal neighbourhood factors, such as the food type and pricing and walkability, play an important role in mitigating household and individual behaviour (Turner et al., 2017; Chor et al., 2016). Such differences in research findings, demonstrate that experiences of the food and PA environments are not homogenous across LMICs, and that longitudinal mixed method approaches are necessary to understanding the nuances for each context.

- Mapping tools

Identified studies used three geographical mapping tools -Maps, GPS, and GIS with GIS tools being most frequently used. One of the key advantages of this technique is the ability to overlap multiple layers of geocoded information, such as household dietary intake or physical activity levels, to create maps showing the spatial outlay of features of interest. However, a potential limitation of using GIS in LMICs is that it relies on up-to-date information pulled from digitised maps which are not always available in LMIC settings, thereby impacting data accuracy. This issue is further exacerbated by rapid urbanisation with observable food and PA environment features in a state of constant flux, limiting the accuracy of existing data systems. (Gelormini et al., 2015; Crush and Frayne, 2011; Goryakin et al., 2017; Riha et al., 2014; Hermosillo-Gallardo et al., 2017; Allender et al., 2008, Allender et al., 2010). Given this context, the use of methods, such as in-person field audits using GPS or community aerial imaging could provide more accurate alternatives for mapping dynamic LMIC urban environments. This review identified one such study in Nairobi, Kenya that used community-based participatory geographic information tools as a contextually appropriate way to map the food environment in a growing settlement in Nairobi, Kenya (Ahmed et al., 2019). This technique utilised relatively inexpensive tools – a digital camera mounted inside a helium balloon – to map out informal food vendor density and has been used in other settings and various fields to provide high-resolution imagery of sites (Dosemagen et al., 2011; Haklay and Francis, 2017; Sieber, 2006).

In comparison to researcher-led approaches, mapping techniques that incorporate community participation are particularly relevant for capturing lived environment realities with the added advantage of being less resource intensive (Jacquez et al., 2013; Ahmed et al., 2019; Díez et al., 2017; Goh et al., 2009; Suminski et al., 2009). This is because some features of the lived food and PA environments might be unknown or overlooked by researchers (Ahmed et al., 2019; Wridt, 2010). Examples include home-cooked meals prepared for re-sale, mobile vendors, informal transit stops, and alleys that provide shortcuts for pedestrian routes. Previous research, from HICs, also provides examples of other methods for community participation in the mapping exercise including the use of mobile phones to capture images of adolescent interaction with the food environment (Riggsbee et al., 2019) and the use of web-based interactive mapping surveys to map out adolescent travel routes (Hinckson et al., 2014; Stewart et al., 2017). Findings from these studies highlight the importance of participatory methods in better capturing lived environment realities and the need for more research in LMICs that utilise this innovative approach to data collection.

- Units of analysis

The majority of identified studies mapped both food and PA environments at the city-wide scale in two ways: mapping and comparing features in different parts of the city or looking at city level spatial distribution of relevant environmental features of interest. These city-wide comparisons highlighted disparities in the availability, or accessibility of food and PA environment features present in between neighbourhoods. For example, availability of supermarkets or recreational parks in neighbourhoods of differing socio-economic factors (Battersby and Peyton, 2014; Gomez et al., 2010b). However, there is the potential to miss the contextual features of the intra-city differences in the food or PA environment. This is illustrated in two related studies conducted in Cape Town, South Africa, that showed a higher density of large-chain supermarkets in higher SES neighbourhoods compared to their low SES counterparts (Battersby and Peyton, 2014). However, when interrogating the food environment in the latter, it was observed that the presence of additional informal food outlets (such as spaza shops and informal food vendors) filled gaps in food accessibility and availability within these areas (Peyton et al., 2015). It is therefore crucial that such differences in neighbourhood characteristics are considered and sufficiently captured in future comparative research studies.

A smaller proportion of the studies (18%) mapped environments at the neighbourhood level by investigating the food and PA opportunities available to individuals within pre-defined neighbourhood geographical boundaries. Although this approach provides a sense of the hypothetical environmental resources available to individuals, it does not capture the lived experiences of individuals and their utilisation of the available resources. As such, evidence is lacking on the extent to which the available food and PA resources are utilised, and the barriers to use that exist, which may not be apparent in mapping exercises. Thus, it is imperative that future research mapping food and PA environments in LMIC also explore the use of these opportunities, and the enabling and constraining factors to use. This notion is evidenced in research conducted in South Africa and Brazil, showing that individuals may purchase food items outside of their neighbourhoods at transit stops, around their place of work, or wholesale areas (Backes et al., 2019). Similarly, for PA environments, individuals may engage in recreational physical activities away from their places of residence or may choose not to use theoretically available resources close to home due to perceptions of safety or injury risk or due to inequitable governance in the access to these spaces.

5. Strengths and limitations

To our knowledge, this is the first review highlighting the tools and techniques in mapping urban food and PA environments in LMIC. We acknowledge a number of limitations. Although our inclusion strategy did not set any language restrictions, the search terms used for data collection were in English. Therefore, we may have omitted some relevant non-English articles in our search. Secondly, we note that research on food and PA environments span across multiple disciplines. Other fields may not exclusively use the "food environment" and "physical activity environment" terminology used in this review, thereby excluding relevant studies. Future reviews may consider broadening the scope of the current study by exploring subjective methods for mapping food and PA environments to gain an understanding of techniques and tools used in LMICs to explore individual perceptions of their environments.

6. Conclusions

This review highlights a paucity of research mapping food and PA environments in LMIC with research clustered in Latin America and Caribbean and East Asia countries. Almost all studies included in this review used digital tools in mapping of urban food and PA environments. While this is in accordance with methods used in HIC settings, there is a need for advances in methods to address resource constraints that make cross sectional and longitudinal mapping studies challenging in LMIC contexts. Such advances would enable the conduct of research that measures the impacts of interventions in the food and built environments on dietary and activity behaviours over time, particularly in the context of rapidly changing environments. We further identify a need for future research studies that use mixed methods approaches to simultaneously map objective and subjective domains of food and PA environments in LMICs. Such research is needed to address the evidence gap identified on the mapping of food and PA environments in LMICs and to support the development of evidence-informed interventions and strategies to tackle obesogenic exposures that increase the risk of NCDs.

In countries with predominantly young populations, transdisciplinary research is further recommended to explore the feasibility and validity of engaging adolescents and youth, often agents of social change, in participatory mapping of their food and PA environments to better capture the "lived" environments.

Authors contributions

JB, TO and TM initiated and developed the study protocol. TM conducted the literature search, drafted the manuscript, prepared the final draft. PD, MK, BG, and TM reviewed the articles for eligibility. All the authors reviewed the draft and approved the final manuscript.

Funding

This study was funded by Urban Food Systems Governance for NCD Prevention in South Africa, Kenya and Namibia (Nourishing Spaces) IDRC, Canada Project # 108458. TO is supported by the National Institute for Health Research (NIHR) (Global Health Research Units and Groups Programme) for a Global Health Research Group and Network on Diet and Activity. The views expressed in this publication are those of the authors and not necessarily those of the National Health Service (NHS), the NIHR or the Department of Health and Social Care. Funding from NIHR (16/137/34) is gratefully acknowledged. MK was supported by the South African National Research Foundation (NRF) under joint funding with the German Academic Exchange Service (DAAD) for her PhD.

Declarations of interest

None.

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