BMC Public Health

RESEARCH

Open Access

Spatial distribution of healthy food options: an evaluation of the food environment in Putrajaya

Nur Farhana Mohammed Noor[1], Siti Aisah Mokhtar[1*], Zarirah Adzni Mokhtar[1,2], Halimatus Sakdiah Minhat[1] and Siti Anom Ahmad[3]

Abstract

Introduction The prevalence of overweight and obesity in Malaysia has reached historically high levels, with particularly high rates observed in Putrajaya, the administrative capital of the country. Despite this, limited attention has been given to the role of the local food environment in shaping dietary behaviours within the Putrajaya community. This study aimed to assess the healthfulness and spatial configuration of the food environment in Putrajaya.

Methods This observational study evaluated the food environment in Putrajaya, Malaysia, using the Nutrition Environment Measures Survey for Stores (NEMS-S) and Restaurants (NEMS-R). All food stores and eateries were assessed for the healthy food options. Kernel Density Estimation was applied to examine spatial clustering patterns of relatively healthy and unhealthy food environments.

Results A total of 80 food stores and 665 eateries were assessed. Supermarkets achieved the highest NEMS-S scores, with a median total score of 27.0 (IQR: 19.0), driven primarily by availability sub-scores (20.0; IQR: 14.0) rather than price incentives (3.0; IQR: 3.0). Although 80.5% of stores stocked whole-wheat bread, only 6.5% offered lean meat options, and price favouring healthier alternatives scores were consistently low across all store types (range: 2.0-3.5).
For restaurants, aggregate NEMS-R scores indicated limited healthfulness across outlet types, with 24-hour restaurants recording the highest median score (5.0; IQR: 1.0). While 87.3% of eateries provided at least one healthy main dish, only 0.5% offered low-fat milk. Facilitators supporting healthy choices were absent across outlets (median:0.0), and barriers to healthy eating sub-scores were negligible (median:0.0), indicating limited structural support within the restaurant food environment to promote healthier choices.
Spatial analysis identified clustering of healthy food environments in Precincts 1, 14, 15, and 16. However, density mapping demonstrated substantial spatial overlap and adjacency between healthy and unhealthy food environment clusters, indicating that healthier food access is embedded within a broader obesogenic environment.

*Correspondence:
Siti Aisah Mokhtar
sitiaisah@upm.edu.my

Full list of author information is available at the end of the article

Conclusion The findings indicate the presence of food swamp–like conditions in Putrajaya, characterised by the dominance and spatial salience of unhealthy food environments despite apparent outlet diversity. Targeted policy, community-based, and urban planning interventions are warranted to improve the healthfulness of food environments in Putrajaya.

Introduction

The food environment refers to the context in which individuals acquire and consume food, shaped by the food availability, accessibility, and affordability. It serves as a critical interface between the broader food system and individual dietary behaviour and is influenced by a dynamic interplay of physical factors such as the density of food outlets, economic elements such as pricing, regulations around food safety and marketing, as well as the sociocultural influences that shape preferences and dietary norms [1, 2]. Collectively, these elements determine the accessibility, affordability, and acceptability of food options within a community and, in turn, shape population-level consumption patterns.

With the rising prevalence of non-communicable diseases (NCDs), the health implications of the food environment have gained increasing attention [3]. Communities characterised by high densities of fast-food outlets, convenience stores, and takeaway restaurants consistently report high obesity prevalence and related adverse health outcomes [4–9]. Such environments are commonly described as food swamps, defined by the predominance of energy-dense, nutrient-poor foods relative to healthier alternatives.

Evidence from Malaysia, Vietnam, and Indonesia indicates that many urban neighbourhoods in Southeast Asia are characterised by high concentrations of fast-food restaurants, convenience stores, and sweetened beverage outlets located in proximity to residential areas, schools, and workplaces [10]. Rapid urbanisation, motorisation, and the expansion of commercial food retail over the past two decades have substantially reshaped local food environments across the region [11]. Traditional wet markets and home-prepared meals are increasingly supplemented or displaced by convenience stores, fast-food outlets, processed or pre-prepared food, and sweetened beverages [12].

Importantly, food swamps in Southeast Asia may differ structurally from those described in Western settings due to the prominence of hawker stalls, night markets, and 24-hour eateries [13]. High-calorie and processed foods are becoming increasingly accessible, and a substantial portion of the urban population regularly consumes items from the informal food sector [14]. Extended exposure to unhealthy food options beyond conventional operating hours further increases temporal access to energy-dense foods and may reinforce late-night eating behaviours, which have been consistently linked to a higher risk of overweight and obesity [15].

According to the Theory of Planned Behaviour (TPB), behaviour is driven by intention, which is shaped by attitudes towards the behaviour, subjective norms, and perceived behavioural control. Within this framework, the food environment functions as a critical contextual determinant influencing all three constructs simultaneously. A supportive food environment characterised by greater availability, accessibility, and affordability of healthier food options fosters more favourable attitudes towards healthy eating by increasing its perceived convenience and benefits, normalises healthier choices, and enhances perceived control over food selection, thereby shaping subjective norms and increasing the likelihood that healthy intentions translate into actual behaviour [16]. Conversely, obesogenic food environments characterised by the pervasive availability and affordability of energy-dense and sugary food undermine these TPB constructs by reinforcing positive attitudes towards unhealthy options, normalising their consumption, and constraining perceived behavioural control through availability, convenience, and pricing [15, 17]. This dynamic ultimately promotes unhealthy dietary behaviours [18]. Consistent evidence indicates that residents of such obesogenic environments exhibit poorer dietary habits and experience adverse health outcomes. [5, 6, 19]

Mirroring global trends, the Malaysian food environment is characterised by the widespread availability of energy-dense foods across both formal and informal retail settings, while healthier options are often less visible, less affordable, and less competitively promoted [20]. According to the National Health and Morbidity Survey (NHMS) 2023, 52.9% of Malaysian adults are classified as overweight or obese, placing Malaysia among the countries with the highest prevalence in Southeast Asia [21]. Notably, Putrajaya, Malaysia's federal administrative capital, reported among the highest prevalence nationwide, with more than 61.3% of its adult population affected [21]. Despite relatively high health literacy levels and a built environment that supports physical activity, the persistently elevated prevalence of overweight and obesity in Putrajaya suggests that dietary behaviours shaped by the local food environment may be a critical contributing factor [22].

However, to date, no comprehensive assessment of the food environment in Putrajaya has been conducted using validated audit instruments such as the Nutrition

Environment Measures Survey (NEMS). This absence of robust, context-specific evidence constrains the development of targeted public health nutrition interventions and informed urban planning strategies. Accordingly, the present study aimed to describe the healthfulness and spatial configuration of the food environment in Putrajaya, providing a basis for understanding its potential public health and policy relevance.

Methods

This research was conducted in Putrajaya, Malaysia. Established in 1995, Putrajaya spans approximately 4,900 hectares and is a planned city developed based on the "garden city" concept, characterised by integrated land-use planning that balances government offices, residential areas, greenery, and protected wetlands [23]. With a population estimated at 119,200, predominantly government employees, its distinct planning framework and demographic profile make it a unique study setting [24].

An observational study was employed to assess the health-supportiveness of the food environment in Putrajaya using the Nutrition Environment Measures Survey for Stores (NEMS-S) and Restaurants (NEMS-R).[25,26] Data were collected at a single point in time, between June and July 2024, to provide a snapshot of food outlet characteristics within the study area. The sampling frame included all operating food outlets in Putrajaya during the data collection period, categorised as: (1) food stores, including supermarkets, grocery stores, convenience stores, and fresh markets; and (2) eateries, including restaurants, 24-hour restaurants, coffee shops, bakeries, fast-food outlets, and hawker stalls.

Data preparation

An initial list of food establishments in Putrajaya was obtained from the governing body, the Putrajaya Corporation, through its online database. The list was cross-validated using additional sources, including meal delivery service platforms and relevant social media pages, to enhance data accuracy and completeness. All eligible food outlets within the predefined geographic boundary were included, and no sampling or random selection was performed. Outlets that were permanently closed or inaccessible during the study period were excluded. This census-based approach minimised selection bias and ensured comprehensive coverage of the local food environment.

All food establishments were geocoded using online mapping sources, Google Maps. The resulting latitude and longitude coordinates were visually inspected using Google Street View and further validated through on-site verification with handheld GPS devices or mobile mapping applications using real-time satellite positioning. Coordinates were manually cross-verified against base maps in ArcGIS to ensure spatial accuracy. Spatial joins and density analyses were conducted at the precinct level, corresponding to Putrajaya's administrative boundaries, thereby reducing the risk of geographic misclassification.

Two trained raters conducted the food environment assessments to minimise observer bias and misclassification. Both raters underwent standardised training and calibration exercises to ensure consistent interpretation of the NEMS scoring criteria. Each establishment was visited and assessed simultaneously by both raters. To minimise observation bias, raters maintained discretion during assessments to avoid altering retailers' usual practices. Observations were recorded manually for each food outlet. Outlets that were closed at the initial visit were revisited, and those remaining closed after two separate visits during the study period were excluded. Audit forms were reviewed by the principal investigator for completeness and consistency before data entry.

Nonetheless, while the NEMS tool provides a structured method for evaluating the healthfulness of food outlets, several sources of uncertainty may affect interpretation of the findings. Food items not explicitly labelled as whole-grain, reduced-sugar, or reduced-fat were classified as not meeting the healthy criteria under the NEMS tools. Items that were temporarily out of stock on the day of assessment were treated as unavailable. Additionally, menu offerings can vary daily and outlet operational hours may limit the availability of certain items at the time of data collection. For eateries offering composite dishes, scoring was based on the predominant ingredient and preparation method observed at the time of assessment, regardless of the portion size. Besides, some outlet types, such as 24-hour restaurants or late-night eateries, may have been underrepresented, potentially limiting the generalisability of the results. Furthermore, observer judgement, despite standardised training, may also introduce minor variability in scoring. Therefore, while the observed scores provide useful insights into the local food environment, they should be interpreted as approximations of relative healthfulness rather than absolute measures, and conclusions regarding residents' dietary exposure should be drawn with caution.

Following data collection, all observations were cleaned and entered into two independent databases. Inter-rater agreement was assessed by comparing scores between raters, yielding a high level of consistency (99% agreement). When discrepancies occurred, particularly regarding item availability, pricing, or facilitators and barriers to healthier eating, an adjudication process was undertaken. This involved a joint review of the item against the NEMS scoring guidelines and supporting field notes. Where consensus could not be reached, menu documentation was consulted, and a final decision

was made based on predefined NEMS criteria. The adjudicated score was used for analysis. For discrepancies in food quality scores, the mean of the two ratings was used as the final value. This process enhanced scoring reliability and minimised measurement error across outlets.

Study instrument

NEMS-S and NEMS-R were employed to evaluate the food environment of Putrajaya in this study. Both instruments have demonstrated high reliability and validity, with Kappa values for inter-rater and intra-rater reliability above 0.80 and 0.72, respectively, in previous studies [13, 14]. The NEMS tools have been widely adopted internationally to evaluate the healthfulness of food environments across diverse countries and settings, including in the US, Chile, Iran, China, and Australia [25–29].

NEMS-S assesses the availability of healthy food options in food stores by evaluating three key components: availability (score range 0–30), price (score range – 9 to 18), and quality (score range 0–6) of ten food items considered important for a nutritious diet. These items include fresh fruits and vegetables, skim or low-fat milk, lean ground beef, low-fat hot dogs, reduced-calorie frozen dinners, diet or low-calorie soda, 100% juice, lower-fat baked goods, 100% whole grain bread, and baked or low-fat snack chips [30]. The total NEMS-S score, calculated by summing availability, quality, and price, ranges from – 8 to 54, with higher scores indicating a healthier food environment.

Comparably, NEMS-R assesses the availability of healthy food options at restaurants. Its scoring includes the availability of healthy meal options, including main dishes/entrées, salads, non-fried vegetables, fruits, whole grain bread, baked chips, and low-calorie/low-fat beverages, with a score range of 0 to 15; facilitators of healthy eating (0–8); barriers to healthy eating (-5–0); and the presence of a healthy kid's menu (-3–9). The total NEMS-R score ranges from – 8 to 30, with meals classified as healthy if they meet predefined nutritional criteria [31].

In this study, the original NEMS-S and NEMS-R instruments were applied without modification. The NEMS tools conceptually align with the Malaysian Dietary Guidelines (MDG), which emphasise fruits and vegetables, whole grains, lean proteins, reduced-fat and reduced-sugar options, and healthier preparation methods [32]. Hence, retaining the original NEMS structure enables international comparability while providing locally relevant insights into the healthfulness of Putrajaya's food environment and ensures methodological rigour and reduces measurement bias. A summary comparison between the NEMS instruments and the Malaysian Dietary Guidelines is presented in Appendix.

For this study, the 'healthy kid's menu' category was omitted from the assessment because the focus was on characterising the adult consumer food environment. Children's menus target a different population, with distinct portion sizes, pricing, and promotional strategies, and including them would create a misalignment with the study focus. The total NEMS-R score without the kid's menu ranges from – 5 to 23.

Data analysis

Sub-scores were then developed based on the availability, price, and quality of food items for NEMS-S and on the availability of healthy options, facilitators encouraging healthy eating, and barriers to healthy food choices for NEMS-R. The cumulative score for each food establishment was calculated by summing the sub-scores across various categories. Normality was assessed, and descriptive statistics were reported as means or medians, as appropriate.

For descriptive mapping purposes, outlets were categorised into tertiles based on their NEMS total scores to illustrate spatial variation in healthy food availability. This tertile-based grouping followed established methodological precedent rather than arbitrary cut-off values, thereby maintaining analytical objectivity [33]. Guided by the interpretation of Carins and Rundle-Thiele, a cut-off of 45% of the maximum attainable NEMS score was used, whereby establishments scoring at or above 45% were classified as healthy food environments, while those scoring below 45% were classified as unhealthy, reflecting weak support for healthy eating [33]. Each outlet was mapped using ArcGIS software to visualise the spatial distribution of healthy and unhealthy food environments across Putrajaya. Kernel density estimation, conducted through the Spatial Analyst tool in ArcGIS, identified high-density areas of healthy and unhealthy food environments, allowing detailed analysis of spatial clustering patterns.

This study was approved by the Ethics Committee for Research Involving Human Subjects, Universiti Putra Malaysia (JKEUPM-2024-354). Data collection involved publicly accessible food establishments, and no protected or privately restricted lands were accessed.

Results

A total of 99 geocoded food stores were initially identified. Of these, 19 were excluded due to geocoding duplication ($n = 4$), location within private compounds ($n = 6$), classification as home-based enterprises ($n = 3$), temporary cessation of operations ($n = 2$), or permanent closure ($n = 4$). The final analysis included 80 food stores, comprising four supermarkets, 36 grocery stores, 30 convenience stores, and 10 fresh markets, including wet markets, butcher shops, and greengrocers.

Among these stores, items such as whole-wheat bread (80.5%), diet soda or 100% juice boxes (79.3%), low-fat

Table 1 Percentage of healthy food items sold by each type of food store

Type of food	Supermarket (%)	Grocery store (%)	Convenience store (%)	Fresh market (%)
Low-fat milk	100	80.6	86.7	25.0
Fruits	100	55.6	16.7	50.0
Vegetables	100	69.5	16.7	75.0
Lean meats	25.0	2.8	0	37.5
Low-fat hot dogs	100	63.9	83.3	50.0
Low-fat frozen dinners	75.0	13.9	80.0	75.0
Low-fat baked goods	100	2.8	13.3	50.0
Diet soda/100% juice	100	80.5	93.3	50.0
Whole-wheat bread	50.0	77.8	100	12.5
Low-fat chips	50.0	19.4	0	0
Low-sugar cereal	100	58.3	100	12.5

milk (77.9%), low-sugar cereals (71.4%), and low-fat hot dogs (71.4%) were more readily available across the stores. In contrast, vegetables (50.7%) and fruits (41.6%) were less frequently available. The most commonly stocked vegetables were choy sum (*sawi*), tomato, and cabbage, while the most common fruits were oranges and bananas, followed closely by apples and pineapples. Some healthy food items were less common in these stores, including low-fat frozen dinners (44.2%), low-fat baked products (6.5%), lean meat (5.2%), and baked chips (2.6%).

In addition, the availability of healthy food items was documented by food store type, as presented in Table 1. All supermarkets, as well as the majority of convenience stores and grocery stores, offered low-fat milk, diet soda, 100% juice, low-fat hot dogs, whole-wheat bread, and low-sugar cereals. Supermarkets, fresh markets, and grocery stores were the primary stores offering fruits and vegetables. Some convenience stores also carried low-fat frozen dinners. Nevertheless, lean meat options were comparatively limited; although certain supermarkets and fresh markets sold lower-fat cuts of meat, these products were generally offered without accompanying nutritional labelling.

The NEMS-S scores data were not normally distributed, as indicated by both the Kolmogorov-Smirnov and Shapiro-Wilk tests ($p < 0.05$). Visual inspection of the histogram revealed a right-skewed distribution, which was further supported by the stem-and-leaf plot, box plot, and Q-Q plot, all indicating deviation from normality.

Overall, supermarkets demonstrated the most favourable food environment profile, with the highest median total score (27.0, IQR: 19.0), driven primarily by substantially higher availability scores (median: 20.0, IQR: 14.0) relative to other store types. It is followed by convenience stores and grocery stores, with median total scores of 15.0 (IQR: 6.0) and 14.5 (IQR: 13.0), respectively. Fresh markets recorded the lowest median total score (12.0, IQR: 8.0), largely reflecting lower availability scores (median: 6.0, IQR: 4.0), despite achieving comparable quality scores to grocery stores (median: 4.0, IQR: 6.0). Table 2 summarises the overall NEMS-S sub-score and total scores.

Table 2 Overall score and the availability, quality, and pricing sub-scores for each type of food store

Type of food store	*N*	Median score for availability (IQR)	Median score for quality (IQR)	Median score for price (IQR)	Median total score (IQR)
Supermarket	4	20.0 (14.0)	6.0 (4.0)	3.0 (3.0)	27.0 (19.0)
Grocery store	36	10.0 (7.0)	4.0 (2.0)	2.5 (5.0)	14.5 (13.0)
Convenience store	30	11.0 (1.0)	0.0	3.5 (6.0)	15.0 (6.0)
Fresh market	10	6.0 (4.0)	4.0 (6.0)	2.0 (3.0)	12.0 (8.0)

Table 3 Percentage of healthy food items sold by each type of eatery

Type of food	Restaurants, %	24-hour restaurants, %	Coffee shops, %	Hawker stalls, %	Fast-food outlets, %
Healthy main dish/entrée	94.6	100	81.7	66.2	3.0
Main dish vegetables	34.4	75.0	9.2	2.7	23.7
Non-fried vegetables	30.0	75.0	17.1	2.7	0
Low-fat salad dressing	10.5	0	7.9	0	0
Fruits	7.1	0	1.3	0	0
Baked chips	1.7	0	0	0	0
Whole-grain bread	1.0	8.3	0	0	10.5
100% juice	26.3	75.0	17.1	0	0
Low-fat milk	0.7	0	0	0	0

Moreover, a total of 665 food eateries were included in this study, comprising 404 restaurants operating during regular hours, 13 restaurants that operated 24 hours, 74 coffee shops, 27 bakeries, 110 hawker stalls, and 37 fast-food outlets. Among the healthy items available, 87.3% of eateries served at least one healthy main dish/entrée, including rice, cereals, fish, poultry, meat, eggs, legumes, tofu, and tempeh; 25.4% provided salad; and 22.3% offered non-fried vegetables. Additionally, 19.5% of eateries offered 100% juice, 7.4% served low-fat salad dressings, 4.5% included fruits, 1.4% offered whole-grain bread, 1.1% served baked chips, and 0.5% included low-fat milk options on their menu.

Table 3 presents the percentages of healthy food options available across different types of eateries in Putrajaya. Notably, restaurants served all the listed healthy food items. Many 24-hour restaurants included main dishes/entrées, non-fried vegetables, whole-grain bread, and 100% juice on their menus. Additionally, most coffee shops that serve Western-style cuisines would

Table 4 Median total score and sub-scores for each category of availability, facilitators, and barriers to healthy eating in food eateries in Putrajaya

Type of eateries	*N*	Median score for the availability of healthy eating options (IQR)	Median score for the facilitator of healthy eating (IQR)	Median score or barrier to healthy eating (IQR)	Median total score (IQR)
Restaurant	404	3.0 (2.0)	0.0	0.0	3.0 (2.0)
24-hour restaurant	13	5.0 (1.0)	0.0	0.0	5.0 (1.0)
Coffee shop	74	3.0 (2.0)	0.0	0.0	3.0 (2.0)
Bakery	27	0.0	0.0	0.0	0.0
Hawker stall	110	1.0 (2.0)	0.0	0.0	1.0 (2.0)
Fast-food outlets	37	3.0 (1.0)	0.0	1.0 (1.0)	2.0 (2.0)

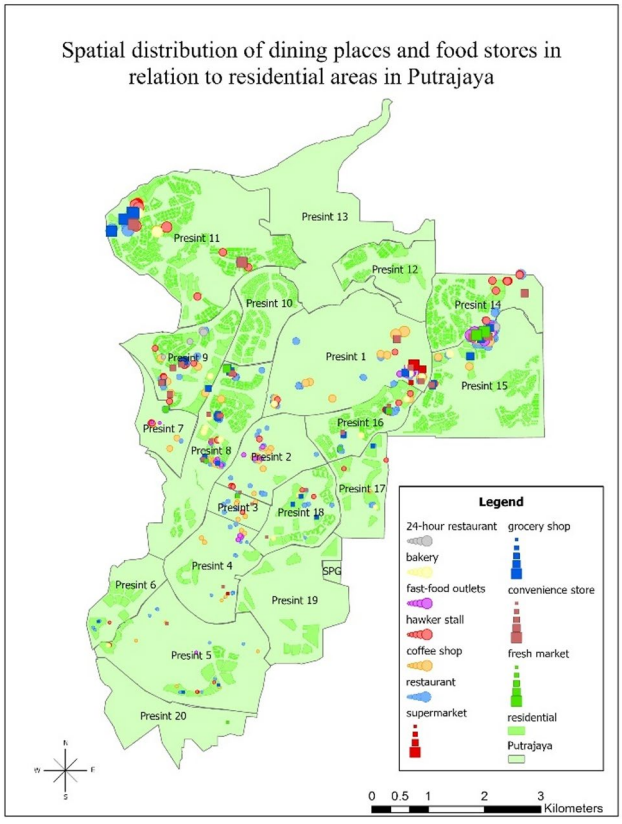

Fig. 1 Spatial distribution of food stores and eateries in Putrajaya; squares denote the location of food stores, while dots show the location of the eateries. The size of the dot/square was based on the total score, with a smaller size indicating a lower score

include healthy main dishes/entrées, salad, fruits, and 100% juice on their menus. Comparatively, most hawker stalls primarily offered snacks and fast food, with only a few featuring healthy main dishes/entrées and non-fried vegetables. Among fast-food outlets, some offered healthy main dishes/entrées, salad, and whole-grain bread.

Similarly, NEMS-R scores data also exhibited a non-normal distribution. The median NEMS-R scores across different types of food eateries in Putrajaya indicated limited support for healthy eating (Table 4). Availability of healthy options was generally low, with 24-hour restaurants scoring highest (median: 5.0, IQR: 1.0), followed by restaurants and coffee shops (median: 3.0, IQR: 2.0), fast-food outlets (median: 3.0, IQR: 1.0), and hawker stalls (median: 1.0, IQR: 2.0). Bakeries scored 0.0, reflecting an absence of healthy food options. Median scores for facilitators of healthy eating were 0.0 across all outlet types, indicating minimal environmental support to encourage healthy food choices, while barriers were negligible, except in fast-food outlets (median: 1.0, IQR: 1.0). Correspondingly, median total scores were low, with 24-hour restaurants achieving the highest (median: 5.0, IQR: 1.0) and bakeries the lowest (0.0), highlighting a largely unsupportive food environment in Putrajaya.

Based on a 45% NEMS threshold, 15 food establishments (2.01%) were classified as representing a healthy food environment. There are 3 supermarkets, 7 grocery stores, and 5 restaurants. The map below illustrates the spatial distribution of food stores and eateries, according to their scores, in relation to residential areas in Putrajaya (Fig. 1).

Figure 1 illustrates the spatial distribution of food establishments, including both food stores and eateries, in Putrajaya. The point sizes in the spatial data represent NEMS-S and NEMS-R total scores, with smaller symbols indicating lower scores. Overall, food establishments were clustered in the northern area, at Precincts 1, 2, 9, 11, 14, 15, and 16, whereas they were more dispersed across the southern area, at Precincts 3, 4, 6, 17, and 18. Most food establishments are concentrated in shopping malls and commercial zones, with some located in office and residential areas. The density of both healthy and unhealthy food environments is then illustrated in the maps below (Fig. 2a and b).

Figure 2 further delineates the density of healthy and unhealthy food environments in Putrajaya. Dark blue areas in Fig. 2a indicate the highest density of healthy food environments, with gradually lighter shades representing lower densities. Contrarily, dark red areas in Fig. 2b depict the highest density of unhealthy food environments, with the shades becoming lighter as the density diminishes.

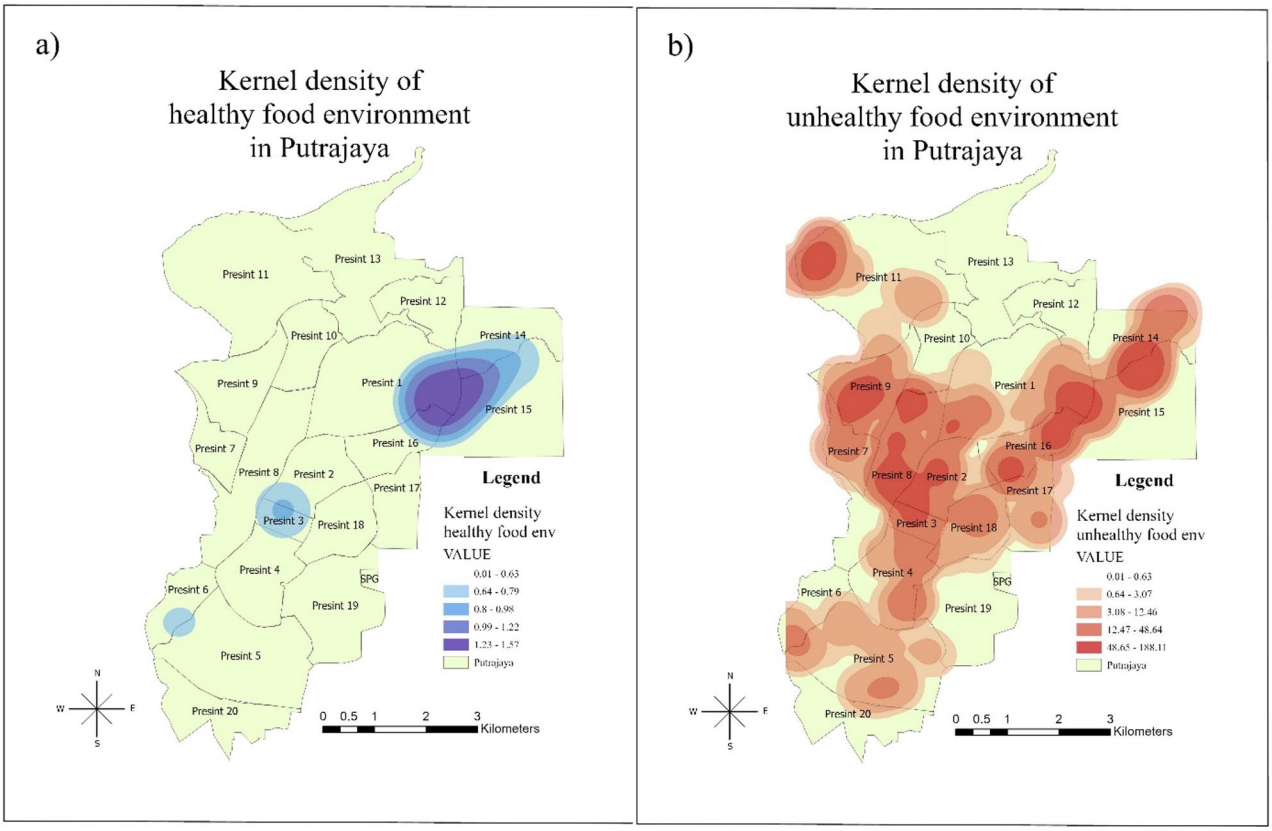

Fig. 2 Kernel density of (**a**) healthy and (**b**) unhealthy food environments in Putrajaya

Based on the map, the highest density of healthy food environments was observed between Precincts 1 and 15, in Precinct 3, and between Precincts 5 and 6. Unhealthy food environments were concentrated mainly across Precincts 1 and 16, 2, 3, 9, and 11, as well as between Precincts 14 and 15.

Furthermore, the figure also reveals substantial spatial overlap between clusters of healthy and unhealthy food environments. Areas identified as having higher densities of healthy food environments are not spatially distinct from areas with high densities of unhealthy environments. Instead, both environments co-locate within the same neighbourhoods. Importantly, within these overlapping clusters, unhealthy food environments are more widespread and spatially dominant, creating a setting where unhealthy food environments outweigh healthier alternatives.

Discussion

The availability of healthy food options is a central dimension of the food environment, as it reflects the structural conditions that enable or constrain healthy dietary choices within local food landscapes. Using the NEMS-S framework, supermarkets emerged as the most health-supportive food outlets, offering a broader selection of fresh produce and healthier processed items, such as canned and frozen foods, compared with other retailer types. This pattern is consistent with previous studies [34]. Typically located in urban centres, supermarkets cater to a broad consumer base and offer a substantial number of imported products, emphasising product quality, freshness, and perceived value [35, 36].

Nevertheless, in Southeast Asia, supermarkets are reshaping the urban food environment [11]. While they can enhance access to healthy options such as fresh produce, they simultaneously increase the availability and promotion of energy-dense, processed foods, snacks, instant meals, and soft drinks [11]. This dual effect may drive unhealthy dietary behaviours, particularly when healthier options are unaffordable or culturally less prioritized [37]. Rapid supermarket expansion is therefore a key driver of the region's broader nutrition transition, accelerating shifts toward more processed and convenience-oriented diets, with implications for rising overweight and obesity prevalence [38].

Another rapidly growing food outlet in Asia is the convenience store [39]. Contrary to earlier studies, convenience stores in this study demonstrated greater health-supportiveness than grocery stores [40, 41]. The rapid expansion of convenience store chains in Malaysia has enabled these outlets to diversify their product offerings to include ready-to-eat salads, healthier snacks, cut

fruits, and selected frozen meals [40, 42]. Strong supplier networks, centralised distribution systems, and economies of scale allow convenience stores to maintain a broader selection of healthy food options [35]. Furthermore, their 'on-the-go' business models align closely with the time constraints and consumption patterns of Malaysia's working population, for whom convenience is a dominant factor in food choice [35, 40, 43].

In contrast, grocery stores are predominantly small, family-operated outlets situated within neighbourhood areas, providing convenient access to essential food items in small quantities [35]. However, the higher costs associated with sourcing, storing, and preserving fresh produce limit their capacity to offer healthier options. As a result, these outlets tend to prioritise processed and packaged foods with longer shelf lives, reflecting both economic constraints and local food safety perceptions, where visibly substandard foods are often regarded as unsafe by the local consumers [44–46]. Consequently, although grocery stores enhance geographic food access, their limited availability of healthier items may unintentionally reinforce less nutritious dietary patterns among residents.

Fresh markets, while primarily specialising in fruits, vegetables, and fresh protein sources, recorded lower overall NEMS-R scores due to their limited availability of other nutrient-dense food groups such as dairy products, plant-based alternatives, and grains. Nevertheless, their role in safeguarding access to fresh produce remains critical in many Asian countries [12]. Their offerings often align closely with traditional Asian food cultures and consumption habits, and their neighbourhood-based locations enhance walkable access, supporting frequent food purchasing patterns that reduce reliance on ultra-processed or long-shelf-life foods [11]. By providing affordable fruits, vegetables, and protein sources, fresh markets continue to support core components of a balanced diet and play an important role in sustaining healthy eating practices and local food systems [47].

With regard to food eateries, the results demonstrate that the majority of eateries, including restaurants, 24-hour restaurants, coffee shops, and hawker stalls, predominantly offer nutritionally imbalanced meals, a pattern consistent with previous evidence on eating-out practices in urban Asian settings [48].

Compared with other types of eateries examined in this study, 24-hour restaurants, most of which are '*mamak*' restaurants, achieved the highest healthfulness scores, despite their common association with energy-dense and high-calorie menu offerings. This comparatively better performance may be explained by the presence of a wider range of menu options, including selected healthier choices such as non-fried vegetables, fruits, 100% fruit juice, and milk, which were largely absent in other dining outlets. Within the NEMS-R framework, these findings highlight the critical role of menu diversity and the provision of healthier alternatives in enhancing the health-supportiveness of food service environments. Importantly, these findings suggest that even food outlets not conventionally regarded as conducive to healthy eating can contribute positively to dietary quality when healthy options are made available, thereby highlighting potential entry points for targeted nutrition interventions and policy initiatives aimed at improving out-of-home food environments.

Lower NEMS-R scores were observed for the restaurant category, reflecting the limited availability of healthy menu options such as fruits, vegetables, whole grains, and low-fat alternatives. This is particularly concerning given Malaysia's strong dining-out culture [35]. Nevertheless, the availability of healthy menu options in restaurants is strongly shaped by economic considerations, as ingredients such as fresh produce, lean proteins, and whole grains generally incur higher costs. To remain price-competitive and sustain profitability, food operators relied on lower-cost ingredients, thereby limiting the inclusion of healthy options [49].

In addition, low consumer demand for healthy foods, particularly fruits and vegetables, may further discourage eateries from offering such items, prompting retailers to prioritise more popular but less nutritious menu choices. [2, 50, 51] This is consistent with studies showing that Malaysian diners place high importance on taste, freshness, appearance, and affordability when eating out [52–54]. However, meeting these preferences with healthier ingredients often entails higher costs, which may pose a barrier to healthy eating among individuals who frequently dine out. [55, 56]

From a food environment perspective, this scarcity of nutritious choices may limit consumers' ability to make healthful selections, particularly in contexts where restaurants constitute a major source of daily meals. This constraint is especially pronounced among Asian populations, for whom prior research has identified time constraints and demanding work schedules as key drivers of eating out or purchasing ready-to-eat meals [11]. Collectively, these findings highlight the persistent lack of healthier eating opportunities within conventional dining establishments and underscore the need for interventions that enhance the accessibility and appeal of nutrient-dense options.

Notably, evaluation of fast-food outlets indicated limited health-supportiveness, consistent with findings reported in other countries [57]. However, in contrast to patterns observed in many urban settings, fast-food outlets were not widely available in Putrajaya [58]. This suggests that the local obesogenic food environment is not primarily fast-food-centric. Rather, everyday eating practices at commonly frequented local eateries may play a more substantial role in shaping dietary habits here.

Finally, bakeries demonstrated minimal structural support for healthier food choices. None of the bakeries offered whole-grain alternatives, savoury pastries with poultry, fish, meat, or vegetable fillings, reduced-sugar or reduced-fat baked goods, or fruit-based options without added sugar that would qualify for positive scoring under the NEMS-R tool. As a result, all assessed bakeries scored zero across availability of healthier food options, indicating limited capacity within this outlet category to support healthier dietary choices.

Importantly, the findings indicate that although certain neighbourhoods demonstrate spatial concentrations of relatively healthier food outlets, these areas commonly overlap with or are immediately adjacent to clusters characterised by a high density of less healthy outlets. Consequently, even where healthier options are available, their potential benefit may be attenuated by the surrounding dominance of unhealthy food outlets, situating healthier access within a broader obesogenic food environment. Similar spatial patterns have been documented in previous studies conducted in Malaysia and other Southeast Asian settings. [59, 60] This spatial configuration aligns with the food swamp concept, where the relative density and salience of energy-dense food outlets may undermine the functional accessibility of healthier choices, thereby reinforcing obesogenic consumption patterns despite apparent outlet diversity.

Furthermore, while fast-food outlets and convenience stores are often assumed to epitomise food swamp environments, this assumption was not fully supported by the present findings. This observation is consistent with evidence from a review indicating that the nutritional quality of foods available in fast-food and convenience store settings is not necessarily inferior to that offered by other types of food outlets [61]. Taken together, these findings highlight the importance of moving beyond outlet typology alone when characterising food swamps, particularly in Southeast Asian urban contexts. Instead, food environment scoring and spatial clustering of the configuration of healthy and unhealthy food environments may be more informative indicators of obesogenic food environments. Such an approach better captures the complexity of urban food landscapes in the region and has important implications for the design of context-specific policy and environmental interventions.

Practical and policy implications

The consistently low NEMS-R scores across eateries in Putrajaya have clear practical implications for individuals seeking healthier meals when dining out. These scores reflect a restaurant environment characterised by limited availability of healthier options, minimal nutrition information, weak facilitators for healthy eating, and the presence of economic or structural barriers to healthier choices. For residents, this translates into constrained opportunities to make healthier food choices, as outlets rarely offer healthier substitutions such as fresh produce, baked chips, whole-grain bread, and low-fat milk, which appear to fall outside prevailing local dietary norms and are therefore not routinely incorporated into menus. Consequently, even motivated individuals may find it challenging to eat healthily, highlighting the influence of structural factors within the food environment on dietary behaviour.

Other than that, the low NEMS-R scores observed in Malaysian food establishments may reflect a lack of promotion or marketing of healthier menu options. Few restaurants, cafes, or hawker stalls actively highlight nutritious items or provide signage, menu labelling, or other cues to encourage healthful choices. This limited visibility of healthier options likely reduces consumer uptake and reinforces the dominance of energy-dense, less nutritious foods in the dining environment.

In this context, consumers must rely heavily on self-regulation and individual knowledge to seek healthier options, often in the absence of supportive cues from the food environment. Overall, the findings indicate that Putrajaya's eatery environment remains largely unsupportive of routine healthy eating, constraining healthier choices and weakening population-level dietary improvement efforts.

Moreover, the spatial clustering of food environments identified in this study carries important policy implications for promoting healthier eating in Putrajaya. High-density clusters of unhealthy food outlets, particularly in areas with limited access to fresh markets or health-supportive eateries, indicate neighbourhoods where residents may be disproportionately exposed to energy-dense, nutrient-poor foods.

A comprehensive strategy is therefore needed, encompassing expanded availability of nutrient-dense foods, removal of cost barriers, and increased public awareness. Currently, small retailers such as grocery stores account for the majority of food sales (56%), followed by supermarkets (43%), convenience stores (1%), and other outlets [18, 37]. Efforts should focus on increasing accessibility and affordability of nutritious foods, particularly fruits and vegetables, within grocery stores. Leveraging online delivery platforms can also enhance fresh produce distribution, while collaboration with retailers may improve engagement and coordination. Additionally, incorporating urban farming initiatives in retail and community spaces can provide a direct supply of fresh produce, encourage healthier eating habits, and foster stronger connections between consumers and local food systems.

For eateries, the focus should be on improving the nutritional quality of foods that contribute to discretionary calories, rather than eliminating the outlets themselves. Local traditional meals, which are often energy-dense, can

be reformulated to include more vegetables and fruits, lower-calorie options, and healthier cooking methods. Additional strategies include labelling healthier choices, implementing portion control, raising consumer awareness, promoting moderation, and integrating public health initiatives to increase demand for nutritious meals. Specifically, fast-food outlets can offer smaller portion sizes, vegetable-rich sides, and lower-sugar beverages, while bakeries can provide whole-grain alternatives, lower-sugar or lower-fat products, and protein- and fruit-based items. This approach balances public health objectives with the economic viability of food vendors.

At the policy level, incentives for outlets offering healthier foods, coupled with taxes on less nutritious items and a 20% price reduction for healthier options, could encourage better dietary choices [62]. Revenues generated from these taxes could be used to support small-scale local farmers through incentives, supply assistance, and cold storage facilities, while subsidies for manufacturers could improve the affordability of healthier foods, including bread, milk, and frozen products. Expanding the Ministry of Health's "Kafetaria Sihat" (Healthy Café) certification to more eateries can further promote healthier dining [63].

Furthermore, innovative marketing approaches, including food samples, recipe showcases, and healthy food festivals, can inspire individuals to incorporate more nutritious ingredients into their diets. Providing nutritional information on menus may also improve customers' perception of food quality [64]. As more consumers now acquire food information online, promotion of healthy eating should also leverage digital channels such as social media and podcasts.

Finally, given the long working hours typical in Malaysia, promoting work-life balance is essential to support healthier eating habits and home-cooked meals. Affordable, nutritious pre-made meals and increased availability of fruits and vegetables should be promoted as convenient alternatives to support healthy eating in urban lifestyles [65].

Limitations

This study examined food stores and eateries within Putrajaya. However, residents may not exclusively patronise outlets located within their immediate neighbourhoods, as food purchasing and dining behaviours often extend beyond administrative boundaries. In addition, brand-switching is common in highly competitive food retail markets, potentially influencing exposure patterns that were not captured in this locality-based assessment. Besides, certain informal food sources, such as farmers' markets and night markets, which may provide access to fresh produce, were also not included. Furthermore, the assessment tools did not account for portion sizes or the nutritional composition of meals in terms of caloric content, sugar, or salt, which may further influence dietary quality.

Moreover, although the NEMS-S and NEMS-R instruments provide a structured approach to assessing food environments, they were developed based on Western dietary norms and may not fully capture Malaysia's local nutrition culture and eating practices. Common staple foods, mixed dishes, and culturally specific preparation methods are insufficiently represented, potentially leading to misclassification of outlets offering culturally appropriate, healthier options. In contrast, items such as low-fat salad dressings, low-fat hot dogs, frozen dinners, and baked chips are not culturally salient within the local food landscape and are therefore infrequently stocked in food stores. Adapting these tools to align with Malaysian dietary guidelines and local consumption patterns would improve their contextual relevance, validity, and usefulness for informing policy and intervention strategies.

Furthermore, statistical uncertainty may have arisen from the relatively small sample sizes within certain outlet categories, such as the limited number of supermarkets, which may constrain the precision and stability of category-specific estimates. Besides, a snapshot of the food environment might not capture temporal variations in food availability, pricing, or menu offerings that may occur across different times of day or seasons. These factors should be considered when interpreting the findings, and future studies employing larger samples and longitudinal designs would strengthen inference and generalisability.

Lastly, healthfulness categorization in this study was adapted from existing cut-off proposed by Carins and Rundle-Thiele, which were developed in a different context and may not fully reflect the diversity and hybridity of food outlets in Malaysian and broader Southeast Asian settings, potentially influencing the categorisation and interpretation of food environment characteristics [33]. Future research could explore alternative scoring thresholds, weighting of subdomains, or context-specific adaptations through sensitivity or simulation analyses to better reflect local food environments.

Conclusion

The high density of an unhealthy food environment in Putrajaya is concerning, given the high obesity prevalence. A comprehensive strategic plan encompassing efforts to enhance the availability, accessibility, and affordability of nutritious food, besides advocating for good eating habits, is urgently needed. By promoting a supportive food environment, more individuals will embrace healthier dietary practices and lifestyles, both of which play a crucial role in disease prevention and population well-being.

Appendix

Table 5 Comparison between the NEMS Instruments and the Malaysian Dietary Guidelines

Items	Healthier alternative as defined by NEMS	Malaysian Dietary Guidelines
NEMS-S		
Milk	1% or 2% fat and skim, 0% fat	Direct alignment – Low-fat milk is recommended for weight management.
Ground beef	90% lean, 10% fat	Partial alignment – both promote healthier protein choices, though MDG does not specify protein types.
Hot dogs	≤ 9 g of fat per serving	MDG discouraged processed food. Item was retained to preserve NEMS-S scoring integrity but were interpreted cautiously as indicators of relative healthfulness.
Frozen dinners	Reduced fat: ≤ 9 g of fat per 11 oz serving	MDG discouraged frozen food. Item was retained to preserve NEMS-S scoring integrity but were interpreted cautiously as indicators of relative healthfulness.
Baked good	≤ 3 g of fat per serving	Direct alignment – both recognise lower-fat and whole-grain options.
Beverages	Diet soda with 0 kcal, 100% fruit juice with no added sugar	Direct alignment – MDG does not explicitly address diet soda or 100% fruit juice but recommends low-sugar or unsweetened drinks.
Bread	100% whole wheat bread	Direct alignment – Whole-grain bread is recommended in accordance with MDG.
Baked chips	≤ 3 g of fat per serving	Direct alignment – all tubers (like potato, sweet potato, and yam) are recommended for meals or as snacks in accordance with MDG.
Cereal	< 7 g of sugar per serving	Direct alignment – Whole-grain breakfast cereals are recommended in accordance with MDG.
NEMS-R		
Main dishes/ entrées	Menu items of ≤ 800 calories, ≤ 30% calories from fat, or ≤ 10% of calories from saturated fat.	Direct alignment – Consistent with MDG recommendation of 1,500–2,000 kcal per day.
Main dish salad	≤ 800 calories, ≤ 30% of calories from fat, or ≤ 10% of calories from saturated fat with low-fat or fat-free salad dressings - such as grilled/ broiled chicken breast salad, grilled fish or seafood salad, or turkey breast or hams salad.	Direct alignment – the salad concept is not explicitly in MDG, but vegetables are encouraged as part of daily meals.
Non-fried vegetables	Vegetables served raw, such as sliced tomato, steamed, grilled or chargrilled, baked, and pickled. And without added sugar.	Direct alignment – Consistent with MDG, promote vegetables with healthy preparation methods.
Fruits	Fresh fruit or canned fruit, fresh fruit compote, fresh fruit salad without dressing or on the side, fresh fruit with yogurt, fresh fruit plate with cottage cheese.	Direct alignment – Consistent with MDG, both promote fruit consumption – either fresh or canned fruits without flavourings, syrups, sugar, or salt.
Bread	100% wheat or whole grain bread	Direct alignment – Consistent with MDG, both promote whole grains over refined grains.
Chips	Baked chips (< 3 g fat/ serving)	Partial alignment – all tubers (like potato, sweet potato, and yam) are recommended for meals or as snacks in accordance with MDG.
Beverages	Low-calorie beverages such as 100% juice, 1% low-fat, skim, or non-fat milk	Direct alignment – Low-sugar drinks and low-fat milk are recommended in accordance with MDG.

Abbreviations

GPS	Global Positioning System
IQR	Interquartile Range
NHMS	National Health and Morbidity Survey
NCDs	Non-Communicable Diseases
NEMS-R	Nutrition Environment Measures Survey for Restaurants
NEMS-S	Nutrition Environment Measures Survey for Stores
TPB	Theory of Planned Behaviour

Acknowledgements
The authors would like to thank Universiti Putra Malaysia (UPM) for providing financial support for this study. We also extend our sincere appreciation to Perbadanan Putrajaya for their cooperation throughout the study.

Authors' contributions
All authors (NFMN, SAM, ZAM, HSM, and SAA) contributed to the conceptualization of the study. NFMN., SAM, and ZAM were involved in data acquisition. NFMN and SAM contributed to the design of methodology. NFMN, HSM, and SAA performed data analysis. SAM and ZAM secured funding for the study. All authors contributed to the writing and reviewing of the manuscript. All authors read and approved the final manuscript.

Funding
Not applicable.

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Faculty of Medicine and Health Science, Universiti Putra Malaysia, Serdang, Selangor 43400, Malaysia
[2]Kuala Kangsar District Health Office, Jalan Sultan Idris Shah, Kuala Kangsar, Perak 33000, Malaysia
[3]Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor 43400, Malaysia

Received: 6 May 2025 / Accepted: 5 March 2026
Published online: 14 April 2026

References

1. Turner C, Aggarwal A, Walls H, et al. Concepts and critical perspectives for food environment research: a global framework with implications for action in low-and middle-income countries. Glob Food Sect. 2018;18:93–101. https://doi.org/10.1016/j.gfs.2018.08.003.
2. Phulkerd S, Saptari AF, Borazon EQ et al. Policy briefs from the SEAOFE study. 2024. Available from: https://idl-bnc-idrc.dspacedirect.org/server/api/core/bitstreams/a81be32e-57e0-4ce8-b7d5-b02582fd8c71/content
3. Yamaguchi M, Praditsorn P, Purnamasari SD, et al. Measures of perceived neighborhood food environments and dietary habits: a systematic review of methods and associations. Nutrients. 2022;14(9):1788. https://doi.org/10.3390/nu14091788.
4. Ávila Arcos MA, Shamah Levy T, Del Monte Vega MY, et al. Convenience stores: an obesogenic promoter in a metropolitan area of northern Mexico? Front Nutr. 2024;11:1–10. https://doi.org/10.3389/fnut.2024.1331990.
5. Hughey SM, Kaczynski AT, Porter DE, et al. Development and testing of a multicomponent obesogenic built environment measure for youth using kernel density estimations. Health Place. 2019;56:174–83.
6. Namgung M, Gonzalez BE, Park S. The role of built environment on health of older adults in Korea: obesity and gender differences. Int J Environ Res Public Health. 2019;16(18):3486. https://doi.org/10.3390/ijerph16183486.
7. Qiu G, Liu X, Amiranti AY, et al. Geographic clustering and region-specific determinants of obesity in the Netherlands. Geospat Health. 2020;15(1):131–9. https://doi.org/10.4081/GH.2020.839.
8. Tian YQ, Troppy TS, Dripps W, et al. An exploratory spatial analysis to identify the appropriate scale and potential risk factors for understanding obesity distributions. Boston, USA: Department of Environmental, Earth and Ocean Sciences; 2018.
9. Zhao P, Kwan MP, Zhou S. The uncertain geographic context problem in the analysis of the relationships between obesity and the built environment in Guangzhou. Int J Enviro Res Public Health. 2018;15(2):1–20. https://doi.org/10.3390/ijerph15020308.
10. Khusun H. (2025). Compressed Modernization and Nutrition Transition: Implications for Diet Quality and Disease Prevalence in Southeast Asia. In Global Perspective on the Relationship between Dietary Habits and Health (pp. 1–9). https://doi.org/10.5772/intechopen.1010887
11. Gaupholm J, Papadopoulos A, Asif A, Dodd W, Little M. The influence of food environments on dietary behaviour and nutrition in Southeast Asia: A systematic scoping review. Nutr Health. 2023;29(2):231–53. https://doi.org/10.1177/02601060221112810.
12. Farrell P, Rachmi CN, Mulcahy G, Helble M, Thow AM. Food environment research is needed to improve nutrition and well-being in Asia and the Pacific. Public Health Nutr. 2021;24(14):4706–10. https://doi.org/10.1017/S1368980021002410X.
13. Tee ES, Voon SH. Combating obesity in Southeast Asia countries: current status and the way forward. Global Health J. 2024;8(3):147–51. https://doi.org/10.1016/j.glohj.2024.08.006.
14. Rousham E, Clark M, Latham M, Oo SP, Read S, Griffiths P, Blankenship J, Goudet S. Resilience and vulnerabilities of urban food environments in the Asia-Pacific region. Maternal Child Nutr. 2026;22(1). https://doi.org/10.1111/mcn.13513.
15. Phan TTL, O'Leary D, Mottiar Z. a Review of Street Food Management in Asia. Annals Gastronomy Tourism Stud. 2025;2(1):26–37. https://doi.org/10.69527/agats.2025.13.
16. Eng CW, Lim SC, Ngongo C, et al. Dietary practices, food purchasing, and perceptions about healthy food availability and affordability: a cross-sectional study of low-income Malaysian adults. BMC Public Health. 2022;22(1):1–9. https://doi.org/10.1186/s12889-022-12598-y.
17. Mazzola JJ, Jackson AT, Thiele A. Obesity in the workplace: a systematic review of barriers and facilitators to healthy lifestyles. Occup Health Sci. 2019;3(3):239–64. https://doi.org/10.1007/s41542-019-00046-0.
18. Al Mamun A, Hayat N, Zainol NRB. Healthy eating determinants: a study among malaysian young adults. Foods. 2020;9(8). https://doi.org/10.3390/foods9080974.
19. Agovino M, Crociata A, Sacco PL. Proximity effects in obesity rates in the US: A Spatial Markov Chains approach. Soc Sci Med. 2019;220:301–11. https://doi.org/10.1016/j.socscimed.2018.11.013.
20. Goh E, Von, Azam-Ali S, McCullough F, Roy Mitra S. The nutrition transition in Malaysia; Key drivers and recommendations for improved health outcomes. BMC Nutr. 2020;6(1):1–15. https://doi.org/10.1186/s40795-020-00348-5.
21. Institute for Public Health. (2024). Technical Report National Health and Morbidity Survey (NHMS) 2023: Non-Communicable Diseases and Healthcare Demand, Malaysia Produced.
22. Institute for Public Health. (2020). National Health and Morbidity Survey (NHMS) 2019: NCDs - Non-Communicable Diseases: Risk Factors and other Health Problems. In Institute for Public Health, National Institutes of Health (NIH), Ministry of Health Malaysia (Vol. 1). http://www.iku.gov.my/nhms-2019
23. Putrajaya Corporation. (2023). Putrajaya Climate Action Plan 2030.
24. Department of Statistics Malaysia. Statistik subnasional Parlimen dan Dun. W.P Putrajaya; 2022.
25. Carins JE, Rundle-Thiele S, Storr RJ. Appraisal of short and long versions of the Nutrition Environment Measures Survey (NEMS-S and NEMS-R) in Australia. Public Health Nutr. 2019;22(3):564–70. https://doi.org/10.1017/S1368980018002732.
26. Gislaine GM, Montserrat VR, Carrasco JA, Sáez KC, Bibiloni MdelM, Tur JA. Adaption and reliability of the Nutrition Environment Measures for stores (NEMS-S) instrument for use in urban areas of Chile. BMC Public Health. 2022;22(1):1–10. https://doi.org/10.1186/s12889-022-12651-w.
27. Rostami M, Babashahi M, Rezazadeh A, Omidvar N, Zamanpoor H. Development and validation of a food retail environment analysis protocol in Iran. Public Health Nutr. 2025;28(1). https://doi.org/10.1017/S1368980025100773.
28. Hill AB, Kaur R, Sundermeir SM, Kasprzak C, Winkler M, John S, Dombrowski RD, Bode B, Gittelsohn J. (2022). Refining the Nutrition Environment Measures Survey (NEMS) for Healthy Community Stores: Adaptations to Capture Alternative Food Retailers and Align with Dietary Guidelines. International Journal of Environmental Research and Public Health, 19(19).
29. Cai D. Nutrition Environmental Measures for Asian Restaurants and Asian Grocery Store [Master's Thesis]. University of Illinois.
30. Glanz K, Sallis JF, Saelens BE, et al. Nutrition Environment measures survey in stores (NEMS-S): development and evaluation. Am J Prev Med. 2007;32(4):282–9.
31. Saelens BE, Glanz K, Sallis JF, et al. Nutrition environment measures study in restaurants (NEMS-R): development and evaluation. Am J Prev Med. 2007;32(4):273–81. https://doi.org/10.1016/j.amepre.2006.12.022.
32. National Coordinating Committee on Food and Nutrition (NCCFN). Malaysian dietary guidelines. Malaysia: Ministry of Health Malaysia. 2020. Available from: https://hq.moh.gov.my/nutrition/wp-content/uploads/2024/03/latest-01.Buku-MDG-2020_12Mac2024.pdf
33. Carins J, Rundle-Thiele S. Fighting to eat healthfully: Measurements of the military food environment. J Social Mark. 2014;4(3):223–39. https://doi.org/10.1108/JSOCM-02-2014-0013.
34. Horta PM, de Souza PM, Freitas J. Food availability and advertising within food outlets around primary healthcare services in Brazil. J Nutrit Sci. 2020;9:1–5. https://doi.org/10.1017/jns.2020.45.
35. Lau TC. Regulations, opportunities, and key trends of functional foods in Malaysia. Nutraceutical and functional food regulations in the United States and around the world. Academic; 2019. pp. 561–73.
36. Ing P, Osman Z, Tze-Yin L. Marketing mix and STP strategies: an exploratory study into grocery retailers in Malaysia. Asian J Entrep. 2020;1(4):129–43.
37. Ambikapathi R, Schneider KR, Davis B, Herrero M, Winters P, Fanzo JC. Global food systems transitions have enabled affordable diets but had less

favourable outcomes for nutrition, environmental health, inclusion and equity. Nat Food. 2022;3(9):764–79. https://doi.org/10.1038/s43016-022-00588-7.
38. Baker P, Friel S. Food systems transformations, ultra-processed food markets and the nutrition transition in Asia. Globalization Health. 2016;12(1). https://doi.org/10.1186/s12992-016-0223-3.
39. Phulkerd S, Thongcharoenchupong N, Dickie S, Machado P, Woods J, Mo-Suwan L, Prasertsom P, Ungchusak C, Khitdee C, Lawrence M. Profiling ultra-processed foods in Thailand: sales trend, consumer expenditure and nutritional quality. Globalization Health. 2023;19(1):1–13. https://doi.org/10.1186/s12992-023-00966-1.
40. da Costa AP. New Trends in Convenience Stores [Master's thesis on the internet]. [Portugal]: ISCTE-Instituto Universitario de Lisboa.
41. McCormack LA, Meendering JR, Burdette L, et al. Quantifying the food and physical activity environments in rural, high obesity communities. Int J Environ Res Public Health. 2021;18(24):13344. https://doi.org/10.3390/ijerph182413344.
42. Goossensen M, Garcia X, Garcia-Sierra M, et al. The role of convenience stores in healthy food environments: the case of Barcelona (Spain). Cities. 2023;133:104118. https://doi.org/10.1016/j.cities.2022.104118.
43. Haboush-Deloye AL, Knight MA, Bungum N, Spendlove S. Healthy foods in convenience stores: benefits, barriers, and best practices. Health Promot Pract. 2023;24(1):S108–11. https://doi.org/10.1177/15248399221147878.
44. Sugiharto A, Deniar SM. Retail policy dilemma and the existence of modern retail in Indonesia and Malaysia. Jurnal Studi Sosial dan Politik. 2021;5(1):9–21.
45. Pinard CA, Fricke HE, Smith TM, et al. The future of the small rural grocery store: a qualitative exploration. Am J Health Behav. 2016;40(6):749–60. https://doi.org/10.5993/AJHB.40.6.7.
46. Lim SM, Law H, Lee SS. Consumers' quality perception and acceptance of suboptimal food: an online survey in Selangor and Kuala Lumpur. Malaysia Foods. 2023;12(15):2824. https://doi.org/10.3390/foods12152824.
47. Chaput S, Mercille G, Drouin L, et al. Promoting access to fresh fruits and vegetables through a local market intervention at a subway station. Public Health Nutr. 2018;21(17):3258–70. https://doi.org/10.1017/S1368980018001921.
48. Arifen ZN, Shahar S, Trieu K, et al. Individual and total sugar contents of street foods in Malaysia–Should we be concerned? Food Chem. 2024;450:139288. https://doi.org/10.1016/j.foodchem.2024.139288.
49. Rosin M, Mackay S, Gerritsen S, et al. Barriers and facilitators to implementation of healthy food and drink policies in public sector workplaces: a systematic literature review. Nutr Rev. 2024;82(4):503–35. https://doi.org/10.1093/nutrit/nuad062.
50. Zin SH, Rosnan SB, Shafee CT. A study on the fruits and vegetables consumption patterns among adults in Malaysia. Int J Acad Res Bus Soc Sci. 2022;12(11):1550–68.
51. Rohin MA, Hadi NA, Sariff S et al. Knowledge, attitude and practice on vegetables intake among adolescents in rural Terengganu, Malaysia. Malays J Med Health Sci 202;17(2):98–105.
52. Othman M, Kandasamy T, Bakar AZ, et al. Identifying success factors of Mamak restaurants in Malaysia. Int J Eng Technol. 2018;7(325):150–5. https://doi.org/10.14419/ijet.v7i3.25.17534.
53. Bakar AZ, Ganesan L, Othman M, et al. Where to eat: Exploring silver consumer restaurant dining choice in Malaysia. Pertanika J Soc Sci Humanit. 2020;28(4):3297–317.
54. Jamaludin A, Albattat A, Prasetyanto H et al. Customer purchasing intention towards healthy selection of menus in fast food restaurant. TOURMAN 2021–4th International Scientific Conference; 2021 May 21–23; Greece.
55. Jie TH, Bakar AZ. Consumer demand for healthy food: evidence from a regional context in Malaysia. Int J Acad Res Bus Soc Sci. 2023;13(4):469–80. https://doi.org/10.6007/ijarbss/v13-i4/16872.
56. Alwi MN, Hanafi WN, Ali IM, Baharuddin SS. Determinants of Eating behaviours: a study of college students in Malaysia. Glob Bus Manag Res. 2021;13(4):670–80.
57. Rodríguez-Ramírez S, Martinez-Tapia B, González-Castell D, Cuevas-Nasu L, Shamah-Levy T. Westernized and diverse dietary patterns are associated with overweight-obesity and abdominal obesity in Mexican adult men. Front Nutr. 2022;9(June):1–10. https://doi.org/10.3389/fnut.2022.891609.
58. García B, Bueno B, Horn AL, Bell BM, Bahrami M, Bozkaya B, Pentland A, de la Haye K, Moro E. Effect of mobile food environments on fast food visits. Nat Commun. 2024;15(1):1–11. https://doi.org/10.1038/s41467-024-46425-2.
59. Norddin N, Che'Ya NN, Mohidem NA, Zalbahar N. Association between neighbourhood food environment and dietary quality among adolescents in Kuala Lumpur. Malaysia Heliyon. 2025;11(3):e42247. https://doi.org/10.1016/j.heliyon.2025.e42247.
60. Li B, Choi Y, Wong S, Chng S, Cheah L. Hungry after dark: spatio-temporal analysis of food accessibility in a dense city. Int J Urban Sci. 2025;5934:1–26. https://doi.org/10.1080/12265934.2025.2591306.
61. Ares G, Turra S, Bonilla L, Costa M, Verdier S, Brunet G, Alcaire F, Curutchet MR, Vidal L. WEIRD and non-consensual food deserts and swamps: A scoping review of operational definitions. Health Place. 2024;89. https://doi.org/10.1016/j.healthplace.2024.103315.
62. Huangfu P, Pearson F, Abu-Hijleh FM, et al. Impact of price reductions, subsidies, or financial incentives on healthy food purchases and consumption: a systematic review and meta-analysis. Lancet Planet Health. 2024;8(3):e197–212. https://doi.org/10.1016/S2542-5196(24)00004-4.
63. Abdul Rahman AR, Zahari MS, Tamby Chik C. Kafeteria Sihat' initiative in Malaysian public hospitals: Do customers accept it? J Foodserv Bus Res. 2020;23(1):57–77.
64. Zafar MZ, Hashim NA, Halim F. Nutritional menu of eatery make consumer able to select healthy food. Pertanika J Soc Sci Humanit. 2019;27(4):2351–65.
65. Leong TP, Mariadass AM. Factors affecting young adults' purchase intention of green food products in Malaysia. J Tour Hosp Culin Arts. 2019;11(2):20–45.

Publisher's note