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Evaluating the water footprint and nutritional quality of takeaway dishes for selected large cities in China

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Abstract

The takeaway food and delivery market is developing rapidly in China, raising concerns about the impacts of takeaway dishes on both health and the environment. Here, we compare the environmental impact and nutritional performance of 32 popular takeaway dishes, which stem from the top 10 best-selling takeaway dishes in 10 large cities in China. We select water footprint and water scarcity footprint indicators to represent the environmental impact, and the Food Compass Score to measure nutritional quality. Our results show that 24 out of 32 takeaway dishes contains meat, which has a higher water footprint. The inhabitants of water stressed Chinese cities, mainly located in northern China, tend to favor meat dishes, resulting in a larger water scarcity footprint. The results also highlight the lower nutrition quality of the majority of takeaway dishes, with only three takeaway dishes meeting acceptable environmental and nutritional standards. Our study highlights the importance of analyzing dishes rather than individual foods, which can facilitate sustainable dietary choices for consumers.

Keywords

Takeaway dishes; Water footprint; Nutrition quality; Food Compass Score.

1. Introduction

China's rapid urbanization has improved the living standards of many of its citizens, it also affects urban food consumption patterns and eating behaviors (Zhai et al., 2014; Hovhannisyan and Devadoss, 2018). Recently, as a result of the so-called 'gig-economy', there has been a large increase in the ordering of takeaway food for delivery and consumption off-premises i.e. at home or in the workplace (Meituan Research Institute, 2021). Indeed, several well-known e-commerce businesses have sprung up, making use of smartphone and computer technology to streamline the ordering, payment and delivery process (Jiang et al, 2020; Li et al., 2020; Song et al., 2018). By 2022, e-commerce based use across all takeaway platforms in China had reached 520 million users (CNNIC, 2023), and this number is projected to grow to 870 million by 2027 (Statista, 2023). The large urban customer base has triggered a boom in takeaway platforms, which has experienced steady growth between 2011 and 2022, with a notable surge during the COVID-19 pandemic (Meituan Research Institute and China Hospitality Association, 2019; Guo et al., 2023). Between 2020 and 2022, the per capita expenditure on online takeaway food increased from 17% to 25% of total food and beverages expenditure in China (SIC, 2023).

Food consumption provides essential nutrients to humans, but some dietary choices may entail adverse impacts to both health and the environment (Springmann et al., 2018; Crippa et al., 2021; Xue et al., 2021). Researchers have evaluated the sustainability of specific ingredients and products in foods, such as meat and seafood (Mekonnen and Hoekstra, 2012; Ibidhi et al., 2017; Clark et al., 2022; Zhang et al., 2022; Zhang et al., 2022). Studies have also examined the varying effects of different dietary patterns on both the environment and health (Aboussaleh et al., 2017; Tuninetti et al., 2022). While these studies suggest several healthy food ingredients or dietary patterns, such as Mediterranean and vegetarian diets (Chapa et al.,2020), they do not relate their guidance to specific dishes. Specifically, consumers are lack of understanding of nutritional levels and the environmental impacts resulting from the combination of food ingredients i.e., dishes. As a result, consumers may face difficulties in choosing sustainable and healthy diets when ordering food from restaurants or takeaway platforms. While informing the sustainability of specific dishes would be more acceptable and relevant to consumers, studies that connect these dishes with their environmental impacts and nutritional benefits are lacking.

There has been a growing concern about the nutritional aspects of takeaway food in recent years. Researchers have questioned the nutritional quality of takeaway dishes (Glynn Davies et al., 2014; Wang et al., 2021). Increased frequency of consuming takeaway dishes is a contributing factor to obesity (Smith et al., 2009), heart disease and diabetes (Donin et al., 2018). Investigating the nutrient content of different takeaway options is important for public health policymaking.

From the environmental perspective, researchers have focused on single-use, disposable takeaway food packaging and containers which may harm the environment (Gallego-Schmid et al., 2019; Su et al., 2020; Zhou et al., 2020). Studies have also looked at air pollution and carbon emissions associated with the takeaway food industry (Chu et al., 2021; Xie et al., 2021). Water is one of the essential resources for food production (Uhlenbrook et al., 2022), accounting for roughly 63% of total freshwater use in China in 2022 (Ministry of Water Resources of the People's Republic of China, 2023). However, as far as we know, no research has quantified water consumption for specific takeaway dishes.

With the world's largest customer base for online food delivery services (Statista, 2023), China is now considering the environmental and nutritional aspects of takeaway dishes which may influence consumer choice (Xie et al., 2021; Zhao et al., 2021). However, as far as we know, the joint evaluation of nutritional and environmental impacts of takeaway dishes is still absent. Water scarcity is a great concern for many cities in the world due to increasing populations and economic growth (Zhang et al., 2020). The water footprint is a widely used indicator to show human impact on water resources (Mekonnen and Hoekstra, 2011; Zhao et al., 2017). However, the water scarcity derived from human impact is not only determined by the amount of the water footprint but also the water endowment (Liao et al., 2020; Zhao et al., 2021). Hence, we choose both the water footprint and the water scarcity footprint as the environmental indicators, and quantify these indicators for the top 10 best-selling takeaway dishes in 10 large cities in China. The water footprint of a product is defined as the total volume of freshwater consumed in the process of producing the product (Mekonnen and Hoekstra, 2011). The water scarcity footprint can be defined as the water stress-weighted water footprint, which enables the comparisons between different regions or products in terms of their contribution to water scarcity (Ridoutt and Pfister, 2010). The water footprint per calorie and protein unit of the selected takeaway dishes is also reported to link the water footprint with nutritional value. We further combine the water footprint with the Food Compass Score (FCS) indicator (Mozaffarian et al., 2021) to examine both environmental and nutritional aspects of the selected takeaway dishes. FCS is a novel nutrient profiling system in assessing the healthfulness of food, which incorporates a wide range of food characteristics. It provides quantitative algorithms to score the nutritional composition of food from 54 attributes across 9 health-relevant domains. Our findings can help consumers make choices through reasonable references, thereby helping to benefit the environment and health of urban dwellers. Our study therefore makes a valuable contribution to promoting sustainable and healthier dietary practices for consumption of takeaway foods in China.

2. Methodology and data

2.1 The water footprint of takeaway dishes

We use a bottom-up approach to quantify the water footprint of different takeaway dishes (Mekonnen and Hoekstra, 2011). The water footprint of a product is the total volume of freshwater used to produce the product through the production chain. It includes three components: green water, blue water, and grey water. The green water footprint refers to the consumption of rainwater stored in soils. The blue water footprint refers to the consumption of surface water and groundwater, and the grey water footprint is the freshwater volume needed to assimilate the pollutant load based on existing water quality standards (Hoekstra et al., 2011). The water footprint of one takeaway dish can therefore be quantified as:

$$WF_d = \sum_{i=1}^{n} CQ_i * VW_i \tag{1}$$

Where WF_d is the blue, green, and grey water footprint of one takeaway dish (unit: m^3); VW_i is virtual water content of ingredient i in the takeaway dish (m^3/g); CQ_i is the quantity required in the dish for ingredient i (g); and n represents the quantity of variety of ingredients in the dish. To qualify the effect caused by takeaway dish consumption on local water resources, we have assumed that the water footprints of all the ingredients of a dish are locally derived.

Further, depending on the nature of ingredient i, VW_i would be either virtual water content of an animal product VW_a or virtual water content of a crop product VW_c.

$$VW_a = VW_f + VW_d + VW_s \tag{2}$$

VW_a is the total virtual water content of animal products in its life cycle (m^3/g); VW_f is the virtual water content in feeding the animals (m^3/g); VW_d represents virtual water content by animals drinking (m^3/g); VW_s is the virtual water content in rearing the animals (m^3/g) i.e., including disinfection, washing, environmental control and other work.

$$VW_c = VW_{c1} + VW_{c2} \tag{3}$$

$$VW_{c1} = \frac{CWU}{Y} \tag{4}$$

$$CWU = 10 * \sum_{d=1}^{lgp} ET_a \tag{5}$$

$$ET_a = K_c * K_s * ET_0 \tag{6}$$

$$VW_{c2} = \frac{(\alpha * AR)/(c_{max} - c_{nat})}{Y} \tag{7}$$

VW_c is the total virtual water content of crop products in its life cycle (m^3/g), while VW_{c1} is the virtual green and blue water content per unit of crop products (m^3/g); Y represents yield per hectare (g/hm^2); and CWU is the total green and blue virtual water content in crop water usage (m^3/hm^2). ET_a is the adjusted evapotranspiration of a crop throughout its life cycle (mm/d); 10 is the factor used to convert water depths (mm) into the volumes of water per land surface (m^3/hm^2); lgp is the length of crop growing period (d); K_c is the crop coefficient; K_s is the dimensionless transpiration reduction factor depending on available soil water; ET_0 is the evapotranspiration of a reference crop during its life cycle (mm/d). In equation (7), VW_{c2} is the virtual grey water content of crop product (m^3/g); AR is the quantity of fertilizer applied per hectare (g/hm^2); α is the leaching rate; c_{max} is the maximum permissible concentration of pollutant run-off (g/m^3); and c_{nat} is the background concentration of pollutants (g/m^3).

Due to data limitations, we only consider the water footprint of the top 10 best-selling takeaway dishes in different cities in China. We calculate the average water footprint per 100g of the top 10 best-selling takeaway dishes in each city based on a sales ranking index:

$$\overline{WF_s} = \frac{\sum_{s=1}^{n} WF_s * k_s}{\sum_{s=1}^{n} k_s} \tag{8}$$

$$WF_s = \frac{WF_d}{\sum_{i=1}^{n} CQ_i} * 100 \tag{9}$$

Where $\overline{WF_s}$ represents the average water footprint per 100g of the top 10 best-selling takeaway dishes in each city(m^3/100g/capita); k_s is the sales ranking index of takeaway dish d (Table S1), which represents the preference of dishes by city dwellers. Based on the sales order of takeaway dishes in a particular city, the dish with the highest sales in each city is assigned an index of 100. This serves as a reference point for determining the sales ranking of dishes within the city. The indexes of the remaining nine dishes are then calculated proportionately based on their sales compared to the best-selling dish in that particular city. WF_s is the standardized WF_d, which is the water footprint per 100g of takeaway dishes (m^3/100g). The aim of this standardization is to let the water footprint of different takeaway dishes comparable under same mass. CQ_i is the quantity of ingredient i (g) in the dish.

2.2 The water scarcity footprint of takeaway dishes

Due to different water resource endowment between cities, the water footprint indicator alone cannot reflect the impact of takeaway dish consumption on the water stress of cities. Hence, we calculate the water scarcity footprint of takeaway dishes using the Available Water Remaining Characterization Factors (Aware-CFs) approach: (Boulay et al., 2017; Boulay and Lenoir, 2020). This method quantifies the potential of remaining available water in the region after meeting the demand of humans and aquatic ecosystems.

$$AMD_i = \frac{Availability - HWC - EWR}{Area} \tag{10}$$

$$STe_i = \frac{1}{AMD_i} \tag{11}$$

$$CF_{AWARE} = \frac{STe_i}{STe_{world\ avg}} = \frac{AMD_{world\ avg}}{AMD_i}\ for\ demand < Availability \tag{12}$$

$$CF_{AWARE} = Max = 100, for\ demand \geq Availabity\ or\ AMD_i \tag{13}$$

$$CF_{AWARE} = Min = 0.1, for\ AMD_i > 10 * AMD_{world\ avg} \tag{14}$$

Where AMD_i is water availability minus demand per area; it calculates the availability of water resources after deducting human water consumption (HWC) and local ecosystems water requirement (EWR). STe_i (equation (10)) is the reciprocal of severe water scarcity; CF_{AWARE} is the water scarcity characterization factor, it compares world average $AMD_{world\ avg}$ and AMD_i in area i. CF_{AWARE} varies from 0.1 to 100. If AMD_i exceeds $AMD_{world\ avg}$ 10 times, CF_{AWARE} would be a minimum of 0.1 representing the most abundant potential of water resource. If AMD_i is negative or less than 0.01 of $AMD_{world\ avg}$, CF_{AWARE} would equal its' maximum of 100 showing the most serious water scarcity.

The average water scarcity footprint of takeaway dishes in 10 cities per 100g (m^3/100g/capita) can therefore be expressed as:

$$\overline{WSF} = \overline{WF_s} * CF_{AWARE} \quad (15)$$

Where $\overline{WSF}$ is the average water scarcity footprint of takeaway dishes (m^3/100g/capita) in the area.

2.3 The nutritional profiling of takeaway dishes

The Food Compass Score (FCS) method (Mozaffarian et al., 2021) was used to calculate the nutrient content of 10 most popular takeaway dishes. The scoring principles include nine domains of the food compass and 54 attributes of all the domains. The nine domains include nutrient ratios, vitamins, minerals, food ingredients, additives, processing, specific lipids, fiber and protein, and phytochemicals. The score principles are as follows: 0 to 10 (beneficial attributes), -10 to 0 (harmful attributes). Each domain score is calculated according to the attribute scores in that field. To calculate the final FCS, all the domains are summed and three of the domains are given a half weight (specific lipids, fiber and protein, and phytochemicals). Under this principle, the score was scaled to range from 1 (least healthy) to 100 (most healthy). On this basis, food with FCS≥70 is to be encouraged, with FCS ranging from 31 to 69 only to be consumed in moderation. Foods with FCS <30 are recommended to be minimized.

2.4 Data

We collected the data for the top 10 best-selling takeaway dishes for each selected city in China (Table S1). The top 10 best-selling takeaway dishes in different cities have overlaps. For example, all the 10 selected cities have spicy hotpot in their top list. Overall, there are 32 takeaway dishes in the list of the top 10 best-selling takeaway dishes in all the 10 cities. These cities are the first-tier cities with high order demand in the takeaway food market. The sales ranking index of each takeaway meal is released officially by the takeaway platform (NetEase Data Blog, 2019). The detailed ingredients and usage quantity are referenced according to the Chinese Cookbook (Liu, 2014). The water footprint of ingredients in takeaway dishes is derived from Mekonnen and Hoekstra (2011, 2012). These studies contain the average water footprint of crop products in cities, and the average water footprint of animal products in China. Nutritional profiling was used in evaluating the quality of nutrients in dishes. The nutrient profiling of takeaway products is measured by FCS, including 54 attributes across 9 domains (Mozaffarian et al., 2021). Limited by data availability, we only considered 51 attributes, excluding iodine, trans-fats, and alpha-linolenic acid. These attributes will not significantly affect our results due to their low content in the takeaway dishes studied. The data of 51 attributes are derived from the 2019-2020 Food and Nutrient Database for Dietary Studies (FNDDS) (USDA, 2022) and USDA National Nutrient Database for Standard Reference, Legacy (SR-Legacy) (USDA, 2018). We chose these data sources instead of other available nutritional databases because the nutrient and food components in FNDDS and SR-Legacy almost covered the extent of this study. The data on total carotenoids is from the USDA Database for the Flavonoid Content of Selected Foods (USDA, 2018). The nutritional content of takeaway dishes refers only to the edible portion. Due to the difference in dietary food between the USA and China, several components were not identified in the FNDDS, such as donkey meat, potato starch, and fungus. These data were instead obtained from the China Food Composition Database (NINH, 2018; NINH, 2019).

3. RESULTS

3.1 The water footprint of different takeaway dishes

There are 32 takeaway dishes in the top 10 best-selling ranking lists, highlighting diverse taste, often locally clustered preferences (Table S1). People in all selected cities favor takeaway dishes containing meat ingredients (24 dishes) over dishes without meat. There are 22 out of 24 meat dishes containing pork and chicken ingredients, which dominate the meat dishes (Table S2). Three dishes include beef as an ingredient, and two dishes contain mutton. Donkey meat and river snails are each present in only one dish. Only eight dishes contain ingredients without meat. These dishes include staple foods such as congee, durian pizza, and rice noodle soup; and vegetarian dishes such as hot and sour shredded potato and stir-fired shredded cabbage, etc.

The water footprint of the 32 takeaway dishes is varied, ranging from 12.88 L/100g to 2066.42 L/100g (Figure 1). Most of the meat dishes have a higher water footprint, compared to vegetarian dishes. Amongst the 32 takeaway dishes, donkey burger and instant spicy steam pot have the highest water footprint (2066.42 L/100g and 583.85 L/100g, respectively), whilst rice congee and millet congee have the lowest water footprint (12.88 L/100g and 17.91 L/100g, respectively). The water footprint of non-meat takeaway dishes varies from 12.88 L/100g to 186.67 L/100g, except for durian pizza (346.95 L/100g). Cheese, being a dairy product, is a major ingredient in durian pizza, resulting in a higher water footprint compared to most meat-free dishes. The magnitude of the water footprint associated with meat dishes is primarily influenced by the proportion of meat in the recipe. Dishes containing a lower proportion of meat have a lower water footprint, for example mapo tofu contains only a small portion of minced pork. In addition, recipes that include meat typically incorporate a greater variety of ingredients compared to meat-free dishes. In contrast to meat dishes, most meat-free dishes are characterized by simpler and lighter ingredients. Overall, meat dishes have a heavier flavor than meat-free dishes.

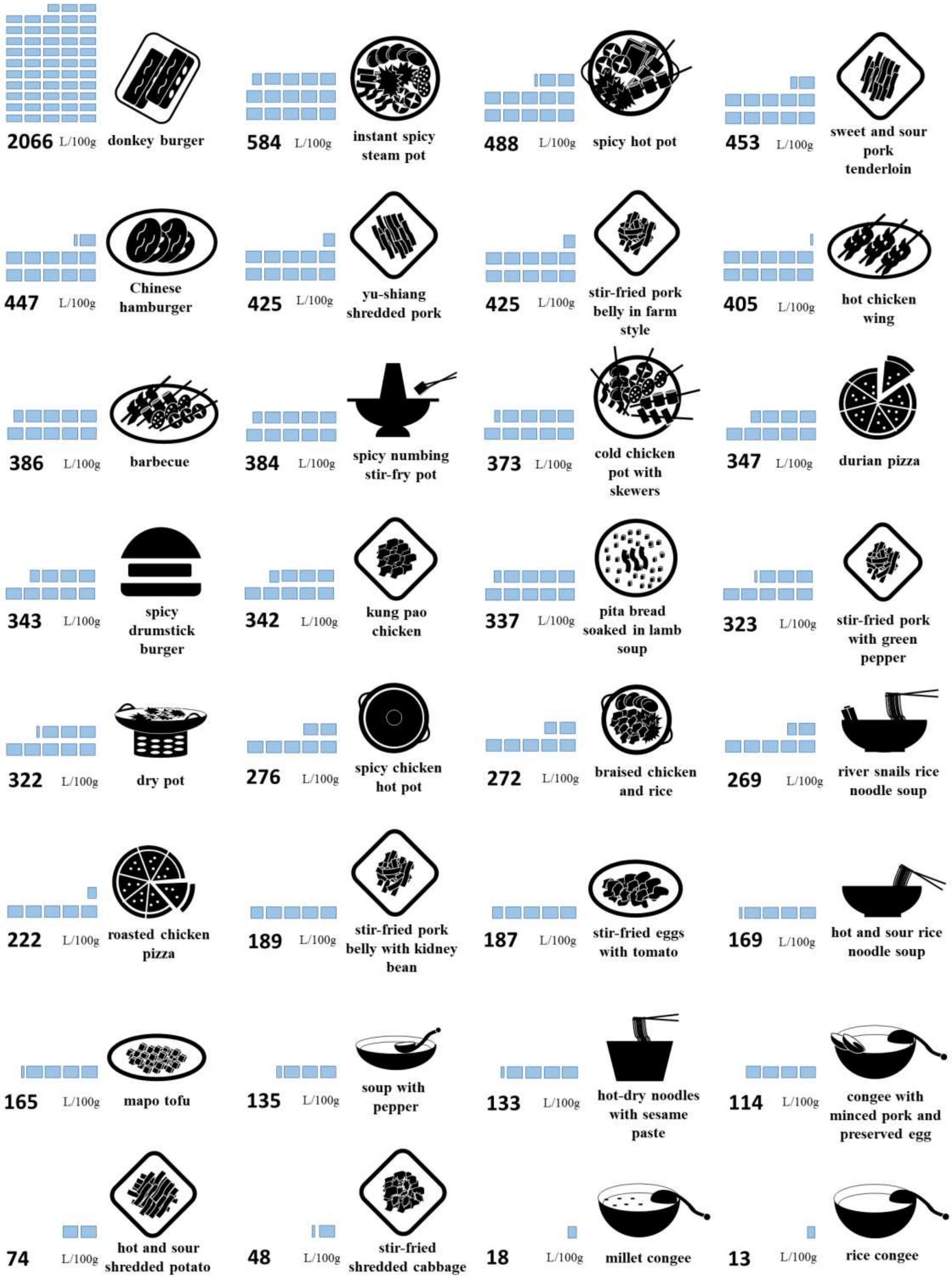

Figure 1. Water footprint for different takeaway dishes in China.

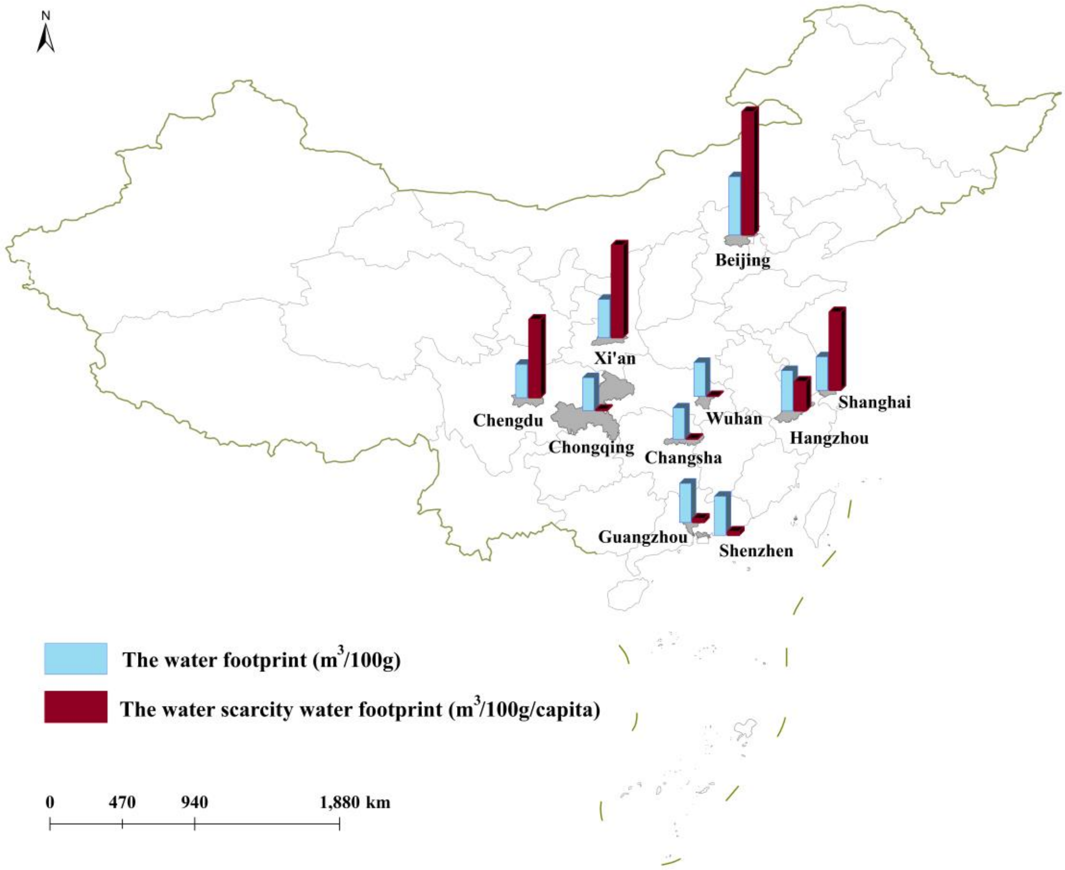

Figure 2. The average water footprint and water scarcity footprint of takeaway dishes in the 10 selected cities.

The average per capita water footprint of the top 10 best-selling takeaway dishes varies among cities, ranging from 0.27 m^3/100g/capita (Changsha) to 0.51 m^3/100g/capita (Beijing) (Figure 2). Such differences are mainly due to diverse consumer preferences available on takeaway platforms in different cities. For example, residents in Changsha and Beijing have six different dishes in the top 10 best-selling takeaway dishes (Table S1). The primary contributor to the highest water footprint per capita in Beijing is donkey burger. However, this type of dish is popular in northern China, but less popular with residents in other southern cities such as Changsha. Similarly, Changsha residents show a preference for certain local dishes, such as rice noodle soup with river snail which is a preferred option in southern China, differing from those favored in Beijing. In addition, the water footprint of the same ingredients among different cities varies, resulting in different water footprints amongst identical takeaway dishes.

The water scarcity footprint enables the inter-city comparisons to show the extent of how takeaway consumption contributes to water scarcity (Figure 2). Under the assumption of self-sufficiency, cities having a higher water scarcity footprint suggests they have both higher water consumption demand and water stress. Compared to water footprint, the disparity in water scarcity footprint is more pronounced between cities. The city with the highest per capita water scarcity footprint is Beijing (48.86 m^3/100g/capita), followed by Xi'an, Shanghai, and Hangzhou. Wuhan has the lowest per capita water scarcity footprint (0.07 m^3/100g/capita). Local water stress primarily contributes to the water scarcity footprint (Table S5). Considering the spatial distribution of water resources, southern China typically possesses more abundant water resources compared to northern China. Located in northern China, Beijing and Xi'an experience the most severe water stress, and exhibit the largest water scarcity footprint among the 10 studied cities. The remaining eight cities are situated in southern China, with Shanghai and Hangzhou exhibiting higher water stress than the other southern cities, and having the higher water scarcity footprints. Shanghai and Hangzhou are economically developed cities with large populations, resulting in the higher water demand and water stress. In contrast, the other six southern cities exhibit lower water stress and have relatively lower water scarcity footprints.

3.2 The water footprint per calorie and protein unit

From both environmental and dietary perspectives, consumers may choose to minimize their water footprint while meeting their nutritional needs. We selected two indicators to link water footprint with nutritional value, which are the water footprint per calorie and protein unit. The top 10 takeaway dishes for water footprint per calorie unit range from 1.73 L/kcal to 7.41 L/kcal (Figure 3). The dish with the highest water footprint per calorie unit is donkey burger, followed by cold chicken pot with skewers, spicy chicken hot pot, sweet and sour pork tenderloin, and instant spicy steam pot. These dishes are characterized by the inclusion of a relatively higher quantity of meat. Compared with other dishes, choosing these dishes would require more water footprint to meet identical calorie requirements.

The top 10 best-selling takeaway dishes with the highest water footprint per calorie unit exhibit varying distribution patterns amongst the different study cities. We find Shanghai, Shenzhen, Hangzhou, Chengdu, and Wuhan have six dishes, while Beijing, Guangzhou, Chongqing, and Changsha have five dishes, and Xi’an has three dishes. For cities with these dishes, it is advisable to substitute them with other options that have a lower water footprint per calorie unit.

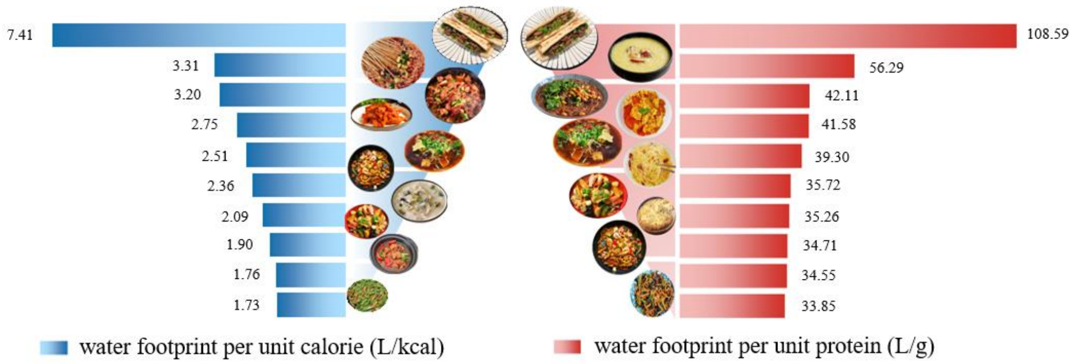

Figure 3. The water footprint per calorie and protein unit for the top 10 best-selling takeaway dishes in China.

The water footprint per protein unit for the top 10 best-selling dishes range from 33.85 L/g (yu-shiang shredded pork) to 108.59 L/g (donkey burger). Half of these dishes include meat ingredients, while the other half do not (Figure 3). Donkey burger, millet congee, hot and sour rice noodle soup, stir-fried egg with tomato, and instant spicy steam pot are the top five dishes with the highest water footprint per protein unit. Certain meat-free dishes including millet congee, hot and sour rice noodle soup, stir-fried egg with tomato, and hot and sour shredded potato display a lower water footprint, but they also possess a higher water footprint per protein unit due to their lower protein content.

Varying distributions of the top 10 dishes possessing the highest water footprint per unit of protein are presented by the study cities. Beijing, Shanghai, and Hangzhou have the highest volume of dishes in the top 10 list (five dishes). Guangzhou, Chongqing, Wuhan, and Xi’an follow closely with four dishes each, while the remaining three cities feature three dishes.

Four dishes are featured in the top 10 for both water footprint per calorie and protein unit, including donkey burger, instant spicy steam pot, spicy numbing stir-fried pot, and spicy hot pot. This illustrates that diverse nutritional standards may lead to different water-saving actions. Setting a low water footprint per calorie unit as the standard, hot and sour rice noodle soup, hot-dry noodles with sesame paste, and rice congee identified as recommended staple foods (Table S11). Advisable stir-fried dishes include hot and sour shredded potato, stir-fried shredded cabbage, and mapo tofu. Following the low water footprint per protein unit standard, hot-dry noodles with sesame paste and rice congee remain as recommended staple foods. Mapo tofu, braised chicken with rice, and spicy chicken hot pot are suggested as stir-fired dishes.

3.3 Combined evaluation of the water footprint and nutrients of takeaway dishes

We apply the FCS indicator to evaluate the nutritional quality of 32 takeaway dishes (Figure 4). Under FCS standards, dishes with a score >70 are considered as healthy options. There are only three recommended healthy dishes (including two meat-free dishes), which are distributed in quadrant I. Twenty-two dishes with FCS between 30 and 70 are located in quadrant II and quadrant V, which are advised for moderate consumption. Seven dishes in quadrant III and quadrant VI are recommended for minimal consumption due to their low FCS. Overall, excessive consumption is not encouraged for most dishes due to their relatively low FCS.

Combining the water footprint and FCS, takeaway dishes with the lower water footprint and higher nutritional value are recommended. Generally, only three dishes are deemed to be environmentally friendly and healthy to choose. Other dishes fail to meet one or even two of the criteria. As shown in Figure 4, three dishes (stir-fried shredded cabbage, stir-fried pork belly with string bean, and millet congee) in quadrant I are recommended in daily food intake. They have both a higher nutrition and lower water footprint than dishes in other quadrants. Dishes in quadrant II are recommended for moderate consumption. Although they have a lower water footprint, their FCS are moderate with relatively low nutritional quality. These dishes include hot and sour shredded potato, soup with pepper, mapo tofu, and stir-fried egg with tomato. In quadrant III, three dishes have a lower water footprint, but with very low nutritional value. These dishes are rice congee, hot-dry noodles with sesame paste, and pita bread soaked in lamb soup. Consumption of these dishes should be minimized from a nutritional perspective, even though they have a minor impact on freshwater resource compared to other dishes in the study. Dishes in quadrant IV, V and VI have a higher water footprint. Ten takeaway dishes fall into quadrant V, but no dishes fall into quadrant IV. Note that all dishes in quadrant V are meat dishes or dishes containing dairy products (durian pizza), resulting in higher water footprint but lower FCS. Four dishes in quadrant VI are not recommended from both environmental and nutritional value perspectives. These dishes include spicy drumstick burger, Chinese burger, donkey burger, and instant spicy steam pot. It is worth noting that meat containing dishes do not necessarily determine whether the dishes have a higher nutritional content. For example, meat dishes in quadrants III and VI such as hot-dry noodles with sesame paste, instant spicy steam pot, and spicy drumstick burger exhibit the lowest nutritional quality.

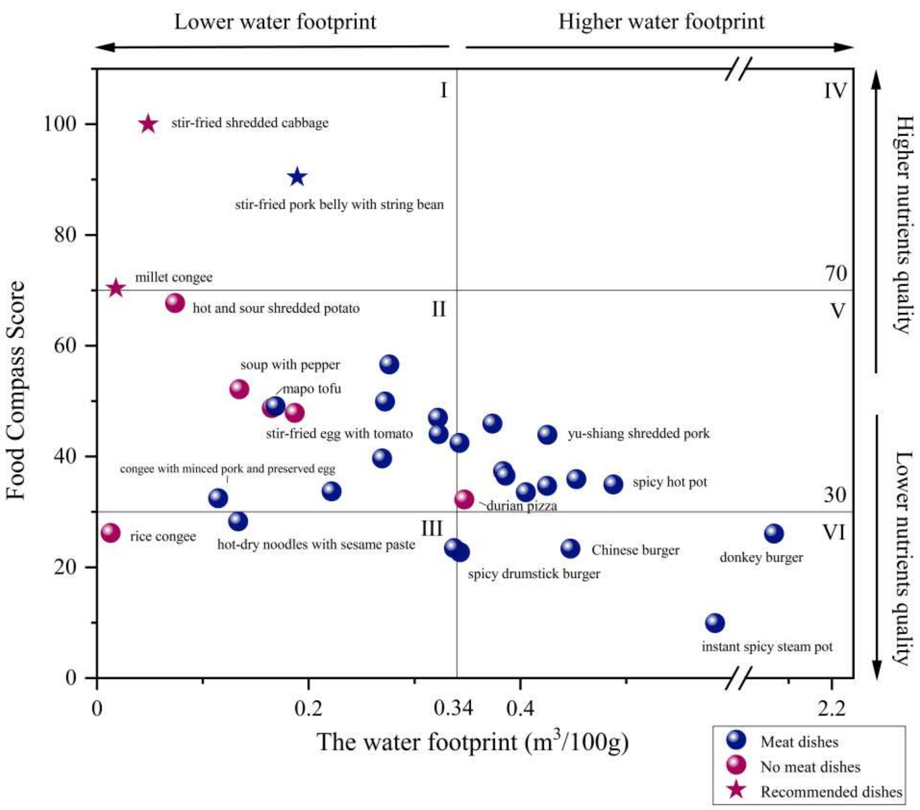

Figure 4. Combined water footprint and nutritional value of takeaway dishes. We grouped all 32 dishes into six quadrants. The average water footprint of takeaway dishes (0.34 m^3/100g) is used to classify the higher and lower water footprint. Nutritional values of FCS 30 and FCS 70 are used to categorize the nutrition quality of dishes. The blue color indicates meat dishes, red represents vegetarian dishes, and the star symbols represent recommended dishes based on the two standards.

4. Discussion

4.1 Emphasizing the environmental and nutritional value of takeaway dishes, rather than the food itself

We evaluated the environmental and nutritional aspects of the top 10 best-selling takeaway dishes for 10 large cities in China. This provides guidance for urban consumers to select more sustainable takeaway options. Rather than analyzing a single food or providing a general dietary framework, we introduced specific dishes in order to raise awareness among city customers about sustainable diets when ordering takeaways. Dishes are a combination of different food ingredients, whose environmental and nutritional impact are more complex to analyze. In contrast to single food ingredients, consumer choice on dishes is influenced by a variety of factors including cultural traditions, local preferences, local agriculture, climate conditions, and economic levels. Such influences are more important in vast countries like China. Hence, the impact of dietary habits on takeaway dishes and the resulting environmental and nutritional effects needs to be analyzed in future research. In addition, compared to single food ingredients, the nutritional quality of dishes is significantly influenced by the combination and ratio of different ingredients. For example, we found that incorporating more non-starchy vegetables in meat dishes, such as spicy chicken hot pot, resulted in higher nutritional quality.

Our study shows that urban dwellers prefer meat rather than vegetarian dishes in the selected large cities, with chicken and pork dominating. This is consistent with trends identified in other research, namely that in recent decades Chinese urban dwellers are preferring more meat, especially pork and poultry, in their diets (FAO, 2022). Such choices lead to an overall higher water footprint for takeaway dishes. Meat can provide substantial energy and essential nutrients for humans, particularly protein and micronutrients (Biesalski, 2005). However, high amount of meat intakes would result in adverse effect on health, for example, increase the risk of major chronic diseases and preterm mortality (Wolk, 2017). In addition, meat production consumes large amounts of water. Globally, the water footprint of animal products makes up nearly one-third of the total agricultural water footprint (Mekonnen and Hoekstra, 2012). We found that the magnitude of water footprint in takeaway dishes primarily depends on the amount of added meat. Dishes with a higher proportion of meat have a higher water footprint.

We used FCS to analyze the nutritional quality of takeaway dishes. Compared with other food profiling systems, this method encompasses a wider range of nutrients and considers the potential adverse effects on health, which makes it suitable for analyzing dishes with mixed food ingredients. Our study revealed that most takeaway dishes have lower nutritional quality (FCS<70), with only three dishes achieving an FCS >70. This aligns with previous research demonstrating the relationship between takeaway dishes and the risks of diet-related diseases (Sousa et al., 2021). The nutritional value of takeaway dishes and the limited choice should be highly concerning for public health policy makers.

Based on our analysis, effort should be directed towards offering more nutritious and environmentally friendly takeaway options, and encouraging consumers to choose these dishes. For food retailers we recommend greater diversity, nutritious ingredients, and environmentally friendly takeaway options. Specifically, fish is a recommended choice that meeting both the environmental and nutritious standard (Hallström et al.,2019; Zhang et al., 2022). However, no fishes are included in the top 10 takeaway dishes of the cities we choose. As for governments, they may promote the labelling of takeaway dishes with nutritional and water footprint information, for example on the takeaway ordering platform.

4.2 Limitations

The scope of our study and data confidentiality restricted the extent of our study. Due to data limitations, same-name dishes may have different preparation processes and ingredient ratios which affect the calculation of water footprint and FCS.

Our research also has several assumptions. First, we assumed self-sufficiency, i.e., that all ingredients used in takeaway dishes are produced locally. Such an assumption means the water footprint and water scarcity footprint data reflects the impact of takeaway consumption on local water resources. Second, the water footprint of condiments, such as salt, vinegar and chili sauce, has been ignored. These ingredients occupy only small percentage of ingredients in takeaway dishes, hence have only a minor effect on the final results. Third, the freshwater used in the food preparation and cooking process has been ignored. However, the water consumption of food preparation and cooking process accounts for a small proportion compared to the water consumption to produce dish ingredients. Fourth, iodine, trans-fats, and alpha-linolenic acid are not included in the FCS accounting. Iodine is found in seafood, and our study contains no marine components. The domain containing trans-fat and alpha-linolenic acid selects the top 3 attributes when calculating the final score, reducing the extreme effects of each attribute. Here, we only analyzed the nutrition score generally, without further analyzing the nutritional component of each dish. As for other studies of this nature, there are uncertainties under different nutrition standards when calculating food nutrients. By utilizing FCS, we have selected diverse evaluation standards and avoided the extreme attributes in each domain. Hence, the results of FCS are considered reasonable.

5. Conclusions

We conducted an investigation of water footprint and nutritional content of the top 10 best-selling takeaway dishes in 10 large cities in China. The combined analysis is an initial step towards assisting consumers in making takeaway meal choices that may conserve freshwater and protect health. Our research confirms that the majority of the top 10 best-selling takeaway dishes have a higher water footprint and lower FCS, with only three dishes recommended as a win-win choice. Meat dishes have a greater water footprint and are favored in the water stressed northern cities in China. With data improvements, future studies could include a wider range of takeaway dish types, considering the impact of dietary preferences on choice. Other important environmental factors, such as land and nutrient pollution i.e., run-off from agricultural land may also be included.

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References

Aboussaleh, Y., Capone, R., Bilali, H. E., 2017. Mediterranean food consumption patterns: low environmental impacts and significant health-nutrition benefits. Proceedings of the Nutrition Society, 76(4), 543-548. https://doi.org/10.1017/S0029665117001033.

Biesalski, H. K., 2005. Meat as a component of a healthy diet - are there any risks or benefits if meat is avoided in the diet? Meat Science, 70(3), 509-524. https://doi.org/10.1016/j.meatsci.2004.07.017.

Boulay, A.-M., Bare, J., Benini, L., Berger, M., Lathuillière, M. J., Manzardo, A., Margni, M., Motoshita, M., Núñez, M., Pastor, A. V., Ridoutt, B., Oki, T., Worbe, S., Pfister, S., 2017. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). The International Journal of Life Cycle Assessment, 23(2), 368-378. https://doi.org/10.1007/s11367-017-1333-8.

Boulay, A.-M., Lenoir, L., 2020. Sub-national regionalisation of the AWARE indicator for water scarcity footprint calculations. Ecological Indicators, 111. https://doi.org/10.1016/j.ecolind.2019.106017.

Chapa, J., Farkas, B., Bailey, R. L., Huang, J. Y., 2020. Evaluation of environmental performance of dietary patterns in the United States considering food nutrition and satiety. Science of the Total Environment, 722, 137672. https://doi.org/10.1016/j.scitotenv.2020.137672.

Chinese Nutrition Society, 2016. Chinese Food Guide Pagoda. http://en.cnsoc.org/dGuideline/611921203.html (accessed 17 May 2023).

Chu, J., Liu, H., Salvo, A., 2021. Air pollution as a determinant of food delivery and related plastic waste. Nat Hum Behav, 5(2), 212-220. https://doi.org/10.1038/s41562-020-00961-1.

Clark, M., Springmann, M., Rayner, M., Scarborough, P., Hill, J., Tilman, D., Macdiarmid, J. I., Fanzo, J., Bandy, L., Harrington, R. A., 2022. Estimating the environmental impacts of 57,000 food products. Proceedings of the National Academy of Sciences of the United States of America, 119(33), e2120584119. https://doi.org/10.1073/pnas.2120584119.

CNNIC, 2023. The 51st Statistical Report on China's Internet Development [in Chinese]. https://www.cnnic.net.cn/n4/2023/0303/c88-10757.html (accessed 17 May 2023).

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food, 2(3), 198-209. https://doi.org/10.1038/s43016-021-00225-9.

Dalin, C., Qiu, H., Hanasaki, N., Mauzerall, D. L., Rodriguez-Iturbe, I., 2015. Balancing water resource conservation and food security in China. Proceedings of the National Academy of Sciences of the United States of America, 112(15), 4588-4593. https://doi.org/10.1073/pnas.1504345112.

Donin, A. S., Nightingale, C. M., Owen, C. G., Rudnicka, A. R., Cook, D. G., Whincup, P. H., 2018. Takeaway meal consumption and risk markers for coronary heart disease, type 2 diabetes and obesity in children aged 9-10 years: a cross-sectional study. Archives of Disease in Childhood, 103(5), 431-436. https://doi.org/10.1136/archdischild-2017-312981.

FAO, 2023. FAOSTAT. www.fao.org/faostat/en/?#data.

Gallego-Schmid, A., Mendoza, J. M. F., Azapagic, A., 2019. Environmental impacts of takeaway food containers. Journal of Cleaner Production, 211, 417-427. https://doi.org/10.1016/j.jclepro.2018.11.220.

Glynn Davies, I., Stevenson, L., Ashton, M., Taylor, C., Long, R., M. Blackham, T., Jaworowska, A., 2014. Nutritional composition of takeaway food in the UK. Nutrition & Food Science, 44(5), 414-430. https://doi.org/10.1108/nfs-08-2013-0093.

Guo, M., Wu, L., Tan, C. L., Cheah, J.-H., Aziz, Y. A., Peng, J., Chiu, C., Ren, R., 2023. The impact of perceived risk of online takeout packaging and the moderating role of educational level. Humanities and Social Sciences Communications, 10(1). https://doi.org/10.1057/s41599-023-01732-9.

Hallström, E., Bergman, K., Mifflin, K., Parker, R., Tyedmers, P., Troell, M., Ziegler, F., 2019. Combined climate and nutritional performance of seafoods. Journal of Cleaner Production, 230, 402-411. https://doi.org/10.1016/j.jclepro.2019.04.229.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., Mekonnen, M. M., 2011. The Water Footprint Assessment Manual: Setting the Global Standard. London: Earthscan.

Hovhannisyan, V., Devadoss, S.,2018. Effects of urbanization on food demand in China. Empirical Economics, 58(2), 699-721. https://doi.org/10.1007/s00181-018-1526-4.

Ibidhi, R., Hoekstra, A. Y., Gerbens-Leenes, P. W., Chouchane, H., 2017. Water, land and carbon footprints of sheep and chicken meat produced in Tunisia under different farming systems. Ecological Indicators, 77, 304-313. https://doi.org/10.1016/j.ecolind.2017.02.022.

Ibarrola-Rivas, M.-J., Nonhebel, S., 2022. Regional food preferences influence environmental impacts of diets. Food Security, 14(4), 1063-1083. https://doi.org/10.1007/s12571-022-01270-3.

IiMedia Research, 2023. Data Analysis of China's Delivery Market: The growth rate of the online delivery market in China in 2022 is 19.80% [in Chinese]. https://www.iimedia.cn/c1061/92068.html (accessed 17 May 2023).

Jagermeyr, J., Ger10, D., Heinke, J., Schaphoff, S., Kummu, M., Lucht, W., 2015. Water savings potentials of irrigation systems: global simulation of processes and linkages. Hydrology and Earth System Sciences, 19(7), 3073-3091. https://doi.org/10.5194/hess-19-3073-2015.

Jiang, X., Dong, M., He, Y., Shen, J., Guo, X., 2020. Research on the design of and preference for collection modes of reusable takeaway containers to promote sustainable consumption. International Journal of Environmental Research and Public Health, 17(13), 4764.

Li, C., Mirosa, M., Bremer, P., 2020. Review of Online Food Delivery Platforms and their Impacts on Sustainability. Sustainability, 12(14). https://doi.org/10.3390/su12145528.

Liao, W., Zhang, L., Wei, Z., 2020. Multi-objective green meal delivery routing problem based on a two-stage solution strategy. Journal of Cleaner Production, 258. https://doi.org/10.1016/j.jclepro.2020.120627.

Liao, X., Zhao, X., Liu, W., Li, R., Wang, X., Wang, W., Tillotson, M.R., 2020. Comparing water footprint and water scarcity footprint of energy demand in China's six megacities. Applied Energy 269, 115137. https://doi.org/10.1016/j.resconrec.2020.104972.

Liu, F., 2014. A collection of Chinese menu [in Chinese], Tianjin Science & Technology Publishing House, China.

Meituan Research Institute, 2021. China Takeaway Industry Development Report 2019 and 2020 H1 [in Chinese]. https://mri.meituan.com/research/report (accessed 8 August 2023).

Meituan Research Institute, China Hospitality Association, 2019. China Takeaway Industry Research Report (2019 Q1-Q3) [in Chinese]. https://mri.meituan.com/research/report (accessed 17 August 2023).

Mekonnen, M. M., Hoekstra, A.Y., 2011. The green, blue and grey water footprint of crops and derived crop products. Hydrology and Earth System Sciences, 15(5), 1577–1600. https://doi.org/10.5194/hess-15-1577-2011.

Mekonnen, M. M., Hoekstra, A. Y., 2011. The green, blue and grey water footprint of farm animals and animal products. Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M. M., Hoekstra, A. Y., 2012. A Global Assessment of the Water Footprint of Farm Animal Products. Ecosystems, 15(3), 401-415. https://doi.org/10.1007/s10021-011-9517-8.

Ministry of Water Resources of the People's Republic of China, 2023. 2022 China Water Resources Bulletin [in Chinese]. http://www.mwr.gov.cn/sj/tjgb/szygb/202306/t20230630_1672556.html (accessed 10 July 2023).

Mozaffarian, D., El-Abbadi, N. H., O'Hearn, M., Erndt-Marino, J., Masters, W. A., Jacques, P., Shi, P., Blumberg, J. B., Micha, R., 2021. Food Compass is a nutrient profiling system using expanded characteristics for assessing healthfulness of foods. Nature Food, 2(10), 809-818. https://doi.org/10.1038/s43016-021-00381-y.

NetEase Data Blog, 2019. The top 10 takeaway list among cities, what dish is the king of takeaway meals? [in Chinese]. https://www.163.com/data/article/ELOEL23B000181IU.html (accessed 17 May 2023).

NINH, 2018. Food Composition List of China [in Chinese]. National Institute of Nutrition and Health, Chinese Center for Disease Control and Prevention.

NINH, 2019. Food Composition List of China [in Chinese]. National Institute of Nutrition and Health, Chinese Center for Disease Control and Prevention.

Poti, J. M., Braga, B., Qin, B., 2017. Ultra-processed Food Intake and Obesity: What Really Matters for Health-Processing or Nutrient Content? Current Obesity Reports, 6(4), 420-431. https://doi.org/10.1007/s13679-017-0285-4.

Ridoutt, B. G., Pfister, S., 2010. A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Global Environmental Change, 20(1), 113-120. https://doi.org/10.1016/j.gloenvcha.2009.08.003.

Schliemann, D., Woodside, J. V., Geaney, F., Cardwell, C., McKinley, M. C., Perry, I., 2019. Do socio-demographic and anthropometric characteristics predict food choice motives in an Irish working population? British Journal of Nutrition, 122(1), 111-119. https://doi.org/10.1017/S0007114519000941.

SIC, 2023. China's shared economic report 2023 [in Chinese]. http://www.sic.gov.cn/archiver/SIC/UpFile/Files/Default/20230223082254946100.pdf?eqid=da0847b600001cda0000000364585bf0 (accessed 17 May 2023).

Smith, K. J., McNaughton, S. A., Gall, S. L., Blizzard, L., Dwyer, T., Venn, A. J., 2009. Takeaway food consumption and its associations with diet quality and abdominal obesity: a cross-sectional study of young adults. International Journal of Behavioral Nutrition and Physical Activity, 6, 29. https://doi.org/10.1186/1479-5868-6-29.

Song, G., Zhang, H., Duan, H., Xu, M., 2018. Packaging waste from food delivery in China's mega cities. Resources, Conservation and Recycling. 130, 226–227. https://doi.org/10.1016/j.resconrec.2017.12.007.

Sousa, S., de Morais, I. L., Albuquerque, G., Gelormini, M., Santos, M., Filipovic-Hadziomeragic, A., Stojisavljevic, D., Damasceno, A., Moreira, P., Breda, J., Lunet, N., Padrao, P., 2021. Nutritional Content of Street Food and Takeaway Food Purchased in Urban Bosnia and Herzegovina. Foods, 10(11), Article 2594. https://doi.org/10.3390/foods10112594.

Springmann, M., Wiebe, K., Mason-D'Croz, D., Sulser, T. B., Rayner, M., Scarborough, P., 2018. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. Lancet Planetary Health, 2(10), E451-E461. https://doi.org/Doi 10.1016/S2542-5196(18)30206-7.

Statista, 2023. Online Food Delivery – China. https://www.statista.com/outlook/dmo/online-food-delivery/china?currency=CNY (accessed 17 May 2023).

Statista, 2023. Online food delivery in China - statistics & facts. https://www.statista.com/topics/7139/online-food-delivery-in-china/#topicOverview (accessed 17 May 2023).

Su, Y., Duan, H., Wang, Z., Song, G., Kang, P., Chen, D., 2020. Characterizing the environmental impact of packaging materials for express delivery via life cycle assessment. Journal of Cleaner Production, 274. https://doi.org/10.1016/j.jclepro.2020.122961.

Tuninetti, M., Ridolfi, L., Laio, F., 2022. Compliance with EAT–Lancet dietary guidelines would reduce global water footprint but increase it for 40% of the world population. Nature Food, 3(2), 143-151. https://doi.org/10.1038/s43016-021-00452-0.

Uhlenbrook, S., Yu, W., Schmitter, P., Smith, D. M., 2022. Optimising the water we eat-rethinking policy to enhance productive and sustainable use of water in agri-food systems across scales. Lancet Planetary Health, 6(1), e59-e65. https://doi.org/10.1016/S2542-5196(21)00264-3.

USDA, 2018. USDA Database for the Flavonoid Content of Selected Foods. https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/methods-and-application-of-food-composition-laboratory/mafcl-site-pages/flavonoids/.

USDA, 2018. USDA National Nutrient Database for Standard Reference, Legacy (SR-Legacy). https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/methods-and-application-of-food-composition-laboratory/mafcl-site-pages/sr11-sr28/.

USDA, 2022. 2019-2020 Food and Nutrient Database for Dietary Studies. https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/fndds-factsheets/.

Wang, X., Xu, M., Yang, A., Wang, Y., Hou, S., Zheng, N., Liang, D., Hua, X., Dong, D., 2021. Health risks of population exposure to phthalic acid esters through the use of plastic containers for takeaway food in China. Science of The Total Environment, 785. https://doi.org/10.1016/j.scito10v.2021.147347.

Wolk, A., 2017. Potential health hazards of eating red meat. Journal of Internal Medicine, 281(2), 106-122. https://doi.org/10.1111/joim.12543.

Xie, J., Xu, Y., Li, H., 2021. Environmental impact of express food delivery in China: the role of personal consumption choice. Environment, Development and Sustainability, 23(6), 8234-8251. https://doi.org/10.1007/s10668-020-00961-1.

Xue, L., Liu, X., Lu, S., Cheng, G., Hu, Y., Liu, J., Dou, Z., Cheng, S., Liu, G., 2021. China's food loss and waste embodies increasing environmental impacts. Nature Food, 2(7), 519-528. https://doi.org/10.1038/s43016-021-00317-6.

Zhai, F. Y., Du, S. F., Wang, Z. H., Zhang, J. G., Du, W. W., Popkin, B. M., 2014. Dynamics of the Chinese diet and the role of urbanicity, 1991-2011. Obesity Reviews, 15 Suppl 1(0 1), 16-26. https://doi.org/10.1111/obr.12124.

Zhang, H., Zhuo, L., Xie, D., Liu, Y., Gao, J., Wang, W., Li, M., Wu, A., Wu, P., 2022. Water footprints and efficiencies of ruminant animals and products in China over 2008–2017. Journal of Cleaner Production, 379. https://doi.org/10.1016/j.jclepro.2022.134624.

Zhang, S., Zhao, X., Feng, K., Hu, Y., Tillotson, M. R., Yang, L., 2022. Do mariculture products offer better environment and nutritional choices compared to land-based protein products in China? Journal of Cleaner Production, 372, 133697. https://doi.org/10.1016/j.jclepro.2022.133697.

Zhang, X., Zhao, X., Li, R., Mao, G., Tillotson, M.R., Liao, X., Zhang, C., Yi, Y., 2020. Evaluating the vulnerability of physical and virtual water resource networks in China's megacities. Resources, Conservation and Recycling 161, 104972. https://doi.org/10.1016/j.resconrec.2020.104972

Zhao, X., Liao, X., Zhang, C., Zhang, X., Mao, G., Zhang, S., Tillotson, M.R., 2021. Unveiling the dynamic of water-electricity conflict within and beyond megacity boundary. Journal of Environmental Management 286.

Zhao, X., Lin, W., Cen, S., Zhu, H., Duan, M., Li, W., Zhu, S., 2021. The online-to-offline (O2O) food delivery industry and its recent development in China. European Journal of Clinical Nutrition, 75(2), 232-237. https://doi.org/10.1038/s41430-020-00842-w.

Zhao, X., Tillotson, M.R. Liu, Y.W., Guo, W. Yang, A.H., Li, Y.F. 2017. Index decomposition analysis of urban crop water footprint. 348, 25-32. Ecological Modelling.

Zhou, Y., Shan, Y. L., Guan, D. B., Liang, X., Cai, Y. P., Liu, J. R., Xie, W., Xue, J. J., Ma, Z. G., Yang, Z. F., 2020. Sharing tableware reduces waste generation, emissions and water consumption in China's takeaway packaging waste dilemma. Nature Food, 1(9). https://doi.org/10.1038/s43016-020-00145-0.