Food Security (2020) 12:1283–1298
https://doi.org/10.1007/s12571-020-01057-4

ORIGINAL PAPER

Spatially analyzing food consumption inequalities using GIS with disaggregated data from Punjab, Pakistan.

Analyzing food patterns in Punjab using disaggregated data with GIS

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Received: 7 January 2020 / Accepted: 12 June 2020 / Published online: 4 July 2020

Abstract
Inequalities are usually measured in context of household income to develop policies ensuring equal opportunities to public services for well being. Sustainable Development Goal 10, however, emphasizes the uniform distribution of per-capita food and nutrition intake and percentage share of expenditure on food consumption. Concerning that, evidence-based approaches should include scientifically examining the spatial aspects of food security to evaluate geographical equity (or inequity) of its various dimensions. The main objective here is to instigate spatial inequalities in food and nutrient consumption and production in Punjab. To do so, we georeferenced the traditional local and global food and nutrition surveys in a Geographical Information System (GIS) environment. Next, we disaggregated household surveys at various sub-national levels (i.e., per km^2, per district, per region with rural-urban divisions). With these levels, we analyzed food data along three categories, i.e., production, consumption, and nutrition intake. We used global Moran's index to identify geographical disparities of production-consumption gaps among regions and commodities. The results obtained reveal clustered food patterns in the north and north-eastern regions, while southern areas face high inequality of producing and consuming cereals, meat, vegetables, fruits, and milk. High spatial autocorrelation of within-districts gaps of food production and consumption observed in the province indicates that inequality is driven by location dynamics and not by population. The evidence-based method in this research will help implicate policies through prioritizing resource allocation in terms of space and equal opportunities.

Keywords GIS · Opportunity mapping · Spatial analyses · Food production-consumption gaps · Sustainability

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Introduction

Food security ensures people have sufficient, safe, and nutritious food to maintain a healthy and energetic life. Approximately 700 million people out of 7.6 billion were food insecure in 2016 (FAO 2017), mostly from the developing world. Whereas, about 10.7% of the world population suffers from chronic health issues due to the unavailability of food. Despite the adequate production of food, millions of people are food-deprived. In Pakistan, about 60% population is food meager and suffers from related health issues (WFP 2017). About 32.2% out of the 60% population is afflicted with any form of food insecurity, while 18.8% experience moderate hunger, and 8.8% are living with severe hunger (FAO et al. 2017). Moreover, about 51% population consumes less than 2100 kcal per day (Ishaq et al. 2018). Whereas, children are mainly affected by food insecurities among all these groups. About 39.6% of children below the age of five are underweight. About 36% of the country's children have moderate iron deficiency anemia due to internal nutritional deficiencies, absence/inadequacy of micronutrient supplementation, and household food insecurity. Moreover, about 15% of children are suffered from moderate iodine deficiency of vitamin A and Zinc (Khalid et al. 2014). Regarding global food security, the Inter-agency and Expert Group on the 2030 Agenda for UN Sustainable Development Goals (IAEG-SDGs) set several goals to help eliminate hunger, food insecurity, and malnutrition (FAO 2017; Assembly 2017). To measuring these goals, it is challenging to develop data sources and methods for timely and cost-effectively monitoring the food demand and consumption at the national and sub-national scales (Fritz et al. 2019).

On the global scale, the FAOSTAT of Food and Agriculture Organization (FAO) provides food demand in terms of the nutritious intake change with people's income flexibility (Faostat 2016). It statistically estimates cross-sectional information to measure food demand from 2010 to 2050. Moreover, the FAOSTAT model is based on trend projection and shared socio-economic pathways scenarios using the demand systems (Gouel and Guimbard 2018). Other global economic models project food demands under the changing climate and population scenarios mostly for 2050(Wiebe et al. 2015; Islam et al. 2016; Scott et al. 2019). Their outcome indicates a food demand increase by 59–98% from 2005 to 2050. This projection is slightly higher than compared of 54% estimated by FAO (Valin et al. 2014). Moreover, these models simulate long-term food demand in terms of calorie demands and income predictions (Bodirsky et al. 2015; Fukase 2017).

On the national scale, however, gaps between food demand and supply of a country directly affect its economic growth, development, and poverty status. Developing countries, like Pakistan, need to have equilibrium between the population food demand and supply for sustainable development to food security, particularly the poor with access to food (Keating et al. 2014). Due to week purchasing power, it is difficult for these countries to import high-priced food from the global market. Furthermore, global food demand is a threat to the growing population and changing consumption patterns (Yu et al. 2016). Despite creating the self-sufficiency of the food, most of the countries import 12% of world food. This situation is continually forcing the countries of enhancing food production to feed their ever-growing populations (Tanumihardjo et al. 2019). Furthermore, usually, countries are facing a high degree of local climate change and related environmental factors (Ali et al. 2017b). All this poses challenges to access future food demands, particularly for developing countries due to data scarcity.

The sustainable development to ensure food and nutrition security has three major dimensions - food availability, access, and utilization (Faostat 2016). Elaborating this with the IAEG-SDGs Goal 10 (i.e., reduce inequality within and among countries), nations worldwide should target empowering physical and economic access to sufficient, safe, and nutritious food to all people, at all times, to meet their dietary needs for a healthy life, irrespective of age, sex, disability, race, ethnicity, origin, religion, or another status (Alvaredo et al. 2018). However, spatial inequalities restrict such assess across different regions and areas (e.g., urban-rural spectrum) within countries (Albert and Raymundo 2016; Organization and et al. 2018). Because household income, consumption, and welfare growth are often lower in rural areas in comparison to urban areas (Hamid and Akram 2014). Pakistani society, like many developing countries, is facing vast inequalities in fiscal, wage, social protection, and other facilities(Imran et al. 2019). They are often related to the region, gender, and ethnicity. People belonging to different castes, tribes, and ethnic groups do not have the same access to health, education, and other facilities leading to different socio-economic gaps among regions (Anwar 2009). The most pronounced food and nutrition inequalities occur when these forms of marginalization overlap with rural areas (Pérez-Escamilla 2017; Boto and Mofolo 2019). Nevertheless, increasing urbanization trends, with already more than half of the world's population in cities, caused unequal distribution of resources among geographical regions (Clendenning et al. 2016; Chu et al. 2018; Szabo et al. 2018). It, therefore, requires multidimensional and multispectral approaches to mapping food security through targeting not only global and national food and nutrition, but also accounting for household and individual scales (Tangcharoensathien et al. 2015; FAO et al. 2017).

Several studies estimated urban-rural and inter-regional disparities in household food consumption through frequently constructing income groups at national and sub-national levels (Nandy et al. 2016; Ali et al. 2017a; Santaeulàlia-Llopis and Zheng 2017). They usually relate different food groups to income and wealth groups. With this, the expenditure elasticity of income groups determined food consumption trends of peoples living in urban and rural areas. For instance, (Ahmad et al. 2015) found the people with a below-average income spend a large fraction of earning on wheat, vegetable, and pulses, while the people with high wages spend more on rice, meat, fish, and milk. Household income is often positively related to their food security status. Therefore, segregation of groups who left behind should also include other inequality characteristics such as gender, religion, ethnicity, income, geographic origin, rurality, age, disability (Alvaredo et al. 2018). (Yousaf et al. 2018) used the Dietary Intake Assessment (DIA) method to estimate the impact of family structure on household food consumption at the sub-national level using seven days reference period. The results revealed determinants of food security vary significantly across the regions, whereas the family structure found negatively correlated with the food security status. Here, we investigate how the sub-national disaggregated data on food consumption, nutrient demand, and production of major commodities can be interlinked in the Geographical Information Systems (GIS) environment to spatially analyze food consumption inequalities.

The main objective of the research is to investigate spatial inequality in food consumption, nutrient consumption, and production-consumption gaps at the sub-national levels (i.e., per district, per region with rural-urban divisions) in the Punjab province of Pakistan. To do so, we applied several algorithms for analyzing food production-consumption gaps in the GIS environment using several social and economic indicators observed from household surveys. The research output will provide a methodology to map spatial inequalities to food and nutrition within-countries. It will help policymakers to monitor progress in inequality reduction and devise policies to eliminate discriminatory laws and practices in areas having urban-rural and inter-regional inequalities.

Materials and methods

Study area

The present research is carried out for Punjab (see Fig. 1), the most populous province of Pakistan, with a population of 110 million just to half of the country's total demography (BOP 2014). Its total area is 205,344 km^2 forming 28.5% of the country's total land. The province has an intensive industry with the lowest poverty rate. Being extremely urbanized in South Asia, 40% of the urban population contributes 59% to the country's economy. Because of an unplanned increase in urban population, the province is considerably affected by urban-rural and inter-regional inequalities in terms of social and economic indicators of education, sanitation, water supply, health, and other services (Imran et al. 2019). Punjab is composed by 36 districts that are primarily administrative units within the province. These districts predominate several disparities among the Central, North, and South regions of the province (Burki et al. 2015). For instance, (Bashir et al. 2012) found Central Punjab more food insecure with 31% of food-insecure households compared to South Punjab and North Punjab 13.5% and 15% of food-insecure households, respectively. The districts in South have limited access to social and economic services. Therefore, in this study, the inequalities in food consumption, nutrient consumption, and production-consumption gaps were spatially analyzed per region with rural-urban divisions. However, each region consists of a different number of districts.

The agriculture sector in the province, as a primary contributor to the economy, provides the largest share in food production. The country's total export has a three-quarters share from the agriculture production, out of which 60% comes from Punjab. The crop area is 16.68 million hectors out of the country's total of 20.63 million hectors. Over the years, the province is fulfilling the country's food requirements through growing 26341.2 and 3648.2 thousand tonnes of wheat and rice on 17250.8 and 4640.0 thousand acres, respectively. For the last couple of decades, however, the province is facing high spatial and temporal variability of weather conditions, such as rainfall, temperature, and fog in winter. All these factors have profoundly influenced patterns of agricultural production and consumption.Punjab has the lowest share of expenditure on food (42% of total expenditure) followed by Sindh (43%) while Baluchistan has the largest share (55%) followed by KPK (54%) (Haider and Zaidi 2017). It indicates income levels in Punjab and Sindh are higher compared to Baluchistan and KPK. Moreover, there is an urban-rural divide on food expenditure in these provinces.

The province records rich evidence-based data to compare food security status among districts and regions in context with food availability, access, and utilization. Given the importance of measuring inequalities concerning IAEG-SDGs Goal 10, the objective of this paper is to examine their spatial distributions that can provide valuable policy implications for the future status of poverty and hunger in the population of this study area.

Data sets

Social indicators about the food consumption, nutrient intake, and production of major commodities in the province were extracted from the country's surveys of households and global data sets, explained as follows,

1. The Household Integrated Economic Surveys (HIES) obtain statistical data on the crucial social indicators of monthly household consumption and expenditure on major food items (PBS 2014). Data on income, food consumption, and food expenditure derived from a large sample of households (about 17.1 million) selected within the enumeration blocks in urban areas and villages in rural areas of the entire province. Each enumeration block is divided into low, middle, and high-income groups. Household survey data are further disaggregated by food consumption quantiles to be used by policymakers to devise various food security plans at the national, provincial, or district levels. In

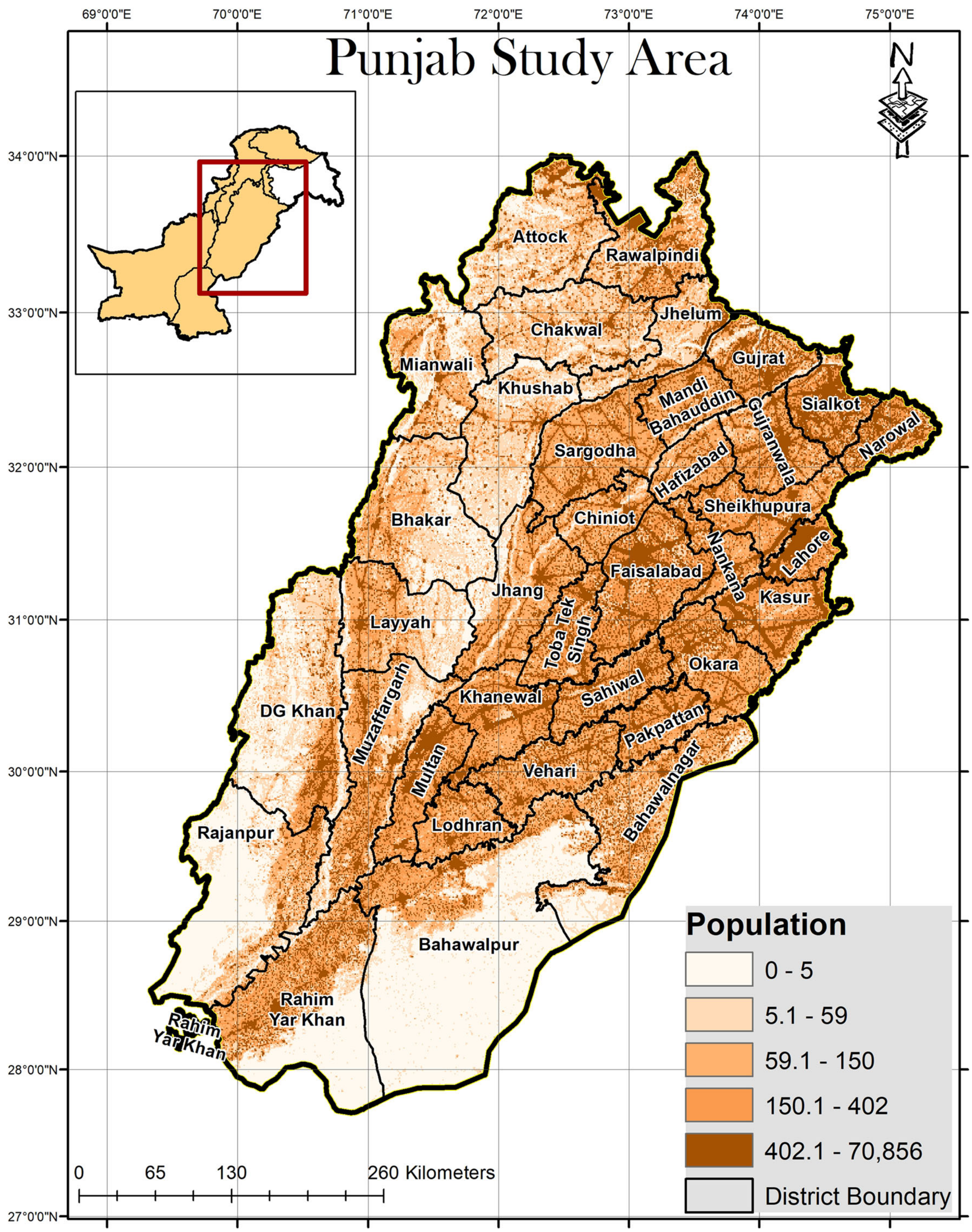

Fig. 1 Map showing LandScan population projected in 36 districts of the province Punjab for the year 2014

this way, they perceive discrepancies in food patterns and income sources of poorer and more affluent households. Moreover, they review the access of poorer households to essential nutritious food. The HIES data on household food consumption and expenditure were obtained for the demand analyses for the year 2014-15.

2. The Agriculture Marketing Information System (AMIS) of Punjab provides district-wise crop production statistics (AIMS 2014). Data on monthly production (in thousand tons) of wheat, rice, pulses, vegetables, and fruit crops were obtained from the AIMS databases for the year 2014-15. Similarly, data

on the monthly production of dairy (milk in litters) and livestock (beef, mutton, and chicken) were obtained from the Punjab Livestock Census (LDDD 2014).

3. USDA National Nutrient Database for Standard Reference (SR 2012) provides yearly-updated databases for food composition used in food policy, research, dietary practice, and nutrition monitoring. It contains data for more than 8000 food items and up to 146 nutrients and food components. Many developing countries like Pakistan do not have their food composition databases. Therefore, the USDA SR emerged as a global database for coding and calculating nutrient intakes for several local and global food security studies (Ahuja et al. 2012). USDA food data portal provides the nutrition percentage value in 100-gram of carbohydrates, fats, and proteins in wheat, rice, pulses, milk, mutton, beef, chicken, fruits, and vegetables (USDA 2012). For the year 2014, the relevant percentage of nutrients in the major food commodities in Punjab were acquired from the USDA SR databases.
4. The LandScan is a global database of population data sets compiled on an approximately 1 km (30″ × 30″) latitude/longitude grid resolution for estimating ambient populations at risk (LandScan 2014). The source later becomes a community standard to global data sets on population distributions for several local and global food security studies. LandScan allocates census counts (at sub-national level) to each grid cell through likelihood coefficients based on slope, road proximity, land cover, high-resolution imagery, and other data sets. We acquired LandScan population distributions at the district level of Punjab for the year 2014-15.

Following the FAO guidelines (USDA 2018), we divided the food commodities into three commonly consumed food categories in the study area: (i) grain products/cereals (wheat, rice, and pulses), (ii) meat (mutton, beef, and chicken), (iii) fruits and vegetables, and milk.

Methods

The methods used in this study projects local and global data sets (in “Data sets”) on the LandScan population raster. For this, both data sets were georeferenced and overlaid in the GIS environment (ArcGIS Version 10) to obtain the input rasters for the urban and rural union councils. The input raster was then used to spatially distribute the estimated food and nutrition consumption, food production, and urban-rural production-consumption gaps at the sub-national levels (i.e., per district, per region with rural-urban divisions) in the province. We used the spatial distributions obtained in this way to map geographical inequalities within the province.

Analyzing patterns of food consumption

The food consumption demands per capita per month (urban and rural) for three food categories were calculated through the linear approximation of the almost ideal demand system (LA-AIDS) model (Green et al. 1991; Shibia et al. 2017).

$$W_i = \alpha_i + \gamma_{ij} \ln P_i + \sum_{j=1}^{n} \beta_i \ln \left[\frac{X}{P*} \right] + \epsilon_i \tag{1}$$

W_i is the expenditure shares of ith food categories (i.e. cereals, meat, fruits, vegetables, and milk) $W_i = P_i Q_i / X$, X is the total expenditure on food, ln P_i is the natural log of price of ith commodity, P is the price index, α_i, γ_{ij}, and β_i are model parameters, and ϵ_i is the disturbance term.

Food demand (kg/capita/month) estimated for all food commodities for both rural and urban households were then projected on the population input raster through the following algorithm implemented with the *Raster Calculator* ArcGIS tool,

$$C_c = \begin{cases} x * U_{cd} \ \ if x \in U & (2) \\ x * R_{cd} \ \ otherwise & (3) \end{cases}$$

where C_c is the food consumed by commodities, x is the population per Km^2, U_{cd} and R_{cd} are food consumption demand per capita per month in urban and rural areas, respectively.

Analyzing patterns of nutrient consumption

We calculated the per capita consumption of carbohydrates, fats, and protein nutrients for urban and rural areas. First, we calculated the per capita amount of a nutrient consumed from a food commodity using the USDA percentages of nutrients in 100-gram of food items. Next, we calculated the total amount of that nutrient consumed per capita from all the food categories 1-III. Finally, the estimated consumption for all nutrients from all food commodities was projected on input rasters of both rural and urban populations through the following algorithm,

$$R_n = \begin{cases} x * \sum_{i}^{cc} f(U_i) \qquad if x \in U & (4) \\ x * \sum_{i}^{cc} f(R_i) \qquad else R_n = x * f(N_c) & (5) \end{cases}$$

where R_n is the per capita nutrient demand, x is the population per Km^2, U_i and R_i are the ith nutrition consumption per capita per month in urban and rural areas, respectively.

Analyzing production-consumption gaps geographical inequalities

To calculate production-consumption gaps, first, we projected the AMIS district-wise crop production data to the district boundaries (AIMS 2014). Next, we summed food consumption values of all pixels in a district to prepare month-wise production surfaces of food categories I-III for both the urban and rural households. Finally, we mapped spatial distributions of the production-consumption gaps by taking the difference of district-wise production and consumption.

The surfaces obtained food consumption, nutrient intake, production, and production-consumption gaps of major commodities were used to calculate geographical inequalities in estimated food and nutrition consumption, food production, and production-consumption gaps at the sub-national levels, i.e., per Km^2, per district, urban-rural, and other directional regions within the province.

The spatial autocorrelation is a measure of spatial autocorrelation based on both districts locations and districts estimates of food and nutrition consumption, food production, simultaneously. The global Moran's index evaluates whether the pattern expressed is clustered, dispersed, or random, given a set of districts and associated food-related estimates (Li et al. 2007), as

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W_{i,j} Z_i Z_j}{S_\circ \sum_{i=1}^{n} {Z_i}^2} \quad (6)$$

where n is the number of districts in the province, Z_i is deviation of an attribute at a district i from its mean $xi - \bar{X}$, Z_j is deviation of the attribute at another district j from its mean $xj - \bar{X}$, $W_{i,j}$ is the spatial weight between districts i and j, and $S_\circ$ is the aggregate of all spatial weights. We used Rook contiguity (i.e., two districts are neighboring if they share common borders, see Fig. 1) for the spatial weights matrix.

$$S_\circ = \sum_{j=1}^{n} \sum_{j=1}^{n} W_{i,j} \quad (7)$$

A Moran's I value close to +1 indicates a clustered pattern, while its value close to -1 indicates a dispersed pattern. The results of spatial autocorrelation are always interpreted within the context of its null hypothesis. For this, we state the null hypothesis that samples of food attribute subject to the analysis randomly distributed among the districts in the study area. We reject the null hypothesis in the case of statistically significant p-values associated with Moran's I results. For this, we tested the inequality patterns of food attributes in this study at the $p < 0.5$ significance level. With the presence of a significant spatial autocorrelation in production and consumption trends for the estimation of food, we can infer the inequality is driven by location dynamics, and not driven by population.

Results

Analyzing patterns of food consumption

Table 1 shows the results of the food demand analyses per capita monthly consumption and percentage share of expenditure on consumption estimated for major food commodities belonging to categories I-III for both rural and urban households. The per capita wheat consumption (9.42 kg) is highest as expected, followed by the milk (7.51 litter). However, unexpectedly, the income percentage spent on milk (21.8%) in urban areas is almost double the households spent on wheat. It indicates the crumbling dairy production systems in urban Punjab. Although this difference is less for rural households, they spent more income percentage on wheat (16.3% verses 12.3%), vegetables (9.40% verses

Table 1 Monthly consumption (Kg/capita/month), per capita monthly income percentage spent on consumption (%), and production ("000", tons/month) of major food commodities belonging to category-I (cereals), category-II (meat), category-III (vegetables and fruits), and category-IV dairy (milk) rural and urban households in Punjab; monthly production of the food commodities in Punjab

Food category	Commodity	Consumption (Kg)		Expenditure share (%)		Production ('000' Tonnes)
		Urban	Rural	Urban	Rural	
I	Wheat	9.42	10.65	12.3	16.30	1643.4
	Rice	0.90	0.83	4.20	4.50	290.1
	Pulses	0.70	0.59	1.90	2.00	2.9
II	Mutton	0.10	0.08	2.00	2.20	131.1
	Beef	0.31	0.26	3.60	3.40	786.3
	Chicken	0.42	0.26	4.80	3.50	134.9
III	Fruits	1.30	0.83	4.30	3.20	323.8
	Vegetables	4.77	4.55	8.40	9.40	261.5
	Milk	7.51	6.65	21.80	22.60	48000

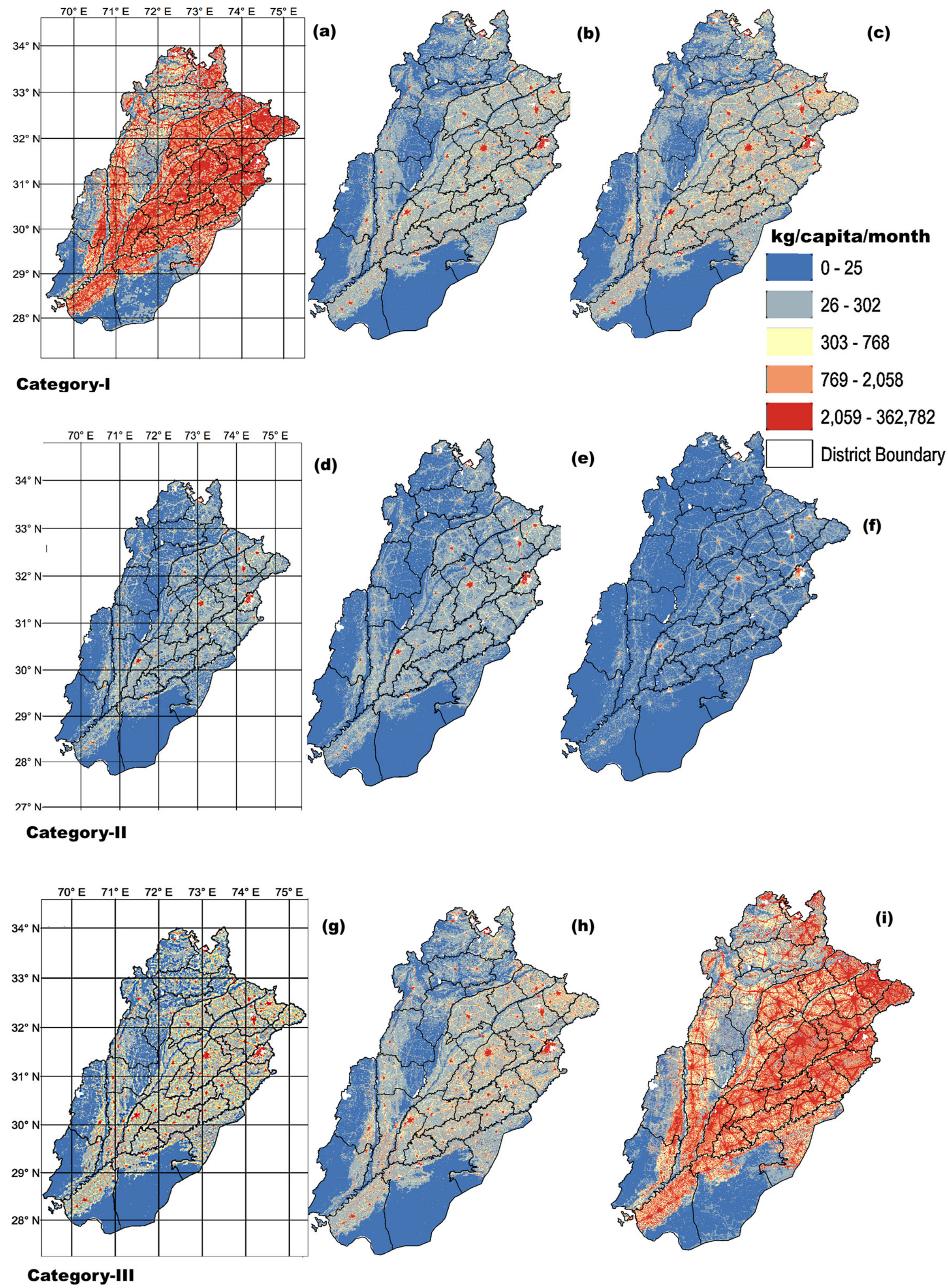

Fig. 2 Estimated per capita monthly consumption of pulses (**a**), wheat (**b**), rice (**c**), beef (**d**), chicken (**e**) mutton (**f**), fruits (**g**) vegetable (**h**) milk (**i**) using natural class breaks on the consumption value ranges in Table 1

8.40%), and milk (22.6% verses 21.8%). Despite mostly produced in rural Punjab, the cereal commodities contribute 42.5% to household's food expenditure in urban areas and 48.3% in rural areas. It indicates the producers are targeting urban markets for a more profit. Households in urban areas spend 63.3% of the monthly income for consuming food, compared to 67.1% in rural areas. Higher expenditure share on food items in rural areas is contrary to what we expect because household incomes are more based on human labor, traditionally.

Figure 2(a–i) show estimated per capita monthly consumption and income percentage spent on consumption projected to combined urban and rural population rasters of cell size $1 Km^2$. Compared to other cereals in category-I Fig. 2(a), wheat consumption per Km^2 is noted high in the entire province because it is usually considered as a staple food in Punjab. Similarly, due to the high costs of mutton, its consumption per Km^2 remains the lowest among the meat items in category-II. Appropriate actions must be taken by the food departments to increase livestock production and

Fig. 3 District-wise distributions of per capita food consumption (tons, 000) in all commodities belonging to (**a**) category I (cereals), (**b**) category II (meat) category III (fruits, vegetable, and milk) in all districts of Punjab

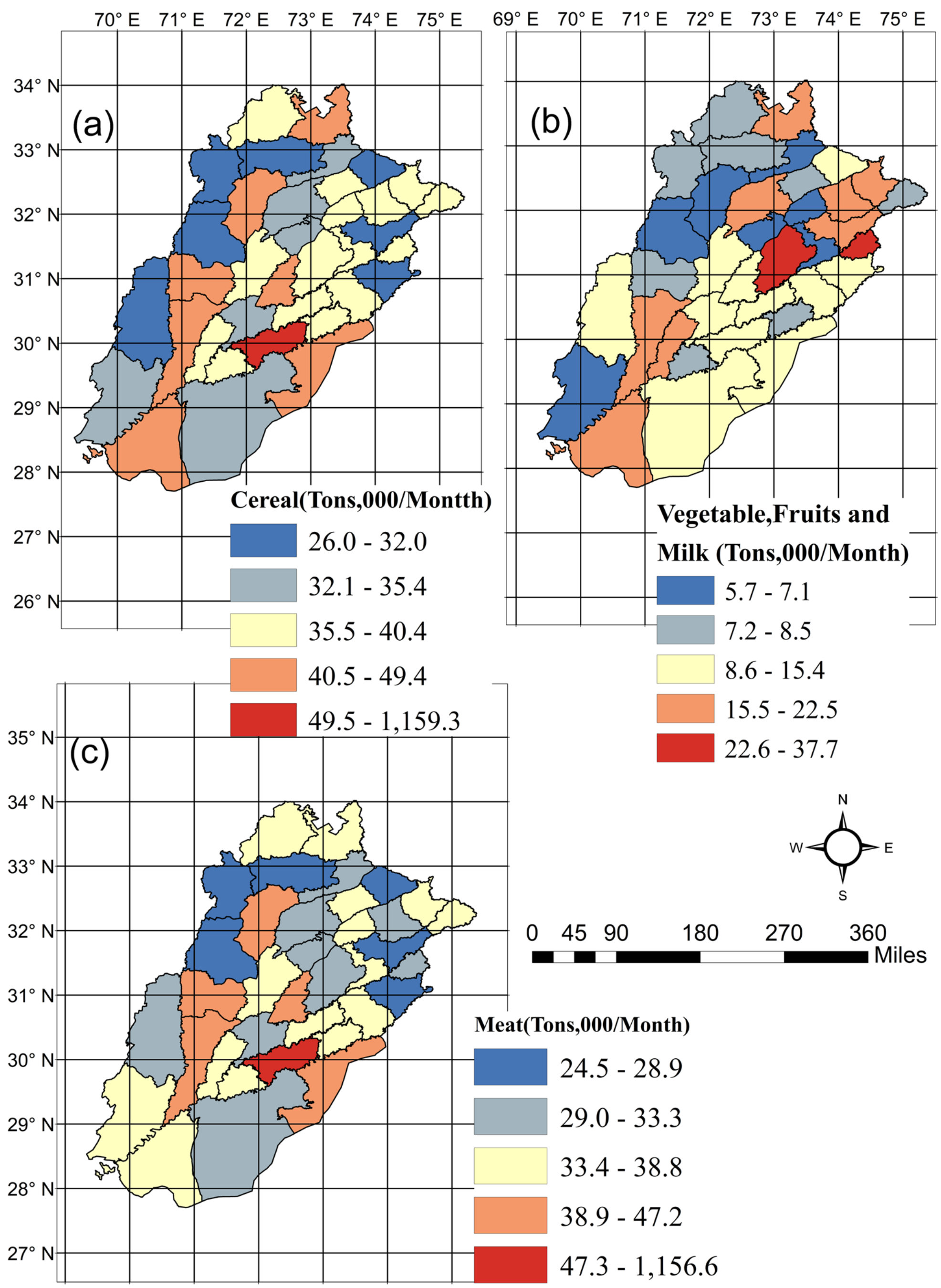

Table 2 Percentage of carbohydrate, fat, and protein intake per capita from monthly consumption of major food commodities belonging to categories I-III for both rural and urban households; and nutrients converted into weights of commodities consumed

Food category	Commodity	Carbs (%))	Kg/month Urban	Rural	Fats (%)	Kg/month Urban	Rural	Proteins (%)	Kg/month Urban	Rural
I	Wheat	72	8.9	11.7	2.5	0.3	0.4	13.2	1.6	2.2
	Rice	28	1.2	1.3	0.3	0.1	0	2.7	0.1	0.1
	Pulses	20	0.4	0.4	1	0	0	9	0.2	0.2
II	Mutton	0	0	0	21	0.4	0.5	25	0.5	0.6
	Beef	0	0	0	15	0.5	0.5	26	0.9	0.9
	Chicken	0	0	0	12.6	0.6	0.4	24.7	1.2	0.9
III	Fruits	18.7	0.8	0.6	1.2	0.1	0	1.7	0.1	0.1
	Vegetables	3.6	0.3	0.3	0.4	0	0	2.9	0.2	0.3
	Milk	5.2	1	1.1	4.7	0.8	0.9	3.2	0.6	0.7

to keep the prices smooth. The spatial distributions of food quantities per Km^2 grid indicate within-districts disparities and determines mismanagement of food policy implications across the province.

Figure 3(a–c) show district-wise food consumption distributions. A distribution for a food category is aggregated from per capita per Km^2 consumption of all commodities belonging to that category. Spatial disparities observed in Fig. 2(a–i) are further confirmed with Moran's I values observed equal to 0.61 for wheat, 0.42 for rice, 0.46 for pulses, 0.39 for chicken, 0.51 for beef, 0.31 for mutton, 0.37 for fruits, 0.23 for vegetables, and 0.61 for milk at the $p < 0.0001$ significance level. It indicates a clustered pattern of food consumption among all districts in Punjab, i.e., the access to major food commodities are not randomly distributed in the province but in a clustered way. The null hypothesis, in this case, is therefore rejected.

Analyzing spatial patterns of nutrient consumption

Table 2 shows results of the nutrition demand analyses in terms of percentage of carbohydrate, fat, and protein intake per capita from monthly consumption of major food commodities belonging to categories I-III for both rural and urban households. Moreover, the weights of commodities consumed (kg/month) to nutrients intake are shown. More negligible differences can be marked in the consumption for percentage nutrient intake from major food items in rural and urban populations. These minor differences may be attributed to the better quality of food commodities in rural areas. However, future studies may investigate the disparities between middle income and more affluent urban populations in the province.

Figure 4(a–c) show per capita consumption of proteins, fats, and carbohydrates, respectively, converted into kg equivalent of food consumed in a month. The proteins and fats consumption is high ($2059 - 3627$ kg/capita/month) in most of the areas in the northeast compared to low-levels ($26 - 768$ kg/capita/month) in the south and central Punjab. It indicates an enormous inequality of nutrition consumption among southern and other districts of Punjab. However, the intake of carbohydrates is comparatively equal and sufficient across the province Fig. 4(c).

Figure 4(a–b) show high clustering effects in the spatial distribution of proteins and fats intake within the districts (i.e., urban-rural disparities) and across the north, center, northeast, and south regions of the province. It is further confirmed with the values of Moran's I and z-score observed equal to 0.58 and 7.3, respectively, at the $p < 0.0001$ significance level. It indicates that proteins and fats intake are not randomly distributed in the province but in a clustered way. The null hypothesis, in this case, is therefore rejected.

Analyzing spatial patterns of food production

Figure 5(a–c) show the production distributions of food commodities belonging to categories I-III in all districts of Punjab. It indicates comparatively low production levels (shown with blue shades) in the south than high levels (shown with red shades) in center and northeast districts. Low cereal production in north Punjab (i.e., Rawalpindi, Attock, Jhelum, Khushab, and Chakwal) may be linked with arid conditions, and, consequently, low water availability, extreme weather, poor soil quality, and mountainous terrain. However, meat production is also seen very low in this region despite suitable conditions for the livestock sector. Policies to intensify meat production in Northern Punjab can increase the per capita availability of meat in the province. Especially, promoting rural poultry can minimize the enormous gaps in chicken production and per capita demand in urban (0.42 Kgs) and rural (0.26 Kgs) areas (see Table 1).

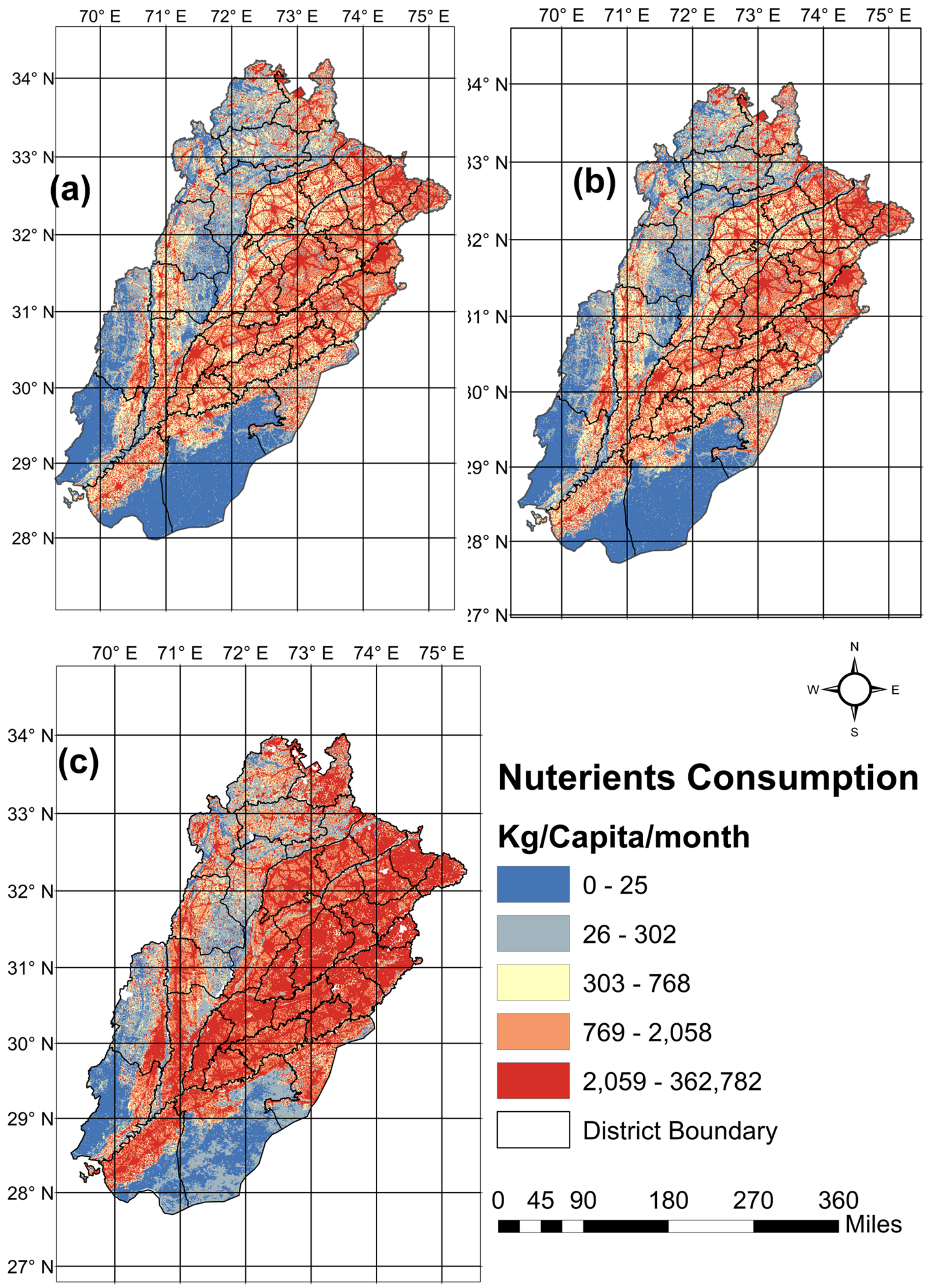

Fig. 4 Estimated per capita consumption of proteins (**a**), fats (**b**), and carbohydrates (**c**) converted into kg equivalent of food consumed in a month

Table 1 shows the production of major food commodities and their per capita availability in the province. It indicates that the production of pulses in entire Punjab is observed very low (2.9 thousand tons), despite the province remained major pulse grower contributing 83% of the area and 77% of production in Pakistan's total area and production of pulses. Consequently, per capita availability of pulses (0.645 Kgs) has gone less than that of wheat 10 Kgs and vegetables (4.66 Kgs) in 2014-15.

Analyzing production-consumption gaps and inequalities

Table 3 shows production-consumption gaps of major foods from categories I-III in the districts belonging to north, center, northwest, and south regions of Punjab. It indicates high negative production-consumption gaps of the category-I food items for all districts belonging to the arid region, including Rawalpindi (-28 thousand tons),

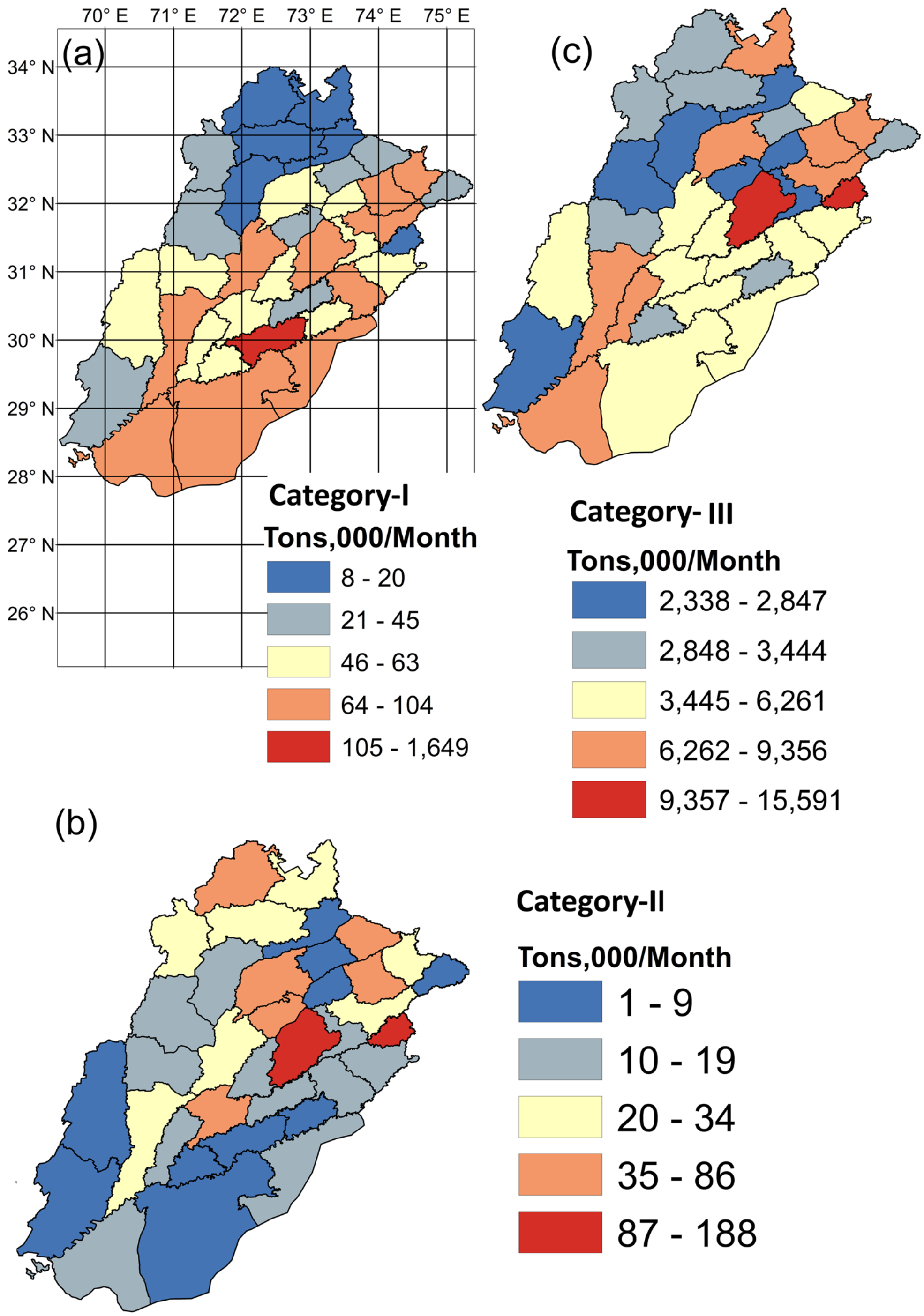

Fig. 5 District-wise distributions of monthly food production (tons, 000) in all commodities belonging to (**a**) category I (cereals), (**b**) category II (meat) () category III (fruits, vegetable, and milk) in Punjab

Khushab (-27), Jehlum (-26.2), Chakwal (-15.5), Attock (-21.0). It shows shortages of cereal supplies in these districts. Consequently, we see low cereal consumption (see Fig. 2(a–c)) and high nutrient deficiencies of the population in those districts (see Fig. 4(a–c)), compared to north and northeastern districts of the province.

Overall negative production-consumption gaps in meat observed in the entire province become more prominent for all districts in south, including Vehari (-115 thousand tons), Lodhran (-36), Rajanpur (-31), Bahawalnagar (-30) Rahim Yar Khan (-29), Layyah (-22), and Bahawalpur (-21). It indicates crumbling livestock production systems in the entire province since spatial disparities are not notable in the estimated per capita monthly consumption and income percentage spent on meat consumption (see Fig. 2(d-f)). High negative gaps in food production and consumption

Table 3 Production-consumption gaps (tons, '000')of major foods categorized with category-I (grain products/cereals), category-II (meat), and category-III (fruits, vegetables, and milk) in the districts belonging to north, center, northwest, and south regions of Punjab

Region	Districts	Cat-I	Cat-II	Cat-III
North	Rawalpindi	-28.0	-5.0	6585.8
	Jhelum	-26.2	-24.0	2451.1
	Gujrat	-3.3	25.0	5560.4
	Chakwal	-15.5	-1.0	3061.4
	Sialkot	36.7	-11.0	7341.9
	Narowal	7.17	-32.0	3410.8
	Attock	-21.0	13.0	3312.9
Center	Sargodha	15.4	15.0	7122.5
	Hafizabad	25.5	-32.0	2332.0
	Mianwali	11.6	-3.0	3039.3
	Khushab	-27.0	-30.0	2496.0
	Jhang	45.8	-14.0	4810.1
	Chiniot	2.2	28.0	2803.5
Northeast	Lahore	-17.0	96.0	13445.1
	Faisalabad	43.6	155.0	15552.9
	Gujranwala	67.5	54.0	9333.2
	Toba Tek Singh	3.1	-37.0	4478.3
	Mandi Bahauddin	6.2	-33.0	3091.8
	Nankhana Sahib	12.8	-23.0	2840.0
	Kasur	27.9	-12.0	6246.1
	Sheikhupura	55.6	6.0	6802.4
	Sahiwal	1.9	-27.0	4632.7
	Okara	55.2	-20.0	5974.5
	Pakpattan	18.5	-30.0	3435.5
South	Layyah	8.3	-22.0	3125.6
	Multan	9.3	-17.0	8380.8
	Khanewal	25.5	12.0	5359.6
	Lodhran	18.2	-36.0	3221.0
	Bhakkar	6.5	-14.0	2778.1
	Vehari	489.5	-1150.0	5434.0
	Bahawalnagar	55.3	-30.0	5818.1
	Bahawalpur	41.6	-21.0	6061.5
	Rahim Yar Khan	43.3	-29.0	8004.2
	Muzafar Garh	33.5	-11	7261.4
	Rajanpur	3.5	-31	2773.5
	D.G Khan	16.4	-21	4571.9

in southern districts can be further linked with the low protein and fat consumption in those areas (see Fig. 4(a–b)). We observed overall positive gaps in the production and consumption of food items in category III (i.e., fruits, vegetables, and milk) for all districts, which indicates the over-supply of these food items in the province. However, the gaps vary profoundly high in the range from 2451 in Jehlam to 15552.9 thousand tons in the Faisalabad districts.

Figure 6(a–i) shows spatial distributions of the production-consumption gaps in all districts of the province. High variability of these gaps indicates inter-district disparities. Clusters of districts to the gaps with low and high intervals indicate high inequality among southern and other districts of Punjab. It is further confirmed with Moran's I value observed 0.49 for category-I, 0.41 for Category-II, 0.61 for pulses Category-III food commodities at the

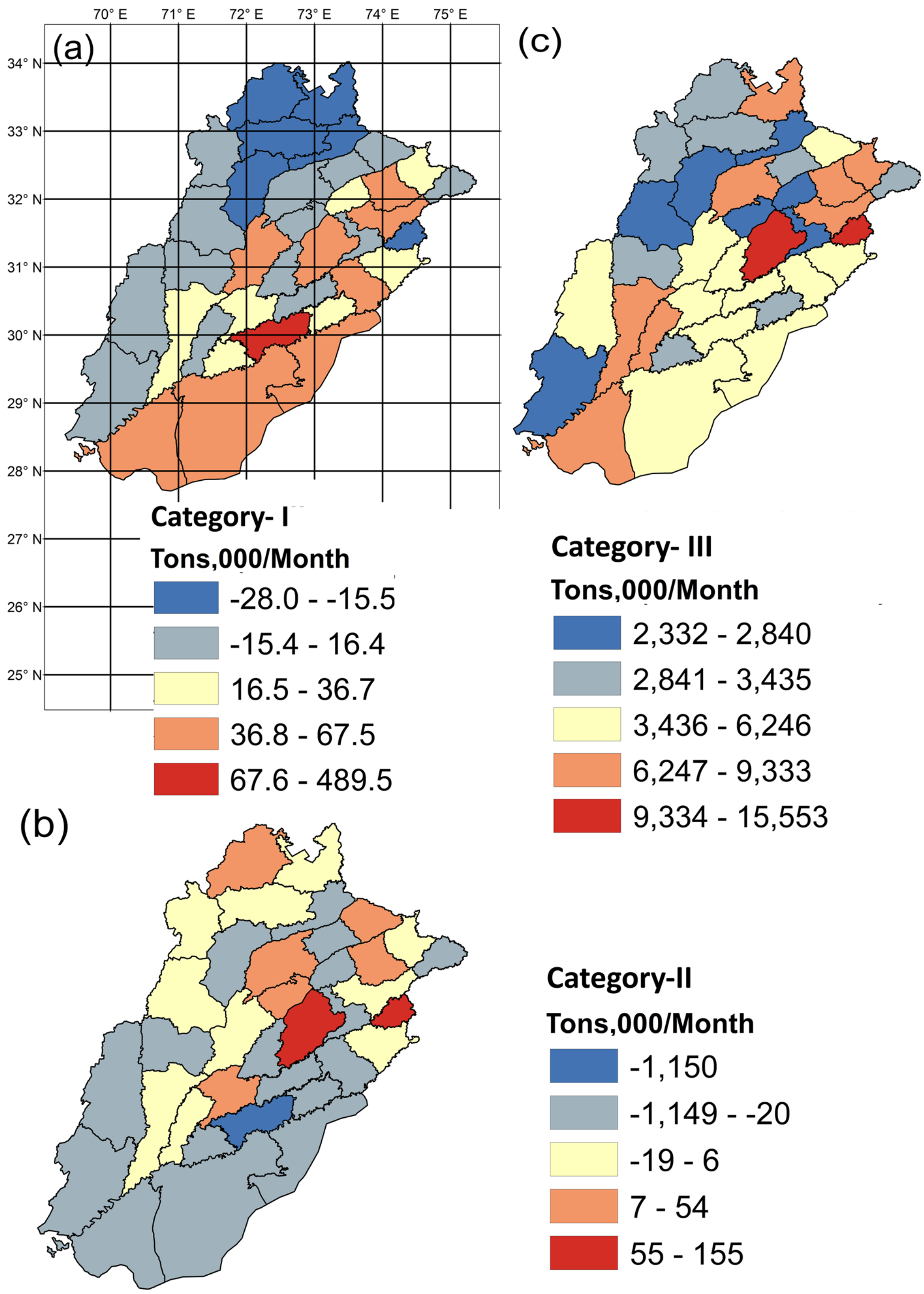

Fig. 6 District-wise distributions of monthly production-consumption gaps (tons, 000) in all commodities belonging to (**a**) category I (cereals), (**b**) category II (meat) category III (fruits, vegetable, and milk) in all districts of Punjab

$p < 0.0001$ significance level. It confirms the production-consumption gaps are highly spatially autocorrelated in Punjab. The null hypothesis that their distribution is random in the study area is therefore rejected. Our findings clearly show that the south of the province is a neglected region in the provision of food and nutrition.

Discussions

The present study derives various indicators from the Household Integrated Economic Surveys (HIES) and the Agriculture Marketing Information System (AMIS) household data sets for the year 2014-15. Next, it disaggregates the food and nutrition surveys to sub-national scales (i.e., per Km^2, per district, per region with rural-urban divisions) on the LandScan population data set in the GIS environment. Finally, it measures spatial inequalities in food provisioning using global and local Moran's indices.

Households in urban areas spend 63.3% of the monthly income for consuming food, compared to 67.1% in rural areas. However, proteins and fats consumption are high (2059 – 3627 kg/capita/month) in most of the areas in the northeast compared to low-levels (26 – 768 kg/capita/month) in the south and central Punjab. Moreover, the production-consumption gaps of the category-I food items are observed profoundly negative for all districts belonging to the arid region, including Rawalpindi (-28 tons, '000'), Khushab (-27), Jehlum (-26.2), Chakwal (-15.5), Attock (-21.0).

One specific aspect is the movement of commodities across the region, which also influences the supply and demand for food, and ultimately the consumption-production gaps. However, during the study period, this effect is not observed because of the Punjab government-imposed restrictions on the inter-district and inter-provincial movement of commodities. Moreover, the movement of commodities in Punjab mostly depends on the road network whose quality is not uniform across the province.

Pakistan's national economy, in general, and the rural economy, in particular, is agriculture-based. Country agriculture has fulfilled the food requirements of its population for many years. However, in recent years, the unplanned and rapid increase in population has widened the gap between population growth and domestic food production. People in the province are facing unequal income and landholding in addition to disparities in health, education, and civic facilities (Imran et al. 2019). Consequently, dimensions of poverty and food security are different in rural and urban areas. Attaining food security in the country needs formulating agricultural policies that address inequalities in food supply and other socio-economic conditions differently in urban and rural areas.

We intend to extend this research to linking spatial inequalities associated with food production-consumption and nutrition gaps to the collocated values of various environmental variables on climate change, land-use change, and land degradation obtained through remote sensing imagery and global data sets. Through spatially exploring these relations over large areas, we want to capture local dynamics of the identified inequalities in this research. Similarly, we have mapped the spatial distribution of inequality in food consumption and nutrition status over large areas. Quantifying the potential implications of findings on health status would require further linking this research outcome to various health consequences obtained from national health surveys.

Conclusion

The evidence-based approach here evaluates geographical equity (or inequity) in the availability of food and nutrition in Punjab. Our results indicate a high inequality of food production-consumption gaps between the South and North Punjab. Geospatially disaggregating traditional food and nutrition surveys at the sub-national scales and linking them to locations in the GIS environment can give better insight into various dimensions of food security. Spatial variability of gaps between the nutrient's demand, food consumption, and production can identify geographical disparities among regions and commodities that are either oversupplied or have shortages.

Our findings reveal the food consumption and nutrition intake are clustered and unevenly distributed, which reflects the true picture of inequalities. High spatial autocorrelation of within-districts gaps of production and consumption observed in the province indicates that inequality is driven by location dynamics and not by population. The absence of credible planning on pulses, livestock, and dairy production, however, is entangled with rural-urban consumption disparities, overall nutrient deficiencies, and inequality in diverse geographical areas. Thus, a holistic approach to analyze food patterns at different sub-national levels (i.e., per Km^2, per district, per region with rural-urban divisions) may better reveal inequalities within countries in reference to the Sustainable Development Goal 10.

We conclude that nutrition intake in Punjab is directly related to the status of food availability in different regions. Overall analyses reveal the sprawling North-South divide in the province observed in recent years. It confirms the upper belt of Punjab is having low production-consumption gaps than the lower. With the on-going initiatives under Sustainable Development Goal 10, upgrading the institutional capacities and resources, especially in disparity areas, will ensure sustainable food security in Pakistan.

The multidimensional methodology developed for this study can help in marking disparity areas and locations to efficiently assess and plan production and consumption of commodities from baseline surveys and agriculture information systems. The use of GIS to geographically assess the food and nutrition status can help to formulate evidence-based policies with demography. Through integrating complex household data sets, spatial analyses, and econometric algorithms, we demonstrated a geographically-explicit and evidence-based approach for mapping food inequality for the Punjab province. This can be extended to other domains and regions and will help authorities for better policy interventions.

Compliance with Ethical Standards

Conflict of interests We declare that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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