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REVIEW ARTICLE

A Review of Food Security and the Potentials to Develop Spatially Informed Food Policies in Bangladesh

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Abstract
Background Food security globally depends primarily on three components: food availability, food access, and food utilization. Regional variations of these components may affect food security via spatial differences in natural, social or economic conditions and the interaction of these in a complex environmental system.
Purpose It is important to understand the regional variation of food security, particularly where and under what natural and socio-economic circumstances people become vulnerable to low food security in a country.
Methods This article provides an overview of food security in Bangladesh in terms of the three main components, identifies knowledge gaps in present food security research, reviews possible impacts of climate change on food security, and sourced a wide range of spatio-temporal data relevant for food security.
Results The study highlights potentials and indicates different processes to develop spatially informed food policies in a country, particularly focuses on Bangladesh. This will contribute to improved food security by considering regional food security conditions, region-specific deficits, climate change, other future risks, and devises actions related to the respective components.
Conclusion The study concludes that different processes can provide a foundation for policy development and these will advance research-policy linkage to improved food security.

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Keywords Bangladesh · Food security · Food availability · Food access · Food utilization · Climate change · Policy

1 Introduction

Food security is a complex and important global issue that is affected by environmental system and human actions (Simelton et al. 2012; Tiwari and Joshi 2012). Many natural variables, including climate change, may influence food production, while socio-economic variables are mostly responsible for food access in a country (Burke and Lobell 2010; Harvey and Pilgrim 2011). One most recent estimate identifies about 795 million undernourished people in the world, with one-third of these people living in South Asia, including Bangladesh (FAO 2015). Bangladesh is facing challenges in attaining and maintaining food security because of its large population, numbering 152 million at the last population census from 2011 (BBS 2011a). In addition, numerous drivers including poverty (Kam et al. 2005), malnutrition (Bose and Dey 2007; Hossain et al. 2005), frequent disasters (Mirza 2002; Ninno and Lundberg 2005), agricultural management practices (Ara et al. 2016) and the effect of climate change (Karim et al. 1996; Sarker et al. 2012; Ruane et al. 2013; Ara et al. 2017) influence food security across the country (Habiba et al. 2015a).

According to the Food and Agricultural Organization (FAO), a country achieves food security when it ensures adequate food along with a nutritious diet for the entire population (FAO 2006). Thus, the concept of food security indicates a situation in a particular place and time where people live without hunger or fear of undernourishment. Food security is constituted by the three components of food availability, food access and food utilization (FAO 2006). Until 1980, food availability was seen as the key component to ensure food security in Bangladesh and the government prioritized food production to overcome food shortages (Elahi and Ara 2008). However, Sen's (1981) analysis clearly indicates that food availability is not the only component of food security in the country. Low food security can result from an individual's lack of ability to access enough food because of poor socio-economic conditions or inadequate food distribution in a place. All food security components are now considered as important in existing food policies in Bangladesh (MoFDM 2006; Ahmed 2015).

Globally, several studies have analyzed the food security components individually, leading to improved food policies in their respective countries (Ray 2007; Rocha 2009; Bashir and Schilizzi 2015). Similarly, in Bangladesh food security has been analyzed in terms of food availability (Mainuddin and Kirby 2015; Parvin and Wakilur 2009), food access (Hossain et al. 2005; Thorne-Lyman et al. 2010, Bose and Dey 2007; Faridi and Wadood 2010) and food utilization (Pitt 1983; Hels et al. 2003; Rahman and Islam 2014). Whilst these findings successfully inform food policy, the full complexity of food security cannot be understood and addressed effectively using the components individually for a better policy (Pinstrup-Andersen 2009). Some assessments (Mainuddin and Kirby 2015; Parvin and Wakilur 2009) have considered the temporal dimension of food security in Bangladesh, but the spatial aspects of food security have mostly been overlooked. Spatial patterns of food security including these components have received attention from food security scholars globally (Belesky 2014; Ray 2007; Iizumi et al. 2013). However, existing food security studies for Bangladesh are not adequately addressing the spatio-temporal dynamics of food security components in the country. To strengthen food security research in Bangladesh and in many countries globally spatial analysis is required to assess all food security components.

Diverse regional and environmental conditions affect food security, but these have received insufficient attention in terms of both research and food policy in Bangladesh. Food production varies due to natural conditions (including climate change) and socio-economic conditions (Faisal and Parveen 2004). Climate change may affect food production in a spatial manner in Bangladesh (MoEF 2005, 2009). Many studies have principally focused on crop production to understand the impact of climate change on food availability (Karim et al. 1996; Sarker et al. 2012; Ruane et al. 2013; Parvin and Ahsan 2013; Sarker et al. 2014; Amin et al. 2015). Hence, these studies have substantial limitations in considering climate change impact on regional food security. Beside climate change, other regional factors such as bio-physical, management, and socio-economic conditions may affect food security. Both the National Food Policy (NFP) (MoFDM 2006) and the National Food Policy Plan of Action (NFPPA) (MoFDM 2008), in particular, do not address regional details effectively to reduce food security challenges in a complex environmental system in the country. A spatially informed food security assessment is needed to advance the research-policy linkage in the country by considering such a system. The objectives of this paper are: (1) to provide an overview of food security in Bangladesh; (2) to examine the national data sources relevant for food security; and (3) to address a way forward for a spatially informed food policy development.

2 Food Security in Bangladesh

Bangladesh is located in the Ganges–Brahmaputra delta with an area of 147,570 km^2 (BBS 2014). At present, the administrative geography of Bangladesh is divided into eight major administrative divisions, 23 greater region, 64 districts (zilas), 545 sub-districts (489 upazilas and 56 thanas), and 4550 unions (GoB 2016). Figure 1 indicates the administrative boundaries of Bangladesh (greater region, districts, and sub-districts). Food security varies across Bangladesh and administrative levels, particularly sub-districts, are typically used to show the regional

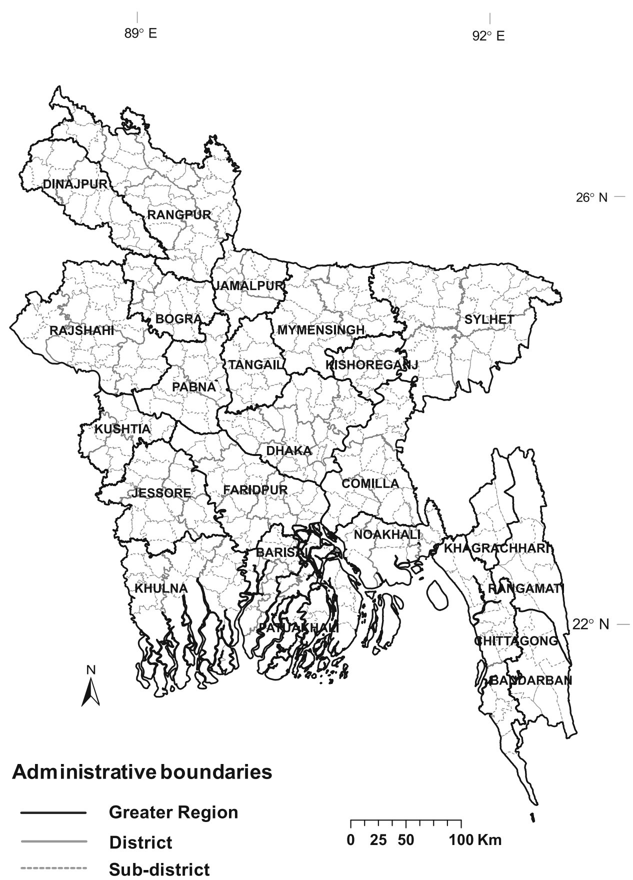


Fig. 1 Administrative boundaries of Bangladesh. Source: BBS (1981, 2014)

variations of food security (GoB and WFP 2004). This section of the paper documents food security in Bangladesh and highlights food security conditions including: (a) spatial variations of food security, (b) food availability, (c) food access, and (d) food utilization.

2.1 Spatial Variation of Food Security

The Food Security Atlas of Bangladesh compiled by GoB and WFP (2004) represents the first major initiative to assess regional variations of food security at the sub-district level in Bangladesh. The atlas uses indicators such as low agricultural production, limited infrastructure, poverty, seasonal unemployment, limited public and health facilities, unawareness regarding hygiene and sanitation practices, and the frequent occurrence of natural hazards. The data used in the atlas for map production were collected from the Bangladesh Population Census, 2001 (BBS 2001), the Local Government Engineering Department (LGED), and the Bangladesh Agricultural Research Council (BARC). To visualize the overall spatial pattern of food security, these indicators were ranked at sub-district level from 1 to 511 (470 upazila and 41 urban thanas included) and summed. The resulting map (Fig. 2) shows distinct clusters of very low to low levels of food security in the following regions: (a) the Northwest, (b) the Sylhet Basin, (c) the Chittagong Hill Tracts (Chittagong, Bandarban, Rangamati and Khagrachhari), and (d) the Coastal Regions. Whilst the atlas is very useful for understanding the spatial variations of food security determinants across the country, the maps are based on 2001 census data without subsequent updates and without the possibility of understanding the spatio-temporal dynamics of different indicators. The regional context was represented in the atlas by using the household data aggregated to respective sub-districts, but this did not show the variations of food security indicators within individual sub-districts.

2.2 Food Availability

Food availability refers to the sufficiency of food that is supplied through domestic production or imports (including food aid) (FAO 2006). Both food production and food requirements in Bangladesh have changed over time. Bangladesh typically depends on grain, particularly rice, wheat, and maize, which meet the majority of food requirements. When national food production does not meet the national food requirement, a nation experiences a food gap. The persistence of a food gap in Bangladesh until 1999 can be visualized by comparing the Net total Food Grain Production (NFGP) with the Food Grain Requirement (FGR), shown in Fig. 3. Net total Food Grain Production is estimated from local food production

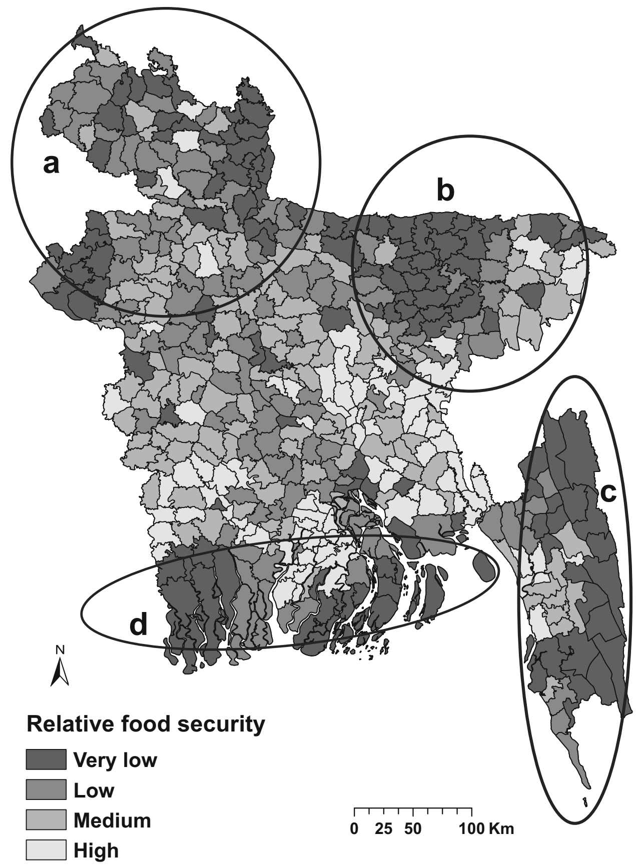
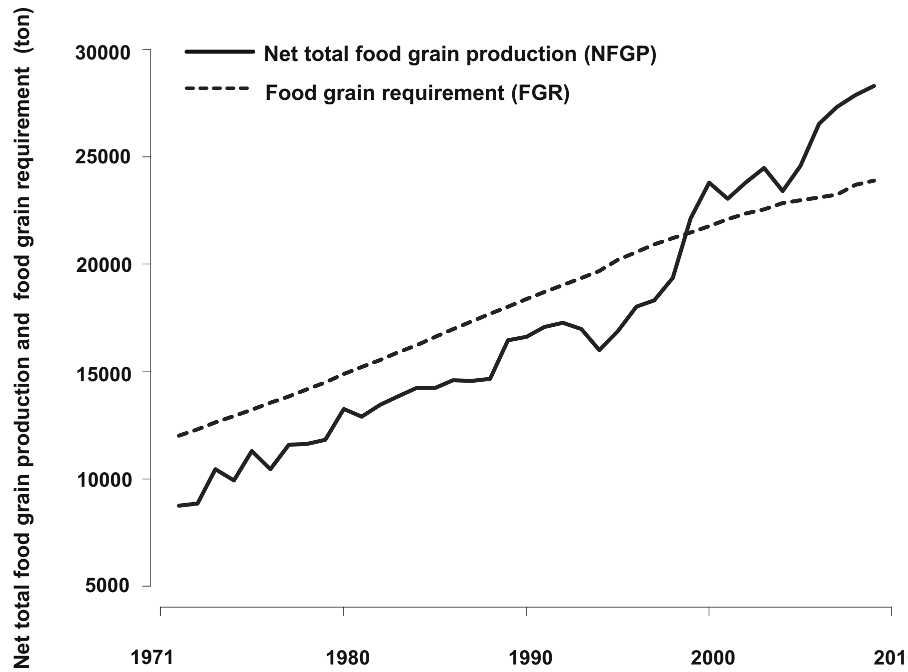


Fig. 2 Spatial distribution of levels of food security in Bangladesh at sub-district level, 2001. The key areas of very low to low food security, **a** the Northwest, **b** the Sylhet Basin, **c** the Chittagong Hill Tracts (Chittagong, Bandarban, Rangamati and Khagrachhari), and **d** the Coastal region of Bangladesh. Source: GoB & WFP (2004)

(particularly rice, wheat, and maize) by assuming national estimates of seed, feed, and wastage, 11.58% (MoF 1991). The Food Grain Requirement can be estimated from population numbers by assuming a constant grain consumption per day per person (here we used, 16 oz or 453.66 g; FPMU 1991). Both the NFGP and FGR increased between 1971 and 2010 (Fig. 3). Bangladesh closed the food gap in 1999 when the food grain requirement dropped below the net total food grain production (Talukder and Chile 2011). This demonstrates the success of government initiatives to overcome the food gap by raising local food production, particularly rice production.

The national production of rice substantially increased from 9774 tons in 1971–72 to 33,889 tons in 2011–12 (BBS 2012a). This was primarily due to the introduction of High Yield Varieties (HYV) from the early 1970s (Deb et al. 2009) and an increase in irrigated land for rice cultivation since 1991 (Parvin and Wakilur 2009). The area under irrigation increased from 1.64 to 6.15 million hectares between 1981 and 2012 (BBS 2012b). Approximately, 65% of the cultivated land was irrigated in 2012,

Fig. 3 Trends in national Net Total Food Grain Production (NFGP) and Food Grain Requirement (FGR) of Bangladesh over the period of 1971–2010



contributing substantially to increased production; predominantly rice (Rahman and Mondal 2015). Cropping intensity also increased from 151 to 183% for the same period (BBS 2011b). Local food production varies regionally due to environmental conditions and varied management practices, including cropping intensity and irrigation (Brammer 2000; Rahman 2010; Alauddin and Sharma 2013). However, these were not considered in previous food security assessments (Mainuddin and Kirby 2015; Parvin and Wakilur 2009) to analyze national food availability. Although Bangladesh now maintains relative self-sufficiency in rice production, this has not been accompanied by substantial rises in the availability of other foods. Food availability in Bangladesh may face challenges in the future because of low production of other non-grain foods, import management of food (Bishwajit et al. 2013) and, regional variations of local food production due to climatic and other environmental conditions.

2.3 Food Access

Food access refers to the economic, social, political and legal rights of individuals to adequate resources for getting sufficient food for a nutritious diet (FAO 2006). Poverty has decreased in Bangladesh since 1992 (FAO 2013). Per capita Gross Domestic Production (GDP) (adjusted to US$ in 2014) has increased over the last 52 years from $100 in 1962 to $1089 in 2014 (BBS 2014). Employment generation has increased through public and private sector programs and the number of the extreme poor reduced from 44 million in 2000 to 26 million in 2010 (FAO 2013). Regardless of these positive achievements, undernourishment still exists in the country, as 60 million people are not able to consume the minimum daily food intake required for a healthy life (FAO 2013). Furthermore, levels of poverty vary substantially across the country (BBS et al. 2010; Kam et al. 2005). The poorest areas are the Northwest, the Chittagong Hill Tracts and the Coastal Region of Bangladesh, where food security was found to be critically low in 2001 (Fig. 2). Income inequality exists in Bangladesh (Hossain et al. 2005) and sources of income (agricultural and non-agricultural) and average agricultural wage rates vary geographically in the country (GoB and WFP 2004; BBS et al. 2010).

Food access often varies between rural and urban areas in Bangladesh (Pitt 1983; Hels et al. 2003). Figure 4 shows trends in per person per day total food intake (grams) by residence type (rural and urban area) (HIES, various years, BBS 2010) and required food intake (MoHFW and BNNC 1997) in Bangladesh over the period of 1983–85 to 2010. The national level per person per day food intake was sourced from various Household Income and Expenditure Survey (HIES) reports and BBS (2010) during 1983–2010. The food items considered are rice, other cereals, vegetables and potatoes, pulses, oils and fats, sugar, fruits, fish, meat, eggs, and milk. Figure 4 shows the total daily food intake in grams by summing these food items and illustrates the changes of total food intake in rural, compared with urban areas, over the period 1983–2010. Overall, per person per day total food intake has increased in both areas (Fig. 4). However, food intake in rural and urban areas has always been lower than the required food intake of 934

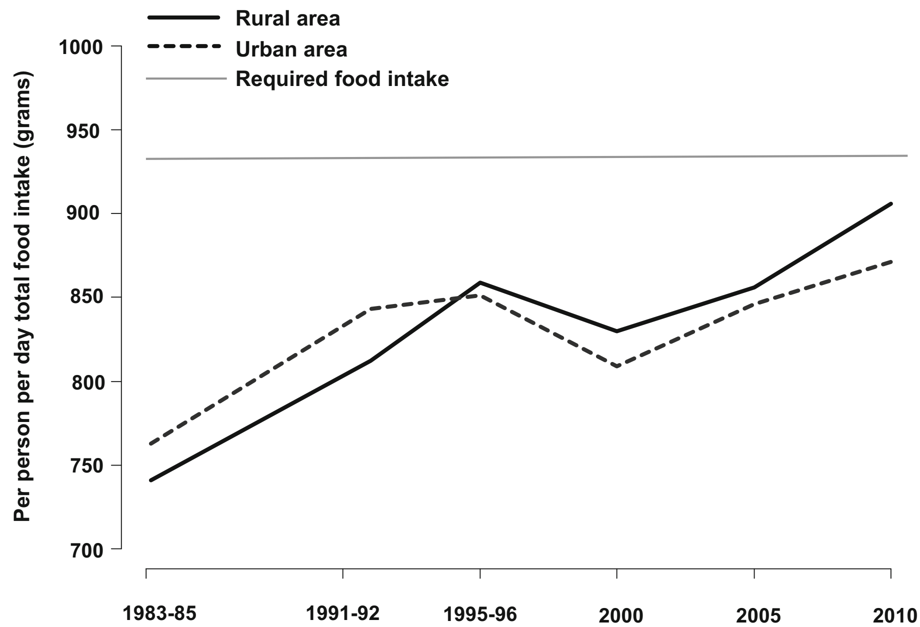


Fig. 4 Trends in per person per day total food intake (grams) by residence type (rural and urban area) in Bangladesh during 1983–85 to 2010. Data collected from (HIES, various year, BBS 2010) and compared to required food intake given by MoHFW and BNNC (1997)

grams per person per day (MoHFW and BNNC 1997). In rural areas, it has increased from 741 g in 1983–85 to 906.4 g in 2010. Food intake in urban areas showed a fluctuating trend during the period, but increased overall from 763 g in 1983–85 to 871 g in 2010 (Fig. 4). These changes may have occurred due to changes in consumption patterns of different types of foods and rural–urban demographic dissimilarities in the country during the period.

Access to infrastructure resources, particularly total delivery distances of food within a region, the location of growth centers, and access to electricity (Scaramozzino 2006; Shin 2010) may affect food access in Bangladesh. Except for the Chittagong Hill Tracts and Coastal Region of Bangladesh, the national average travel time to the nearest growth center is approximately 1 h (GoB and WFP 2004). It is likely that spatial variations of infrastructure development and socio-economic conditions may influence food security. However, little attention has been given to these conditions previously in assessing food security in Bangladesh.

2.4 Food Utilization

Food utilization encompasses the nutritional well-being of a person that comes from adequate food consumption from a diversity of food sources, food storage, and processing, including clean water and healthy environments (FAO 2006). Utilization of food has always been unsatisfactory nationally in Bangladesh. The national average per person per day nutrition intake from a variety of food sources has only slightly increased over the last 50 years from 2251 kcal (kilocalorie) during 1962–64 to 2318 kcal in 2010 (HIES 2010). It remains below the FAO recommended required average calorie consumption of 2410 kcal per person per day for adults from all sources of food (FAO 2008).

At present, Bangladesh is experiencing a substantial variation in food utilization from different food categories (FAO 2013). Figure 5 indicates the national level per person per day calorie consumption and desirable calorie consumption in kcal from 1991–92 to 2010 for rice and other major food items. The national level per person per day food intake was sourced from the reports of the Household Income and Expenditure Survey (HIES) over the period of 1991–92 to 2010 for different food items in grams. The per person per day desirable food intake was given by NFPCSP (2013) for these food items in grams. Data from both sources were converted into kcal for rice and other major food items including wheat, potato, fish, pulses, vegetables, meat, eggs, milk, and fruits by using their nutrition values (Rahman and Islam 2014). However, this estimation did not include food intake from other cereals, oils, and fat. Calorie consumption from major food items other than rice is well below the desirable calorie consumption over the entire period (per capita 1026 kcal for these items) (NFPCSP 2013). Rice consumption marginally decreased from 1991 (1518 kcal) to 2010 (1335 kcal); however, calorie consumption from rice is still higher than the desirable calorie consumption standard (per capita 1124 kcal from rice) (NFPCSP 2013). This represents a dietary imbalance in food utilization in Bangladesh.

Several factors influence the utilization of food. For instance, education levels affect the understanding of the

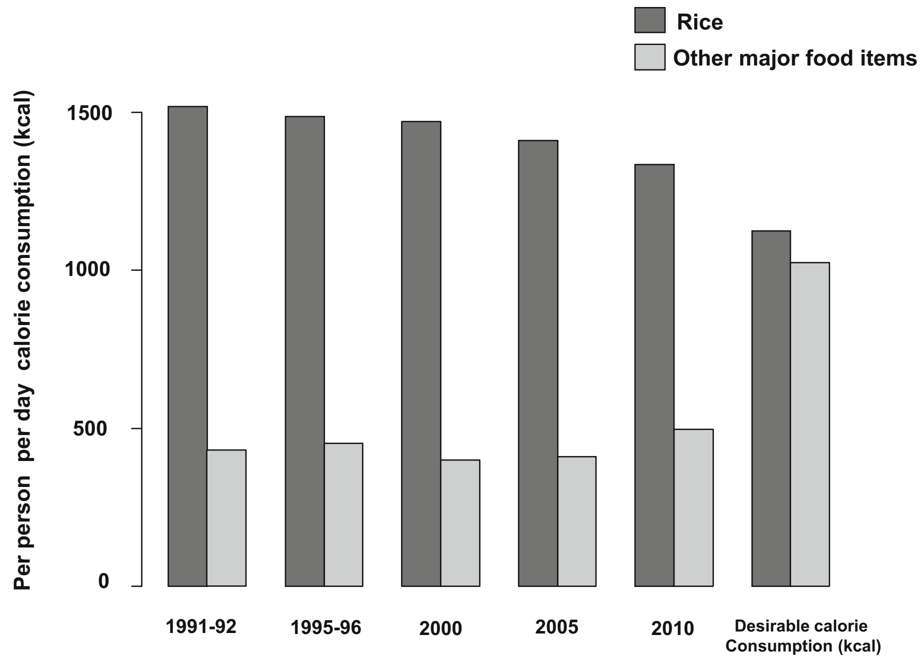


Fig. 5 Average per person per day calorie consumption (kcal) from rice and other food major items in Bangladesh during 1991–92 to 2010, Calorie consumption (kcal) and desirable food consumption (kcal) data collected from (BBS, HIES, various year) and (NFPCSP 2013) respectively

nutritional value of foods (Sajjad et al. 2014). Individual health conditions affect the capacity of the body to absorb food and access to clean and safe drinking water and sanitary facilities are critical in food utilization. In Bangladesh, 70% of the population had access to safe drinking water in 1992. This reached 85% by 2012, and the advancement in sanitation has improved (FAO 2013); however, these averages may not be representative for all regions in Bangladesh. A strong geographical association was found in three anthropometric indicators of undernutrition (stunting, wasting and underweight) at the division level (FAO 2013); with Sylhet division in the Northwest being the worst affected (BDHS 2013). Regional variation of dietary imbalance and other factors related to food utilization may influence food security in Bangladesh and it is important to evaluate these.

2.5 Food Security and Climate Change in Bangladesh

The impact of climate change on food security is an important concern globally (Rosenzweig and Parry 1994; Deryng et al. 2014; Burke and Lobell 2010; Iizumi et al. 2013) including Bangladesh (Habiba et al. 2015b). This section of the paper primarily focuses on food security and climate change in order to consider the potential geographic impact of climate change on food security components in a country, Bangladesh

Climatic variables, particularly rainfall and temperature, vary across Bangladesh over the period 1981–2010 (Fig. 6). The station-based rainfall and temperature data (BMD 2012) were interpolated and aggregated at greater region level using a Geographic Information System (GIS) to show spatial variations of rainfall (Fig. 6a) and average temperature (Fig. 6b) in Bangladesh. Most of the eastern part of the country has high rainfall; averaging 2688–3192 mm over the period (Fig. 6a). The southern part of the country has slightly higher temperatures compared with the northern part of the country (Fig. 6b). Although the spatial variations in long-term temperature are small, the differences may influence food security across the country in the long term and are similar in magnitude to the climate changes predicted to occur during the next decades (Ara et al. 2016, 2017).

Several studies have analyzed the impact of climate change on food production, particularly rice production in Bangladesh as a means of food security evaluation. Table 1 indicates various assessments on the impact of climate change on rice yield/production in Bangladesh for different rice eco-types (Aus, Aman, and Boro). Assessments based on crop models such as Simulation Models, Crop Environment Resource Synthesis (CERES), Decision Support System for Agro-technology Transfer (DSSAT) and Multifactor Impact Analysis predicted a decrease in rice yield due to temperature increase (Karim et al. 1996; Basak et al. 2010; Ruane et al. 2013). On the other hand, empirical assessments showed mixed responses from climate change for different rice eco-types, based on historic evidence (Rimi et al. 2009; Sarker et al. 2012, 2014; Amin et al. 2015). Some studies assessed the combined effect of both climatic (rainfall and temperature) and management practices (irrigation and cropping intensity) variables on rice

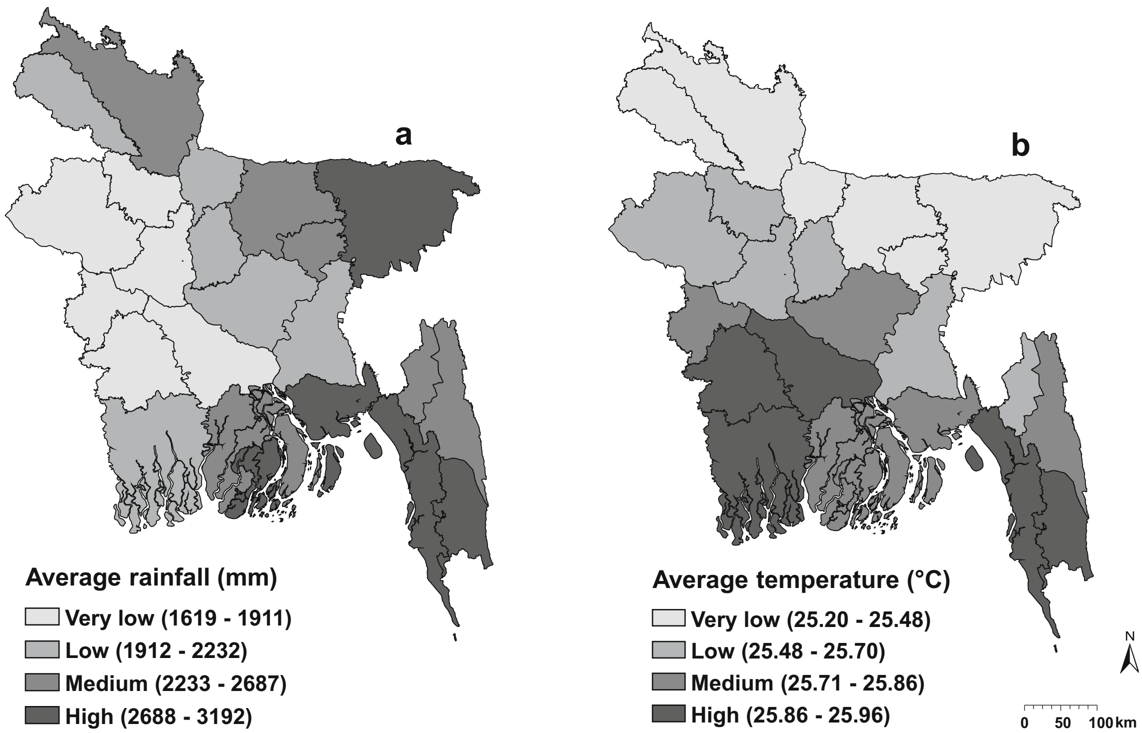


Fig. 6 Spatial distributions of average rainfall (**a**) and average temperature (**b**) at greater regions level in Bangladesh during 1981–2010. Classes represent quartiles

yield. (Ara et al. 2016) whereas others primarily focused on the benefit of transplanting date changes for Boro rice alone (Mahmood 1998; Mahmood 2003). However, there is significant uncertainty concerning changes in rice production/yield associated with climate change (Karim et al. 1996; Ruane et al. 2013) as the effects vary in the different studies (Rimi et al. 2009; Sarker et al. 2012, 2014; Amin et al. 2015). Climate change may also indirectly affect food production in coastal areas because of salinity intrusion and increased yield variability causing reduced food availability (Parvin and Ahsan 2013; Sarwar and Islam 2013).

Table 1 shows that some assessments include the location to ascertain the regional variations of climate change impact on rice yield, particularly at the broad climatic zone (Sarker et al. 2014) or agro-ecological zones (Ruane et al. 2013). Using a multifactorial mixed model analysis, temperature significantly decreased yield by 0.14 t/ha rice yield per 1 °C; thus, even small spatial temperature differences may have noticeable effects on crop yield averages (Ara et al. 2016). Such a spatial difference of temperature may affect other crop (wheat, potato, pulses, and vegetables) production.

Both the National Adaptation Program of Action (NAPA) and the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) recognize the importance of spatially variable climate influences on food security and indicate the need of region-specific adaptation measures to reduce the risk of local low production due to climate change for different crops (MoEF 2005, 2009; Islam et al. 2013a). Unfortunately, the spatial detail in existing understanding of climate change impacts still limits region-specific actions (Islam et al. 2013b). In addition, food security is strongly influenced by natural disasters including flood, drought, cyclones, and riverbank erosion, which will likely increase with climate change (Karim et al. 1990; Brammer 1999). Natural disasters can make areas vulnerable to reduced production, can cause damage to infrastructure and communication networks and can lead to a displacement of people (Islam and Sumon 2013; Coirolo et al. 2013). In Bangladesh, floods influence the food distribution system through their impact on roads and transport networks. However, the regional influence of natural disasters on food security in Bangladesh is little studied.

In addition to food availability, climate change may also affect food access and food utilization in Bangladesh. As agricultural production becomes susceptible to environmental and socio-economic conditions, farmers may change preferences for crop production (Rosenzweig and Binswanger 1993; Simelton et al. 2012; Iizumi and Ramankutty 2015). This eventually influence the availability of food for local consumption; all having a potential influence on household income (Burke and Lobell 2010).

Climate change is likely to become an important part of food security in Bangladesh. In certain districts in

Table 1 Assessments on impact of climate change on rice production/rice yield in Bangladesh

Authors of the assessments[a,b,c]	Year	Rice	Models	Variables	Impact on Rice eco-types*			Location	Climate change (scenarios* /historic evidence)	General comment
					Aus	Aman	Boro			
Karim et al.[a] (1996)	1996	Yield	CERES-Rice	Temperature (average)	–	–	–	6 districts	GCM	Rice yield changes are varied in six districts due to different simulation
				Temperature (average) and Co_2		–	–		CCCM	
				Only Co_2	+	+	+		GFDL	
Mahmood[c] (1998)	1998	Productivity	YIELD	Climate				2 districts (Mymensingh and Barisal)		Comparison of two models for modifying the transplanting date of Boro only
			CERES	Pedological						
				Hydrological						
				Agronomic						
				Climate station ((lat, long)						
Mahmood et al.[c] (2003)	2003	Yield	CERES-Rice	Climate				Climate Station locations (16)		Which region would get benefit from a transplanting date change for Boro cultivation
				Pedological						
				Hydrological						
				Agronomic						
				Climate station ((lat, long))						
Rimi et al.[b] (2009)	2009	Production	Statistical analysis	Temperature (seasonal max)	0	–	+	1district (Shatkhira)	GCM-GFDL-TR	Changes in rice yield varied due to different climate scenarios
				Temperature (seasonal min)	0	–	+		UKTR	
				Rainfall (seasonal total)	+	–	–		HadCM2	
				Soil	–	+/–	+/–			
Basak et al.[c] (2010)	2010	Yield	DSSAT	Temperature (seasonal max)			–	12 districts	PRECIS	Reduction of Boro rice variety (BR3 and BR14) yield in all locations
				Temperature (seasonal min)						
				Rainfall						
Sarker et al.[b] (2012)	2012	Yield	Statistical analysis	Temperature (seasonal max)	+	0	–	National	Historic evidence	Maximum and minimum temperature are more pronounced compared with rainfall
				Temperature (seasonal min)	0	–	+			
				Total Rainfall (seasonal total)	+	+	0			
Ruane et al. [a] (2013)	2013	Production	Multifactor impact analysis	Temperature (seasonal max)	–	–	–	16 agro-ecological zones	GCM	Substantial changes in rice yield for climate scenario in different zones were measured alone
				Temperature (seasonal min)	–	–	–			Sea level rise was not simulated for all regions
				Rainfall (seasonal mean)	–	–				
				Co_2	+	+	+			
				Flood	–	–				
				Sea level rise	–	–	–			

Table 1 continued

Authors of the assessments[a,b,c]	Year	Rice	Models	Variables	Impact on Rice eco-types*			Location	Climate change (scenarios* /historic evidence)	General comment
					Aus	Aman	Boro			
Sarker et al. [b] (2014)	2014	Yield	Statistical analysis	Temperature (seasonal max)	0	+	–	7 climatic zones	Historic evidence	Rice yield changes will be higher for Aman compared with Boro and Aus due to climate change
				Temperature (seasonal min)	–	0	0			
				Rainfall	–	0	0			
				Region	+	+	+			
				Time (year)	+	+	+			
Amin et al. [b] (2015)	2015	Yield	Statistical analysis	Temperature (seasonal max)	0	–	–	National	Historic evidence	Findings indicated impact of climatic variables on rice yield but regional variation of rice and these climatic variables were overlooked
				Temperature (seasonal min)	0	0	+			
				Rainfall (seasonal mean)	0	–	0			
				Humidity (seasonal mean)	+	+	0			
				Sunshine (seasonal mean)	0	0	+			
				Time (year)	0	+	0			
Ara et al.[c] (2016)	2016	Yield	Statistical analysis	Temperature (annual average)				23 greater regions	Historic evidence	Analyzed the combined impact of climate and management practices on rice yield. Increase in annual mean temperature and total rainfall will decrease rice yield
				Rainfall (annual total)						
				Cropping intensity						
				Area under irrigation						

[a] Assesments modeled rice production/yield changes due to changes of climatic variables, (+) increase, (–) decrease

[b] Assesments indicated impacts of individual climate variables on rice production/rice yield, (+) positive effect, (–) negative effect, (0) no significant effect

[c] Assesments do not consider all rice ecotypes

Climate Scenarios considered: *CCCM* climate and carbon cycle modeling group, *GCM* general circulation model, *GFDL* geophysical fluid dynamic laboratory, *GFDL-TR* geophysical fluid dynamics laboratory transient, *HadCM2* Hadley center during 1995 and 1996 using the second version of the United Kingdom Meteorology Office's Unified Model, *PRECIS* Providing regional climates for impacts studies

Table 2 Components, issues, determinants of food security and the available geographic and temporal data sources on these in Bangladesh nationally

Components	Issues	Literature that quotes determinants	Determinants (primary and *Proxy)*	Possible Data Sources	Geographic data availability	Temporal data availability
Food availability	Production	Mainuddin and Kirby (2015), Moslehuddin et al. (2015)	Food production	BBS, BARC	Greater region	1947–2010
			Soil	SRDI, BCA	National	2006
			Seed quality	BBS	Greater region	1991–1997
	Management practices	Abraham et al. (2014), Iizumi and Ramankutty (2015), Hadgu et al. (2009), Tiwari and Joshi (2012), Deryng et al. (2011), Alauddin and Sharma (2013), Rahman (2010), Nasrin et al. (2015), Ahmad et al. (2014), Yengoh (2012), Ara et al. (2016), Kirby et al. (2016)	Cropped area	BBS	Greater region	1981–2010
			Means of irrigation	BBS	Greater region	1981–2010
			Use of fertilizer	BBS	Greater region	1990, 1991
			Use of pesticides	BBS	Greater region	1976–1987
			Groundwater availability	WARPO, IWM	Groundwater well station	1985–2010
	Climatic variables	Rosenzweig and Parry, 1994; Parry et al., 1999; Deryng et al., 2014; Aggarwal and Singh, 2010; Basak and Alam, 2013	Temperature	BMD	Weather station	1948–2012
			Rainfall	BMD	Weather station	1948–2012
			Humidity	BMD	Weather station	1972–2012
			Sunshine	BMD	Weather station	1972–2012
	Disasters	Atkins (2009), Simelton et al. (2012), Ninno and Lundberg (2005), Dewan et al. (2017), Holle and Islam (2017)	Flood	DIMC, CEGIS, SPARRSO	National, district, sub-district	Historic record of flood
			Drought	DIMC, CEGIS, SPARRSO	National, district, sub-district	Historic record of drought
			Cyclone	DIMC, CEGIS, SPARRSO	National, district, sub-district	Historic record of cyclone
Food access	Demography	Bose and Dey (2007), Scaramozzino (2006), Felker-Kantor and Wood (2012)	*Activity rate*	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
			Sex ratio	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
			Dependency ratio	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
			Age structure	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
			Household structure	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
	Economics	Bose and Dey (2007), Scaramozzino (2006)	Land ownership	HIES	District, sub-district	1991–1992, 1995–1996, 1999–2000, 2004–2005, 2010
			Income	HIES	District, sub-district	1991–1992, 1995–1996, 1999–2000, 2004–2005, 2010
			Assets	HIES	District, sub-district	1991–1992, 1995–11996, 1999–2000, 2004–2005, 2010
			Expenditure on food	HIES	District, sub-district	1991–1992, 1995–1996, 1999–2000, 2004–2005, 2010
	Employment	Scaramozzino (2006)	*Labour force structure*	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
				BBS	Greater region	1981[a]

Table 2 continued

Components	Issues	Literature that quotes determinants	Determinants (primary and *Proxy)*	Possible Data Sources	Geographic data availability	Temporal data availability
			Agriculture vs. non-agriculture activities		District, sub-district	1991[a], 2001[a], 2011[b]
	Rural–urban differences	Hossain et al. (2005), Thorne-Lyman et al. (2010), Pitt (1983)	*Ratio of people living in urban and rural areas*	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
	Infrastructure	Scaramozzino (2006), Shin (2010)	Access to roads	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
				LGED	District, sub-district	2015
			Number of schools	BBS	Greater region	1981
					Districts	1991[a], 2001[a], 2011[b]
			Access to electricity	BBS	Greater region	1981[a]
					District	1991[a], 2001[a], 2011[b]
			Access to information technology	BTRC	District	2001–2014
Food utilization	Calorie intake	Bose and Dey (2007), Frongillo et al. (2003) Hels et al. (2003), Hillbruner and Egan (2008), Roetter and Keulen (2007)	Food consumption	HIES, FPMU	District, sub-district	1991–1992, 1995–1996, 1999–2000, 2004–2005, 2010
	Health	Scaramozzino (2006)	*Fertility*	BBS	Greater region	1981[a]
					District	1991[a], 2001[a], 2011[b]
			Mortality	BBS	Greater region	1981[a]
					District	1991[a], 2001[a], 2011[b]
			Anthropogenic indicators	HIES	District, sub-district	1991–1992, 1995–1996, 1999–2000, 2004–2005, 2010
	Education	Sajjad et al. (2014)	Literacy rate	BBS	Greater region	1981[a]
					District, sub-district	1991[a], 2001[a], 2011[b]
	Water and sanitation	Sajjad et al. (2014), Roetter and Keulen (2007)	*Access to drinking water*	BBS	Greater region	1981[a]
					District	1991[a], 2001[a], 2011[b]
			Access to sanitary facilities	BBS	Greater region	1981[a]
					District	1991[a], 2001[a], 2011[b]

Proxy determinants are indicated in italics

[a] Population and housing census year. Administrative boundary changes occurred between 1981 and 1991 census years

[b] Note that not all community series for districts from the 2011 Population and Housing census were available at the time of article publication

Bangladesh, farmers are currently practicing various indigenous techniques to adjust with the local climatic anomalies to produce different crops (Alauddin and Sarkar 2014). However, national level strategies need to improve for different areas to combat climate change. Although the government has launched several initiatives to facilitate climate change adaptation, more interventions are still required to develop region-specific resilience (MoEF 2009; MoFDM 2008). It is important to understand how to design a long-term food security plan for Bangladesh that includes a consideration of regional climate change and other environmental system impacts on all food security components. Such a plan may reduce the degree and severity of low food security nationally in future. The following section of the paper explores the possible national data sources relevant to food security, which may help to develop such a plan by analyzing this data to improve food security in the country.

3 National Data Sources on Food Security in Bangladesh

Data provide the fundamental evidence for assessment of all food security components, but often, data is difficult to obtain and manage. Many factors influence its quality and adequacy, including its use for objectives that were not intended during collection, correlations between determinants, and its derivations for different purposes (Pinstrup-Andersen 2009; Scaramozzino 2006). Food security components often rely on multiple proxies in a country (Alwang et al. 2001). For instance, fertility and mortality (frequently used in demographic research) are relevant in many food security analyses as proxies for population health. The present study explores the availability of directly measured (primary) and proxy determinants for the different food security components. Most determinants were sourced from the recent national and international literature under different food security issues, including production, management practices, climatic variables, disasters, demography, economics, employment, rural–urban differences, infrastructure, calorie consumption, health, education, water, and sanitation.

The present study identifies a wide range of possible national data sources on important determinants (primary and proxy) at the spatio-temporal level of Bangladesh. The following sources have been identified for data relevant to food security analysis:

Bangladesh Agricultural Research Council (BARC)
Bangladesh Bureau of Statistics (BBS)
Bangladesh Country Almanac (BCA)
Bangladesh Meteorological Department (BMD)
Bangladesh Household Income and Expenditure Survey (HIES)
Bangladesh Telecommunication Regulatory Commission (BTRC)
Bangladesh Space Research and Remote Sensing Organization (SARRSO)
Centre for Environmental & Geographic Information Services (CEGIS)
Disaster Incidence Database of Bangladesh (DMIC)
Food Security and Nutrition Data Portal (FPMU)
Household Income and Expenditure Survey (HIES)
Local Government Engineering Department (LGED)
Soil Research Development Institute (SRDI)
Water Resource Planning Organization (WARPO)

Administrative boundaries (Fig. 1) are typically followed by the above-mentioned sources for published spatio-temporal data including greater regions, districts, and sub-districts

Table 2 presents the issues and determinants (primary and proxy) of food security under the three food security components and indicates the available national spatio-temporal data on food security determinants for Bangladesh. The spatial resolution of food security datasets vary from administrative unit-level aggregates to point-based measurements. To be useful in spatial analysis, station-based data (e.g., climate, groundwater) needs to be prepared using appropriate spatial interpolation techniques. Temporal data availability also varies for different years. Time series data are available for most of the primary food security determinants, but it is only possible to get proxy determinants from Population and Housing Census reports for 1981, 1991, 2001 and 2011. Some primary determinants (e.g., Crop production, irrigation, cropping intensity) have been used in national food security assessments previously (Mainuddin and Kirby 2015; Parvin and Wakilur 2009); however, these assessments overlooked many important primary determinants (Table 2). In addition, whilst proxy determinants are considered as important in food security assessment globally (refer to relevant citations in Table 2), little attention so far has been given to proxy determinants in Bangladesh. It is important to consider all primary and proxy determinants to strengthen food security research in the country.

Although Table 2 shows that spatio-temporal data on food security determinants can be achieved in Bangladesh from past records, such data relevant to food security components are often ignored in food security assessments. Most previous food security assessments were based on primary data (Frongillo et al. 2003; Lewis 1993; Coates et al. 2010; Thorne-Lyman et al. 2010) and HIES data (Faridi and Wadood 2010; Hossain et al. 2005; Bose and Dey 2007), which are collected through questionnaire surveys at household/individual level. However, the studies based on these data do not show the spatio-temporal dynamics of food security in Bangladesh. The data identified in the present study (Table 2) allow for the variations of different determinants to be considered over space and time. The following section addresses a way forward for food security analysis that can use spatially explicit data (Table 2) to understand the spatial and temporal pattern of each food security components.

4 Spatially Informed Food Policy Development: A Way Forward

The present study addresses a way forward for food security analysis that highlights a potential path towards a spatially informed food policy development. However, this will depend on data availability at aggregated spatial and temporal resolution in different countries globally. Figure 7 identifies three separate parts in the process towards improved evidence-based, regional decision-making food policy. This includes spatio-temporal data on food security determinant, region-specific deficits, climate change, and other future risks to understand present and future food security conditions regionally. Further, this will address possible regional actions, which will be required for a respective risk in order to improve food security. The following section describes different processes according to Bangladesh context as an example, using spatio-temporal data mentioned in the previous section.

4.1 Part 1: food security data analysis and mapping

The approach starts with the spatial data analysis and mapping (Fig. 7). This has been done before in many

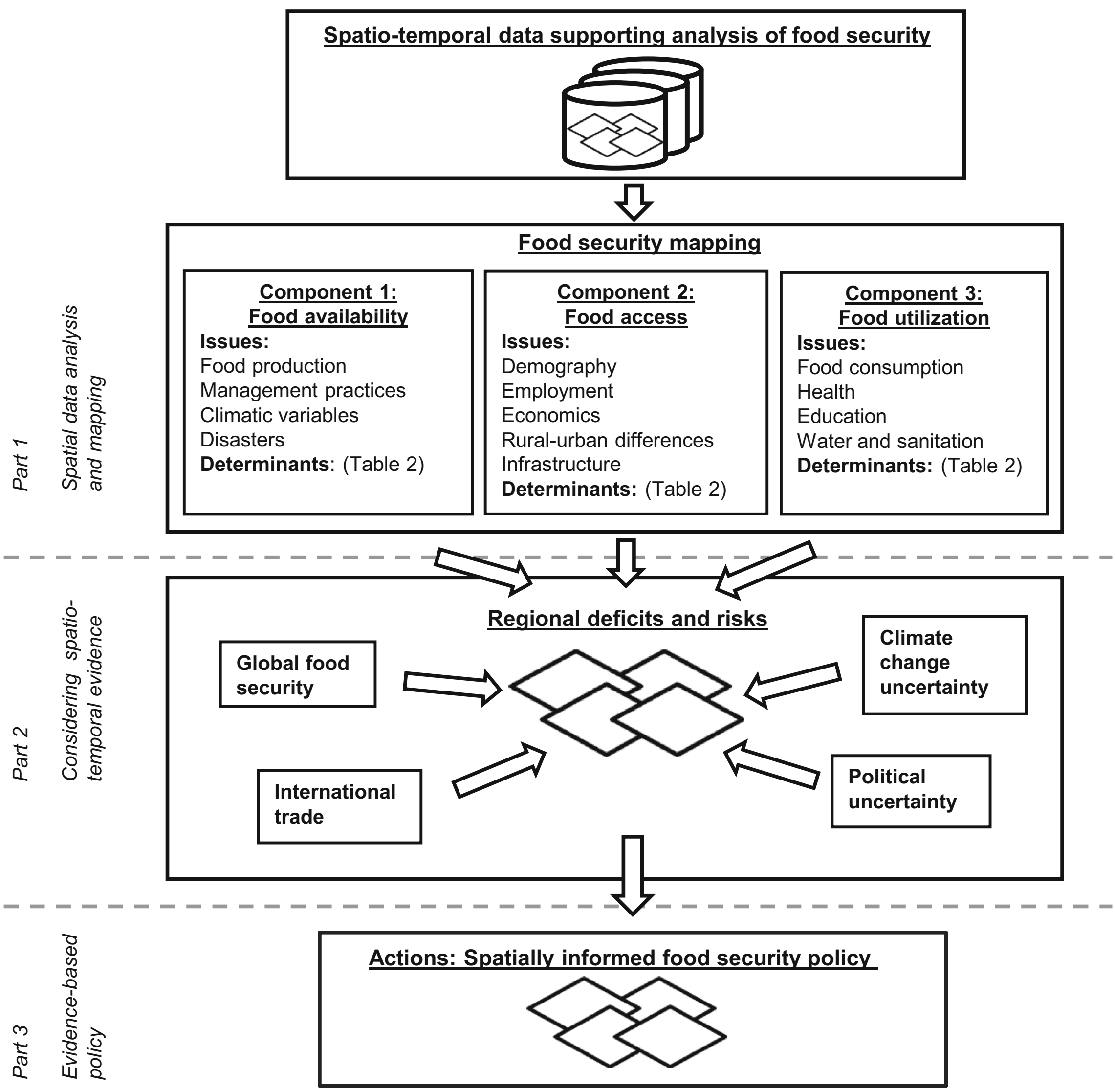


Fig. 7 Spatio-temporal data on food security and processes towards evidence-based spatially informed food policy development

countries (Tiwari and Joshi 2012; Yengoh 2012; Simelton et al. 2012; Qin et al. 2013), but updated and new data provides the foundation for substantial improvement over the time. For instance, a prominent past example is the National Food Security Atlas using data from the 2001 Population Census (GoB and WFP 2004). Several new datasets have since become available that will allow an update, which in itself is an important contribution to food security policy development as data is available for different epochs, providing the means for a spatial visualization of changes in critical food security components in Bangladesh. A detailed temporal data have been collected for all three key components of food security (Table 2; Fig. 7, Part 1). Although some harmonization of data will be necessary because of differences in spatial resolution or temporal availability of the data, the results from the data review above indicate that this is possible.

The mapping of food availability includes food production, management practices, climatic variables, and disasters. Food access analysis is based on the human dimension of food security, including socio-economic conditions, access to resources and communication in different regions. Food utilization analysis mainly considers the food consumption, health, education, water and sanitation of a region. Part 1 results in a visualization of the geographic variation of components of all of the three food security determinants across the country over time.

4.2 Part 2: identifying spatio-temporal evidence for deficits and risks associated with all food security components

The resulting outcomes from different assessments of food security components from part 1 provide the spatio-temporal evidence to identify deficits and risks. For example, an assessment of food availability will help to identify the biophysical limitations of food production of a country regionally. Food access evaluations will help to ascertain the socio-economic and infrastructure inadequacies of food access. Food utilization assessments may indicate a lack of nutrition and dietary imbalances. All these outcomes will help to understand existing regional risks for food security in a country.

This part includes explicitly spatio-temporal interactions in a given environmental system of a country, which have not received sufficient consideration in past policy developments (Ray 2007; Rocha 2009; Bashir and Schilizzi 2015; Habiba et al. 2015c). Examples of possible interactions are off-site effects, i.e., water usage upstream that influences the water availability downstream or potentially unsustainable use of groundwater (Ahmad et al. 2014; Ara et al. 2016) and economic development that indirectly influences movement of people and goods with indirect influences on food security in Bangladesh. Many of these factors are currently being researched (Mainuddin and Kirby 2015; Kirby et al. 2016) in the country and need to be included in future policies. External factors that are outside of direct government influence include global economic factors such as global annual food production and international trade of agricultural or other commodities that can influence individual food security components in a country. There is also political uncertainty that may cause changes in support and lack of policy continuity. As the complexity in this part is high, it is essential to provide easy access to evidence in the form of spatio-temporal data (Part 2, Fig. 7).

Climate change uncertainty influences all aspects of food security. Both flooding and cyclones are likely to increase with future climate change and have spatially differing risk profiles associated with all components of food security, production, distribution, housing, and health. Some of these interactions are well understood (Shin 2010; Sajjad et al. 2014; Hadgu et al. 2009; Shi and Tao 2014); others lack evidence, which may successively reduce uncertainties in modeling when it becomes available through research. This research is crucial to build and apply quantitative models that use risk appraisals to test policy options for diverse future scenarios in a country.

4.3 Part 3: development of a spatially informed food policy

The third part (Part 3, Fig. 7) suggests that regional food security also requires regionally adapted actions to address specific food security components. Actions may include but are not limited to region-specific adaptation measures for food availability, varied livelihood options for food access, and diversified diet preferences and awareness building related to health and hygiene environments for proper food utilization. The present study advocates a spatially informed food security policy by considering regional level deficits, future risks, and devises actions related to the respective components to improve food security for an individual country. The overview of Bangladesh food security indicates that the country has achieved significant increases in rice production. Calorie consumption has increased marginally at the national level. Both production and consumption have increased, along with imports of food from foreign countries in emergencies, and this has played a vital role in the past for improving food security. Regardless of these positive conditions at national level, the present food policy needs to be improved by incorporating spatial representations of environmental system and socio-economic conditions to tackle regional food security challenges (MoFDM 2006, 2008). A comprehensive policy response to food security that fully addresses spatio-temporal variations of food security components is likely to contribute to improving food security there.

5 Conclusions

The present study has shown that food security is not only an issue of producing food. Food access and food utilization are also very important components of food security in Bangladesh. Most food security determinants vary spatially in Bangladesh and this variation should be considered for regional food security assessment. Similarly, the possible geographic impact of climate change needs to be considered. The study identified available spatio-temporal data on food security in Bangladesh, which have not been used previously for regional food security assessment.

Bangladesh has not yet developed spatially informed policies to improve its food security, even though there are documented spatial differences in food security (GoB and WFP 2004). Region-specific analysis is required for future evidence-based policy development globally including Bangladesh. The present study has developed a way forward for regional food security assessment that includes analysis of existing spatio-temporal data but also explicitly stresses interaction of this data with other forms of data. Whereas the first part can be used directly to understand regional variations of factors determining food security, the second part highlights potential connections with factors with high global or national uncertainty. These components need some consideration to obtain spatially informed food policy in a country. This will contribute to the design of robust policy and action plans, capable of addressing food security regionally in more effective ways than are possible at present in Bangladesh and elsewhere. The government can then give priority to areas where existing food security deficits and future risks are high and devise the necessary region-specific actions to improve food security.

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