ISSN 2042-4116

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Population dynamics in the context of environmental vulnerability: Comparison of the Mekong, Ganges-Brahmaputra and Amazon Delta regions

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ABSTRACT

Tropical delta regions experience complex population dynamics, which are strongly influenced by socio-economic and environmental factors. They are subject to increasing pressure from relative sea-level rise, and because of human alterations they are becoming more and more vulnerable to extreme floods, storms, surges, and salinity intrusion, hazards which could also increase in magnitude and frequency with a changing climate. In this context, understanding population dynamics in delta regions is crucial for ensuring efficient policy planning and progress towards social and ecological sustainability. Here we focus on examining population dynamics in the Ganges-Brahmaputra, Mekong and Amazon deltas. Analysis of the components of population change is undertaken in the context of environmental factors affecting the demographic landscape of the three regions, and makes use of multiple data sources, including census data and Demographic and Health Surveys. The results of the analysis show that the demographic trends in the three delta regions are broadly reflective of national trends, although important differences exist within and across the study areas. Moreover, our findings show that all three delta regions have been experiencing shifts in population structures resulting in aging populations, the latter being most rapid in the Mekong delta. The environmental impacts on the different components of population change are important and more extensive research is required to effectively quantify the underlying relationships. The study concludes by discussing selected policy implications in the context of sustainable development of delta regions and beyond.

KEYWORDS

Population change; delta vulnerability; Ganges Brahmaputra Delta; Mekong Delta; Amazon Delta.

EDITORIAL NOTE

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ACKNOWLEDGEMENTS

The research forms part of the international Belmont Forum project BF-DELTAS “Catalyzing action towards sustainability of deltaic systems with an integrated modelling framework for risk assessment” (NSF award no. 1342944). Sylvia Szabo, Zoe Matthews, Robert Nicholls and John Dearing also acknowledge support from the project ‘Assessing health, livelihoods, ecosystem services and poverty alleviation in populous deltas’ (NE/J002755/1) funded by the Ecosystem Services for Poverty Alleviation Programme (ESPA). The UK ESPA programme is funded by the Department for International Development, Economic and Social Research Council (ESRC) and the Natural Environment Research Council (NERC).

POPULATION DYNAMICS IN THE CONTEXT OF ENVIRONMENTAL VULNERABILITY: COMPARISON OF THE MEKONG, GANGES-BRAHAMPUTRA AND AMAZON DELTA REGIONS

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1. INTRODUCTION

Delta regions constitute dynamic ecological and social environments and are often major contributors to national economies. While overall, deltas account for only 1% of global land area, they are home to more than a half billion people, or ca. 7% of world population (Ericson et al., 2006). Given the particular environmental risks faced by tropical deltas and accounting for interlinkages between demographic and environmental factors, it is crucial to analyse population dynamics in delta environments to inform planning and policy making. The Millennium Ecosystem Assessment (2005) showed that beyond provisioning ecosystem services such as food, water, fibre and fuel, regulating and supporting ecosystem services also influence various aspects of human development, such as health and income, and long term sustainability of agriculture and natural resources. Trends in human well-being, however, cannot be fully understood without considering the specific demographic context, including evolving population structures by age and sex, and changes in the dominant demographic drivers of fertility, mortality and migration.

Understanding population trends and dynamics in deltaic regions is especially important in the context of global environmental change which is expected to exacerbate the existing threats to livelihoods through e.g. sea-level rise, land subsidence, increased storminess, flooding and saline intrusion (Nicholls, 2011, Dun, 2011, World Bank, 2000, Wong et al., 2014). In this context, the present study examines population dynamics (growth, fertility, mortality, and migration) in three selected tropical deltas. It draws on the theory of demographic transition and the literature conceptualising the interlinkages between population and environment (de Sherbinin et al., 2007, Hummel et al., 2012). According to fundamental demographic theory (Notestein 1945; Dyson 2011; Dyson 1998), it is common for countries to experience concurrent falling mortality and fertility levels as they progress through the ‘demographic transition’. This is a process through which a country evolves from high to low levels of mortality and fertility, is usually associated with increasing longevity. The theory posits that there is a short lag between mortality decline and a decline in fertility, and thus a short period characterized by rapid population growth. With regard to interlinkages between population and environment, specific components of demographic change can also be influenced by the quality of the

biophysical environment, environmental hazards and creeping processes, such as salinity intrusion and arsenic contamination of water and soil resources. Environmental migration contributes to population loss in an area and might even lead to population collapse in certain areas of delta regions as settlement abandonment becomes the main coping strategy of vulnerable households (McLeman, 2011). Moreover, mortality rates can be affected by the quality of provisioning ecosystem services, natural hazards and extreme weather events. For example, in Bangladesh, 3,406 people died as a consequence of Cyclone Sidr in 2007 (Paul, 2007). In many geographical areas, deteriorating ecosystem services, such as the supply of fresh water, were found to be positively associated with health outcomes and child and maternal mortality (BrownCairncross and Ensink, 2013, Cheng et al., 2012, Silva, 2011). Finally, the quality of the environment can also have an impact on fertility rates, although this relationship is more complex and not fully established. There is, however, some evidence that environmental pollutants can negatively affect fertility, although research findings are not consistent (Fisch et al., 2003, Foster et al., 2008).

The present study focuses on three specific delta regions, i.e. the Ganges-Brahmaputra delta, Bangladesh, Mekong delta, Vietnam and the Amazon deltas. These deltas were selected as they are each globally significant and encompass a range of biophysical and social conditions. Population size, the rate of population growth, and population distribution constitute crucial factors which are not only affecting but which are also influenced by natural habitat. While a relatively large body of literature examined the interlinkages between population growth and environment (de Sherbinin et al., 2007, Hummel et al., 2012, LutzPrskawetz and Sanderson, 2002), there is limited evidence regarding the dynamics of population change in delta regions. Yet, approximately 10% of the world's population live in areas lower than 10m above sea level and the population in these low lying coastal areas is projected to grow in all continents, especially in the developing world (Neumann et al., 2015, McGranahanBalk and Anderson, 2007). By providing a rigorous demographic overview of three delta regions, the study not only contributes to the literature on delta regions, but also considers their policy implications for sustainable development.

2. MATERIALS AND METHODS

The study areas (Figure 1) encompass three deltaic systems, all located in developing/transition countries. The first delta region, the Ganges-Brahmaputra delta, Bangladesh (thereafter: GBD) is represented by 45 districts in whole division areas of Khulna, Barisal, Dhaka, and Sylhet and most of the Chittagong division in Bangladesh[1]. This is an environmentally vulnerable region suffering both from the consequences of rapid-onset hazards (e.g. cyclones) (Kay et al., 2015) and creeping processes, such as salinity intrusion (Clarke, Williams, Jahiruddin, Parks, & Salehin, 2015), arsenic contamination (Abedin, Habiba, & Shaw, 2012; Edmunds, Ahmed, & Whitehead, 2015) and subsidence (S. B. Brown & Nicholls, 2015). There is extensive evidence that multiple stressors associated with climate change place increasing strains on the livelihoods of populations in the region. In particular, food security has emerged as a key developmental concern (Faisal & Parveen, 2004; MEF, 2009).

The second study area is the Vietnamese portion of the Mekong delta region (thereafter: the Mekong delta), which covers 13 Vietnamese provinces and excludes Ho Chi Min City. As with the GBD, the Mekong delta is highly vulnerable to adverse environmental events, in particular flooding and salinity intrusion. While it has been recognised that fluvial floods can bring benefits for the economy, as they convey sediment and benefit fisheries (Tri, Trung, & Thanh, 2013), flooding can also have a disastrous effect on households' livelihoods. Since 2000, the region experienced three major floods (2000, 2001 and 2002); the first affecting approximately 11 million people. As a result of this flood, 800 thousand dwellings were inundated and 55,123ha of rice crops destroyed (Nguyen & James, 2013). Extreme weather events will continue to occur in the region and may occur more frequently (Government of Vietnam, 2009). In addition, climate change is likely to increase not only the risk of flooding, but is also associated with relative sea level rise, salinity intrusion and changes in temperature and rainfall patterns (Dang, Li, Nuberg, & Bruwer, 2014; Nguyen & James, 2013).

Finally, for the Amazon delta (Brazil), to define our study area we combined the parameters provided by Ericson et al. (2006), who used a 5km buffer zone around

[1] The Chittagong division excludes the districts of Khagrachari, Rangamati and Bandarban.

the coastline intersecting with the first distributary, and the limits of municipalities intersecting this buffer zone. In terms of administrative boundaries, the study area comprises 50 municipalities across the Pará and Amapá states in the North region of Brazil (or approximately 6% of the legal Brazilian Amazon). In 2010, our study area contained approximately 16.5% of the total population of the legal Amazon and 18% of its urban population (IBGE, 2010). While other parts of the Brazilian Amazon have undergone significant environmental change during the last three decades, the delta region has seen relatively lower levels of environmental degradation. The region has experienced rapid urbanization and a growing economy based on forest products and agroforestry (Brondizio, Vogt, & Siqueira, 2013). Most urban areas in the region lack basic sanitation and other infrastructure as well as public services, which along with some of the highest poverty rates in Brazil create vulnerable conditions for a significant segment of the population. On the other hand, farmers in the region are reporting increasing tidal flooding and changing salinity in coastal ecosystems, but these changes have not been systematically documented.

In order to conduct our analyses, this paper draws on a number of secondary macro and micro level data sources. For Bangladesh, the data used include 2010 Household Income and Expenditure Survey (HIES) conducted by the Bangladesh Bureau of Statistics (BBS, 2011a), Demographic and Health Surveys (DHS) (Mitra, Ali, Islam, Cross, & Saha, 1994; NIPORT, Mitra and Associates, & ICF International, 2013; NIPORT, Mitra and Associates, & Macro International, 2009; NIPORT, Mitra and Associates, & ORCM, 2001) as well as census data. Similarly, for Vietnam, we use the Vietnamese Living Standards Survey (VLSS), Census data and Demographic and Health Surveys. Finally, for the Amazon we used census data from the Brazilian Institute of Geography and Statistics (IBGE) and demographic data and human development indices compiled by The Institute of Applied Economic Research (IPEA) of Brazil (IBGE, 2010; IPEA, 2010). Data are aggregated at the municipal and census sector levels for 1991, 2000, and 2010 in all three delta regions. Table 1 summarizes the demographic data sources used in the analysis.

Delta region	Data source
Ganges-Brahmaputra	Bangladesh Demographic and Health Surveys (DHS), 2010 Household Income and Expenditure Survey (HIES), Bangladesh Population and Housing Census (2001, 2001 and 1991.)
Mekong	Vietnamese Living Standards Survey (VLSS), Vietnam Demographic and Health Surveys (DHS), 2009 Vietnam Population and Housing Census, online data repository developed by the General Statistics Office of Vietnam.
Amazon	Brazilian Institute of Geography and Statistics (IBGE; 2010 & 2014) Institute of Applied Economic Research (IPEA; 2010.)
Cross-cutting	World Population Prospects (United Nations, 2012.)

Table 1: Sources of demographic data

Figure 1 illustrates the key delta relevant population-environment gradients and socio-environmental characteristics of the three study areas. Gradient bars, associated with variables are shaded to represent the respective "values" of each variable for each study area. Darker shades represent higher values. Population size and population density are greatest in the GBD where the total population exceeded 108 million and the population density in the study area is approximately 1,280 people per km^2 (Ericson et al., 2006). The proportion of delta population at risk is highest in the Mekong delta region and so is the proportion of delta area potentially lost by 2050 (Ericson et al., 2006). It should however be noted that in terms of absolute numbers the greatest impact on population loss is expected to take place in the GBD (Ericson et al., 2006). Amongst the three delta regions, the Amazon delta has the highest proportion of urban population, while the Mekong delta is least urbanized. In terms of environmental characteristics, saline water intrusion penetrates further inland in the GBD and so sediment reduction is the largest compared to natural conditions (Syvitski et al., 2009).

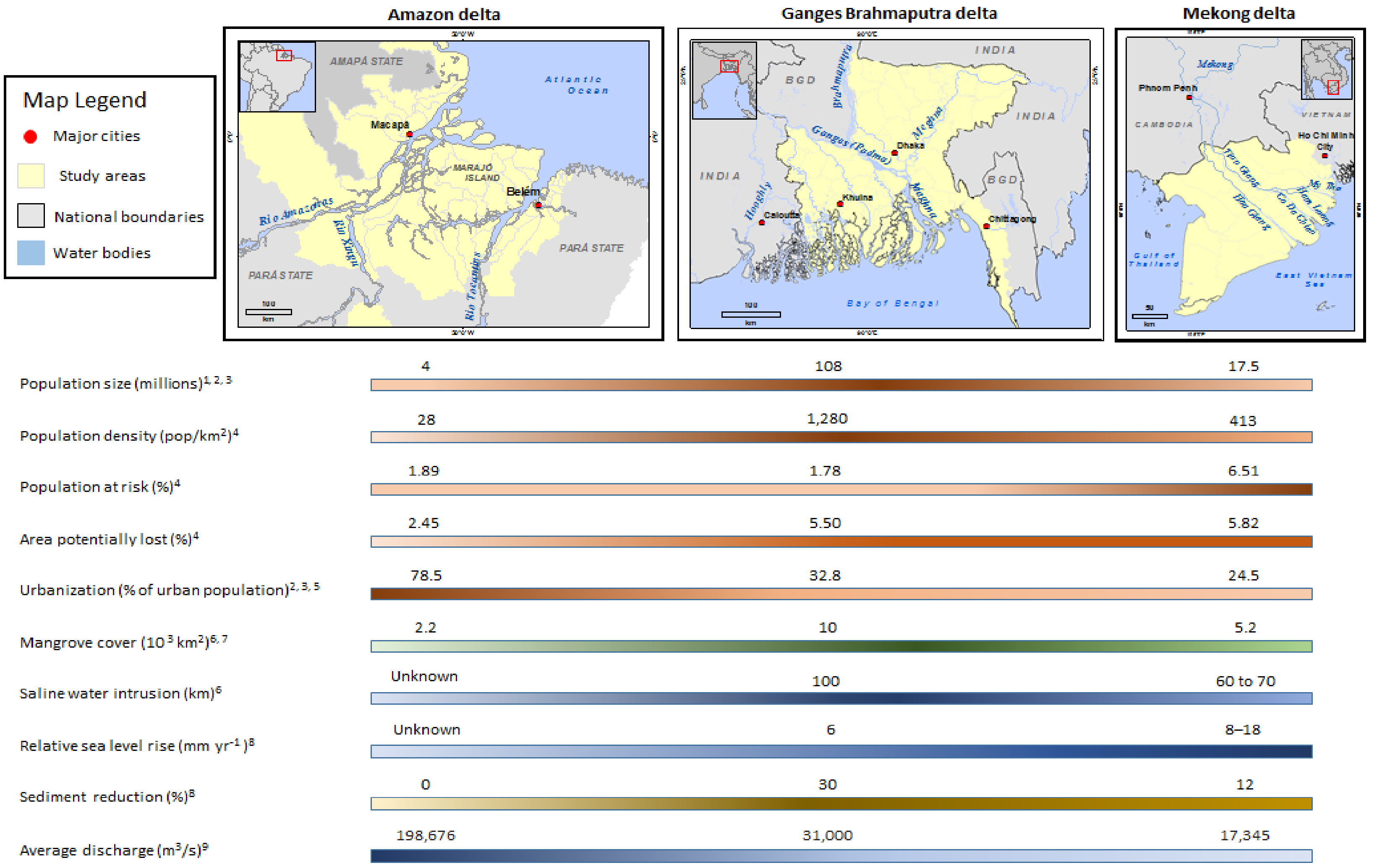

Figure 1: Population-environment gradients in the study areas

Notes: 1. Bangladesh Population and Housing Census (2001, 2001 and 1991); 2. Brazilian Institute of Geography and Statistics (IBGE, 2010); 3. 2009 Vietnam Population and Housing Census; 4. Ericson et al. (2006); 5. World Development Indicators (WDI), World Bank; 6. Parry, M. L., Canziani, O. F. , Palutikof, J. P., van der Linden, P. J., & Hanson, C. E. (2007); 7. Giri et al. (2011); 8. Syvitski, et al. (2009); 9. Syvitski and Saito (2007).

3. POPULATION GROWTH AND STRUCTURE IN THE THREE DELTA REGIONS

In the 20th century, all three countries in which the study areas are located, have been experiencing rapid demographic transitions. In Vietnam, demographic transition was reflected in considerable decline in total fertility rate (TFR), measuring the average number of children born per woman, and improvements in infant survival rates (Ngo et al., 2010). Bangladesh is interesting in this respect because the fertility decline has been largely fuelled by a very successful family planning programme. On the other hand, Brazil represents an example of a country where fertility dropped without direct government intervention, although associated with significant sterilization rates in public and private clinics (Cleland et al., 2006, Demeny, 2011, Siqueira et al., 2007).

In Vietnam, the rate of population growth in the country declined from 2.32% in 1970-75 to 0.95% in 2010-15 (UN, 2013). During the same time period, in Bangladesh the rate of population growth dropped from 1.72% to 1.19%, while in Brazil it decreased from 2.38% to 0.85% (UN, 2013). Figure 2 illustrates the trends in population growth in the three delta regions. In the past two decades, the Mekong delta continued to experience population growth despite falling fertility and relatively high out migration (Dun, 2011). The overall population in the Mekong delta increased from around 15.5 million in 1995 to over 17.5 million in 2013 (Figure 2b). However, the Mekong delta is one of the regions with the lowest population growth rate in Vietnam with large spatial differences within the delta (Garschagen et al., 2012). Similarly, in the GBD, the population size in 2011 increased by approximately 19 million people compared to 1991, which represents a 17.5 % increase in population size over the last two decades (Figure 2a). Based on the 2011 census data, the total population of the study area was about 108 million, comprising approximately 75% Bangladesh's population. Out migration combined with below replacement level fertility rates in some districts contributes to changing population structure and negative rates of population growth. For example, during the last two decades, in Pirojpur district in south-western Bangladesh the population decreased by around 18.4% while in the nearby Barisal district, the population declined by approximately 14.3% (BBS, 2012).

Likewise, the Amazon delta region has experienced continuous population growth since 1990 (Figure 2c), most of it being in urban areas of the delta. As highlighted previously, the study area for the Amazon delta is shared by two states in the Northern region of Brazil. To the north, the state of Amapá includes nine municipalities, while to the south the state of Pará includes 41 municipalities within the Amazon delta region. With approximately 4 million people, the population size of the Amazon delta is the smallest of the three delta regions. Since 1990, the region has experienced over 56% increase in total population growth reaching a total of ca. 4 million people in 2010 (IBGE, 2010). The majority of the population in 2010, 78.5%, declared urban residency. However, there exists considerable variation within the region (IBGE, 2010). The Amazon delta experienced slight decrease in rural population from 1990 to 2000, followed by a slight increase from 2000 to 2010. The increase in rural population reflects increasing economic importance of forest and agroforestry products in the region, opening economic opportunities in rural areas and motivating strong connections between rural and urban areas (BrondizioVogt and Siqueira, 2013).

When analysing population dynamics of delta regions, it is important to consider their population structures. In the Mekong delta region, the population aged 15 to 35 constitutes the greatest percentage of the total population, while the bottom of the pyramid is relatively narrow indicating an aging population structure (Figure 3b). This population structure is reflected in the region's dependency ratios, which is around 42.3 % as compared to the national average of 44.7 % (General Statistics Office, 2011). More specifically, the child dependency ratio of 33.8 % is relatively low when compared to that of other regions. For example, child dependency ratio in the Central Highlands is 50.5 % and the national average is 35.4 %. It should be noted that the current population structure of the GBD (Figure 3a) is younger than that of the Mekong, although it is visible that the youngest age groups (0-4 and 5-9) are disproportionally small, which reflects recent trends in fertility decline. It should be highlighted that during the last decade, all five divisions which fall under the study area have seen a decrease in fertility rates accompanied by a tendency towards smaller households. In terms of regional differences, in 2001, the smallest average household size was 4.7 (Khulna division), while the largest household size was 5.7 (Sylhet division) (BBS, 2011). In the Amazon delta (Figure 3c), a significant proportion of

the population is young, between the ages of 10-25. Similarly, to the Mekong and GB deltas, the demographic profile of the Amazon delta region has been changing since the 1980's, partly as a result of significant fertility decline. Compared to the Mekong delta region, the population structure in the Amazon delta has not yet reached the rapid ageing trend; however, its overall population is older than that of the GBD.

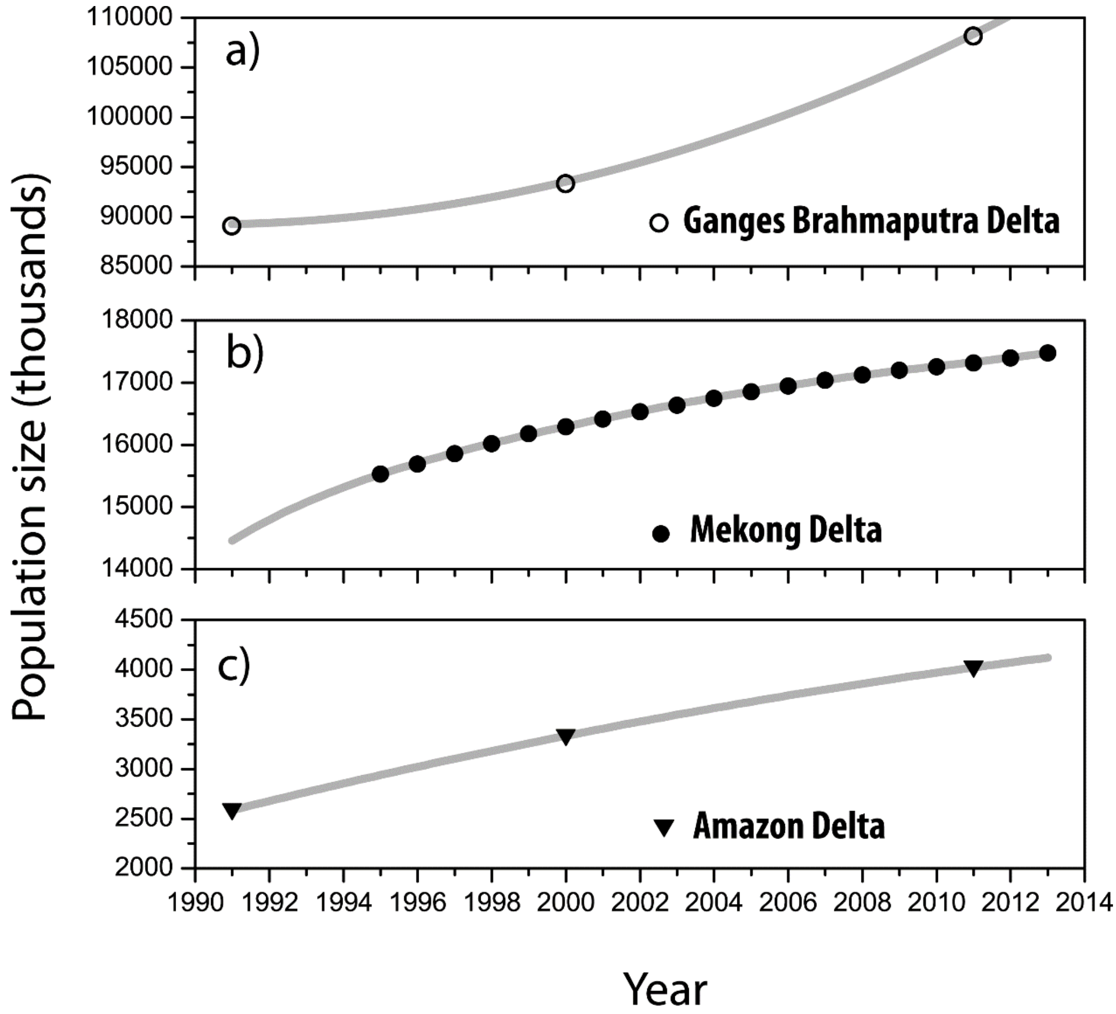

Figure 2: Recent population growth in the (a) Ganges Brahmaputra, (b) Mekong and (c) Amazon deltas.

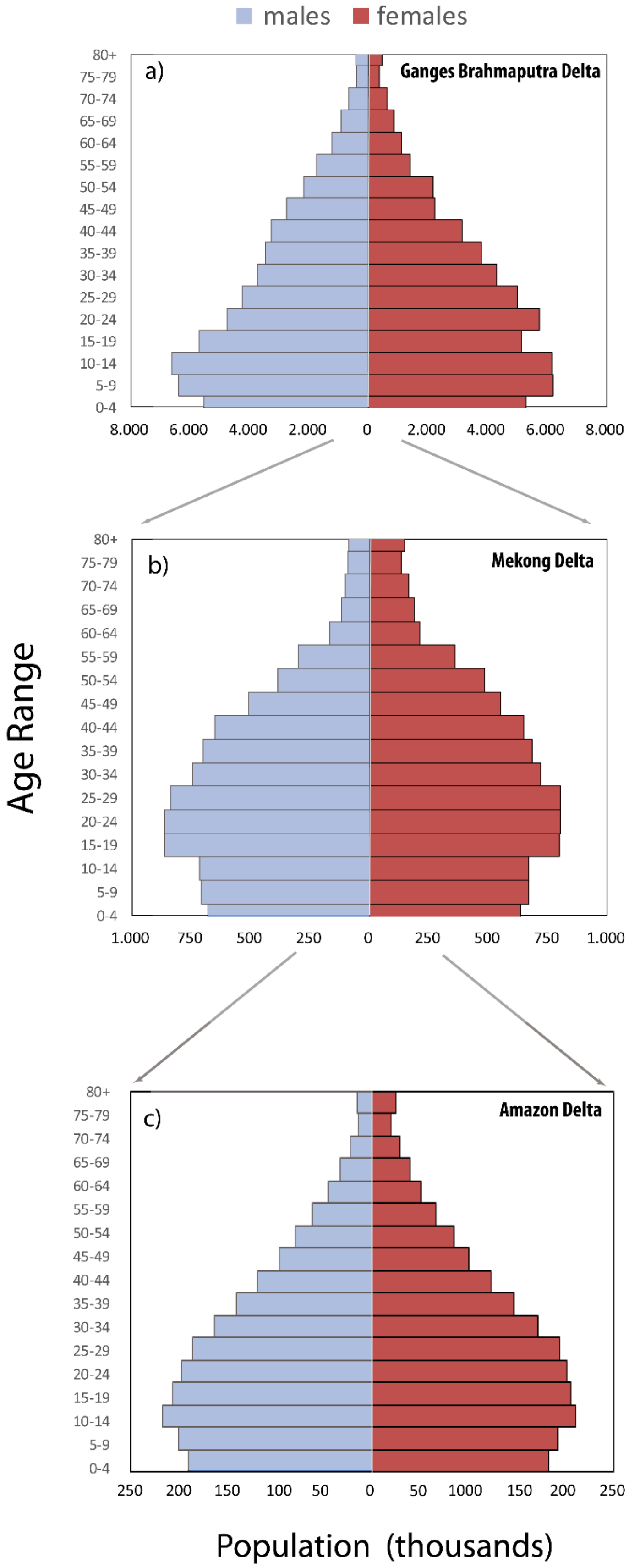

Figure 3: Population structure in the (a) Ganges Brahmaputra (2011), (b) Mekong (2009) and (c) Amazon (2010) deltas.

4. 4. COMPONENTS OF DEMOGRAPHIC CHANGE: FERTILITY, MORTALITY AND MIGRATION

4.1. FERTILITY

Fertility is the key aspect of population change, as it has arguably the greatest impact on population structure, particularly when migration is negligible. As highlighted previously, during the past half-century, Vietnam has undergone rapid demographic transition with the TFR declining from 6.4 in 1960 to 1.8 in 2013 (World Bank, 2012). Today, the unmet need for contraception is estimated at 4.3% at the national level and 3.6% for the Mekong delta region (General Statistics Office, 2011b). While long time series are not available at the regional level, the Demographic and Health Surveys (DHS) provide more recent disaggregated data on fertility and health outcomes. Based on these data, it can be observed that since the 1990s the TFR in the Mekong delta region has been continuously decreasing and is currently estimated at 1.92 (Figure 4). In terms of early childbearing, the percentage of women aged 20-27 who had their first birth before the age of 18 is 5.8% in the Mekong delta region, while the equivalent national proportion is 3% (General Statistics Office, 2011b).

Similar to the Mekong delta, analysing trends in the total fertility rate in the GBD reveals a decline from 3.5 children per woman in 1993 to roughly below 2.5 in 2011 (Figure 4). Fertility decline has been more pronounced for women from wealthier households than for women from poorer households. The average total fertility rates in the coastal divisions of Khulna and Barisal are below the national average except for Barisal district. The lowest fertility rates amongst the coastal districts are observed in Satkhira and Barguna districts with TFR 1.56 and 1.59 respectively (BBS, SID & Planning 2012). Finally, since the early 1990s the Amazon delta region has experienced the most rapid decline in TFR with a drop in TFR from over 6.1 children per women in 1991 to 3.3 in 2010. This fast decline in fertility mirrors the general trends in Brazil which are explained by a combination of government programs, migration from rural to urban areas, and social-cultural change regarding women’s rights and household roles (Siqueira et al., 2007). This trend started first in the urban areas of South and South East regions and then spread gradually to the rest of the country (Siqueira et al., 2007). A key feature of the process

was the reliance on irreversible methods of contraception, such as female sterilization. In 1996, in Northeastern states, 51% of married women between 15 and 49 reported having undergone sterilisation (Caetano, 2001), a trend confirmed for areas of the Northern region by Siqueira et al (2007).

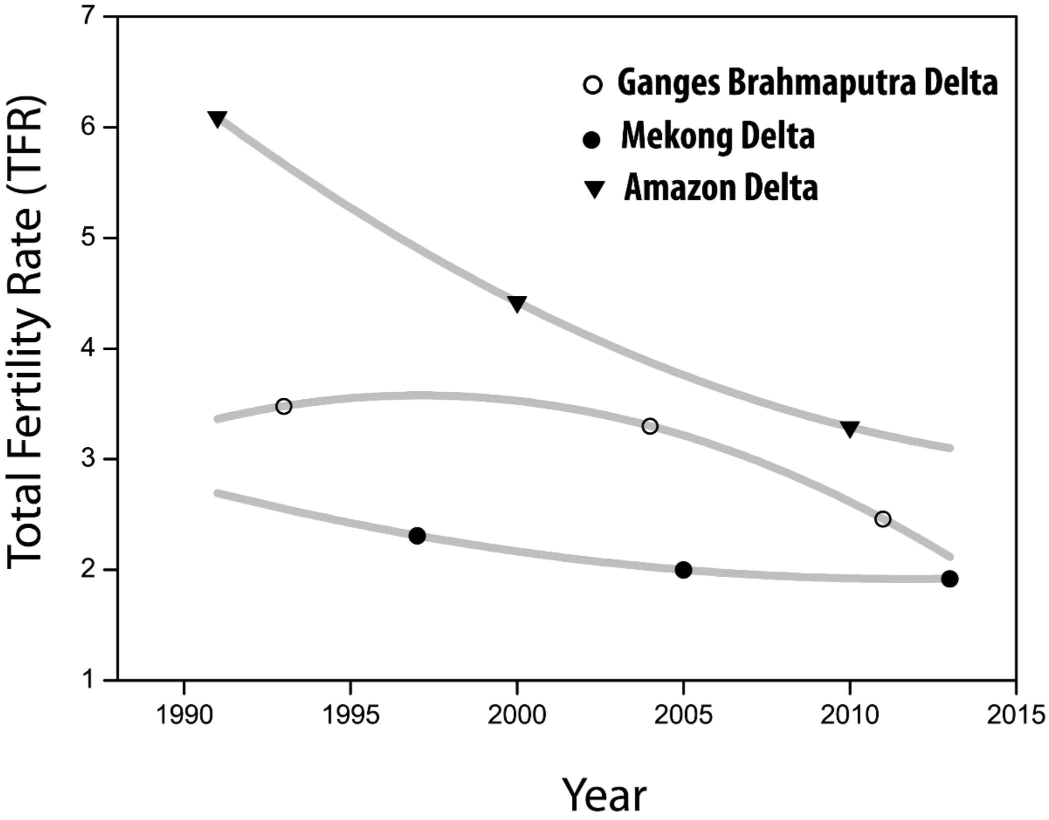

Figure 4: Recent trends in TFR in the Mekong, GB and Amazon delta regions.
Source: BBS, IBGE and General Statistics Office (GSO), Vietnam.

These past trends indicate that future delta populations are likely to drastically change and see smaller households with a greater proportion of elderly dependents. This predicted change is expected to be most rapid in the Mekong delta. Vietnam saw a decrease from an average household size of 4.8 in 1989 to 3.8 in 2009 (General Statistics Office, 2011a) and in 2009 household size in the Mekong delta was estimated at 3.9 (Figure 5). The trends towards smaller households are accompanied by a rising age at marriage and rising divorce rates. The ratios of divorce/separation to marriage are the highest in the Mekong delta and Southeast regions, which is likely to be associated with high rates of out-migration. Comparatively, in the GBD, there has been a trend towards smaller household size, although there exists considerable inter

divisional differences. In our study area, an average household size varies from 4.3 in Khulna to 5.4 in Sylhet (BBS, 2011b). It should be highlighted that during the last decade, all five divisions which fall under the study area have seen a decrease in household size. In 2001, the average family size in the delta region was 5.1 while in 2010 in was 4.8 (BBS, 2011b). Finally, in the Amazon delta region the decline was even more rapid, although an average household is larger than in the Mekong delta region. In 2000, an average household size in the Amazon delta was 5.0 and it has declined to 4.5 in 2010 (Figure 5).

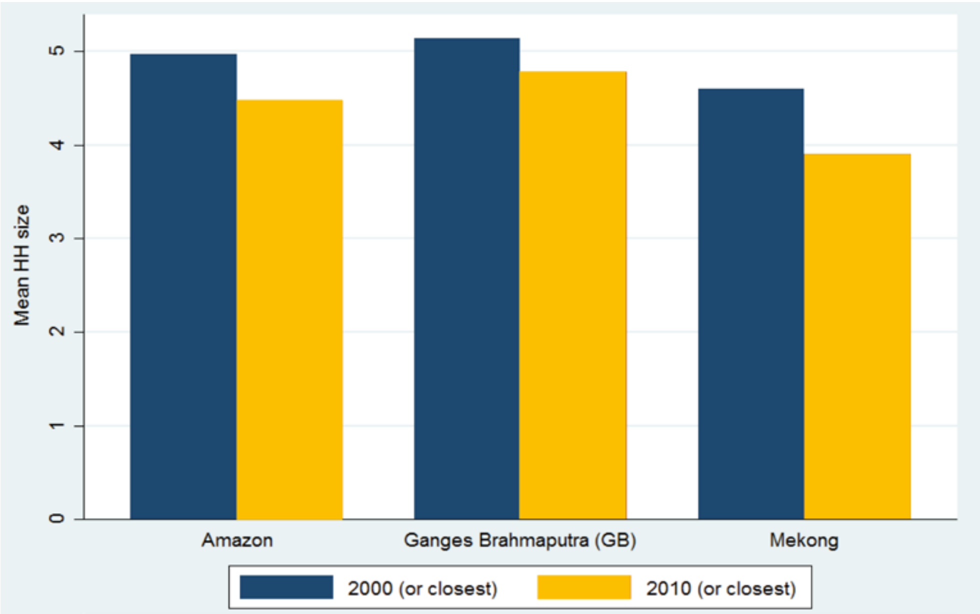

Figure 5: Change in mean household size across the three study areas.
Source: BBS, IBGE and GSO, Vietnam.

4.2. MORTALITY

Mortality constitutes a second aspect of population change and is closely related to human health and overall well-being. With regards to mortality trends, Vietnam has experienced considerable improvements in life expectancy, reducing child mortality. At the country level, life expectancy was 59.1 in 1960 (World Bank, 2012) and increased to 72.2 years in 2005 and 73.1 years in 2013 (General Statistics Office, 2014). In the Mekong delta region, life expectancy increased from 73.4 in 2005 to 74.4 in 2013 (General Statistics Office, 2014) (Figure 6). Concerning child mortality, infant mortality rate (IMR) in the Mekong delta region is the second lowest regionally (after the Southeast region). The IMR in the Mekong delta is estimated at 12.0, while

the national average is 15.3 (General Statistics Office, 2013). It is difficult to examine to what extent mortality trends have been affected by environmental factors. The interlinkages can occur at two levels: first, through direct impact of natural hazards on human life, and second, through the effects of the quality of environment, such as water quality. Between 2001 and 2010, natural disasters affecting the country were responsible for death of 9.5 thousand people (Government of Vietnam, 2011). Between 2000 and 2002, 1,144 people were killed due to floods in the Mekong delta region (Central Committee for Flood and Storm Control, 2015). Children were found to be particularly vulnerable to floods, especially in poorer households were parents worked outside often leaving children without supervision (Nguyen & James, 2013). Secondly, indirect environmental effects on mortality rates include the quality of water and sanitation, which are associated with water borne diseases, such as cholera and typhoid and paratyphoid fevers. Water quality in the frequently populated smaller waterways of the Mekong delta is relatively poor, regardless of the sources exploited (surface-, ground-water, rain water, piped water), with contamination by pesticides (Chau, Sebesvari, Amelung, & Renaud, 2015; Toan, Sebesvari, Blasing, Rosendahl, & Renaud, 2013), nutrients, metals, salinity and microbial organisms (Wilbers, Becker, Nga, Sebesvari, & Renaud, 2014; Wilbers, Sebesvari, Rechenburg, & Renaud, 2013; Wilbers, Sebesvari, & Renaud, 2014). In peri-urban and rural regions of the Mekong delta, large portions of the population are directly exposed to polluted water and consume polluted water with treatments that do not allow eliminating all contaminants (Wilbers, Becker, et al., 2014; Wilbers et al., 2013; Wilbers, Sebesvari, et al., 2014).

Similarly, in the GBD, environmental factors and climate change can have an important direct and indirect effect of human mortality. It should be stressed that Bangladesh as a country has achieved significant progress in a number of health indicators, despite its relatively poor economic situation (Chowdhury et al., 2013). Current life expectancy in Bangladesh is estimated at 69 years for males and 71 years for females, an increase by 9 and 12 years respectively since 1990 (WHO, 2014) (Figure 6). At the same time, however, maternal and child mortality rates are worryingly high. For example, based on the World Bank data, maternal mortality ratio is 170 per 1000,000 live births, which is similar to that of Pakistan and Cambodia and considerably higher than maternal mortality rate (MMR) in Vietnam and Brazil

(World Bank, 2012). The population of the GBD is particularly vulnerable to cyclones, especially in coastal areas. It has been estimated that during the last 50 years approximately 718 thousand people died due to cyclones (Haque et al., 2012). However, the death toll has fallen dramatically and in 2007, 4,234 people died as a result of cyclones compared to 500 thousand deaths in 1970 (Haque et al., 2012). This reflects improved early warnings and provision of a network of cyclone shelters. In addition to their direct effect, i.e. the loss of human life, cyclones affect the quality of water and increase the risk of disease transmission, in particular in resource poor areas. They can also have a post disaster impact on mental health by increasing the risk of stress and depression (Haque et al., 2012; Shultz, Russell, & Espinel, 2005).

Finally, the population of the Amazon delta region experienced a rapid increase in life expectancy reaching 71.8 years in 2010, an increase by 7.2 years since 1991 (IPEA, 2010) (Figure 6). Overall, life expectancy is slightly higher in the Amapá state, although trends between both states (Pará and Amapá) are quite similar (IPEA, 2010). Infant mortality rate remains high (21 per 1,000) although it has declined more than twofold from 49.7 in 1991. This regional IMR is considerably higher when compared to the national IMR, which has been estimated at 15 in 2010 (World Bank, 2012). According to a recent study by the International Institute for Environment and Development (IIED) (Viana, Viana, Euler, Grieg-Gran, & Bass, 2014), the infant mortality rate in Amapá state is the highest in Brazil. In the Brazilian Amazon region, natural disasters, in particular floods, are associated with environmental and health impacts, including loss of life, however disaggregated numbers are difficult to obtain (de Resende Londe, Pellegrini Coutinho, Torres Di Gregório, Bacelar Lima Santos, & Sorian, 2014). In this region, health problems have also been associated with the fast pace of urbanization accompanied by poor infrastructure. Health challenges included infectious diseases, such as malaria, in particular in peripheral areas bordering forests (OPA, 2010). Perhaps, the largest impact of environmental change can be noted in the case of migration.

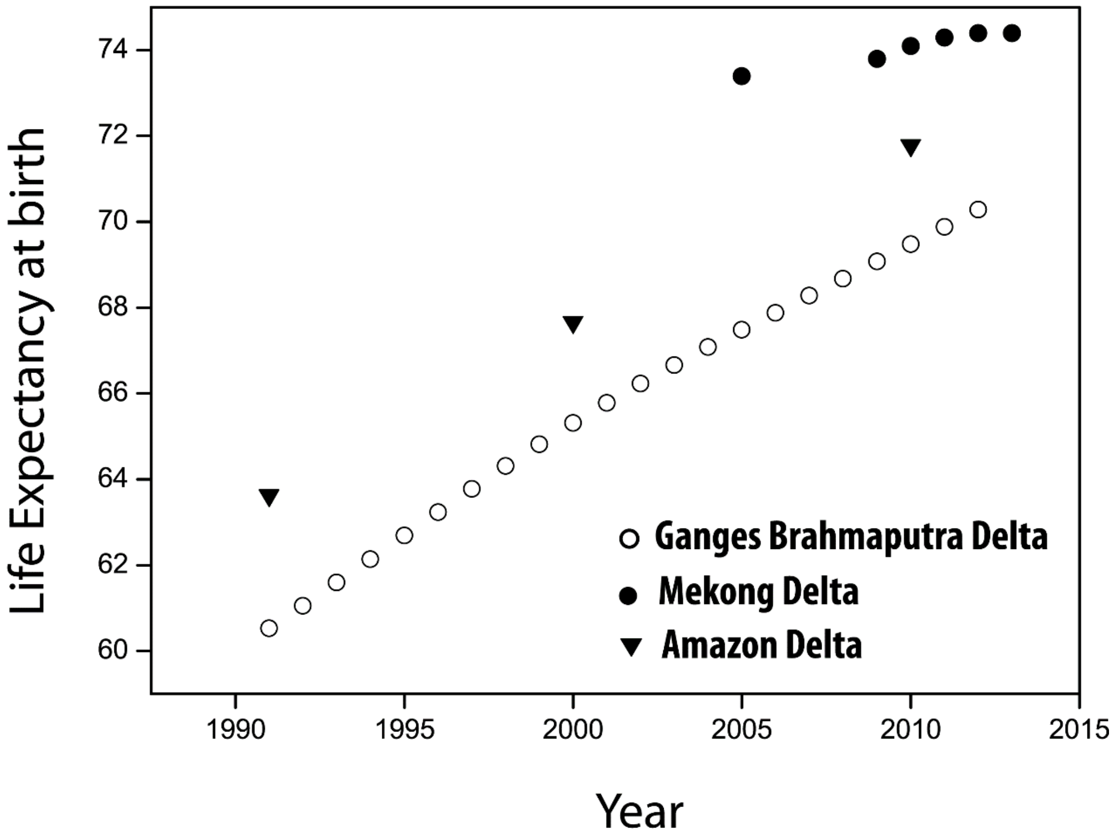

Figure 6: Recent trends in life expectancy in the Mekong, GB and Amazon delta regions. **Source:**World Development Indicators (WDI), IBGE and GSO, Vietnam. For GBD national data were used to approximate trends.

4.3. MIGRATION

Migration is a key element of population change in all three study areas, with the high environmental vulnerability of tropical deltas potentially being an important factor. At the same time, due to its unpredictability, migration is also the most difficult part of demographic modelling. The Mekong delta region is exposed to environmental hazards with extreme weather events leading to frequent flooding which affects people's livelihoods (Dun, 2011; Nguyen & James, 2013). In addition, slow onset hazards such as salinity intrusion continue to pose a severe risk to water and soil quality and thus to water supply and agriculture. Climate change is likely to exacerbate the existing risks and thus further affect future population distribution. Out migration from the environmentally vulnerable areas is a widely recognised coping strategy (Rayhan, 2008). Seasonal migration to the cities can provide income during the times of distress. For example in the Thạnh Mỹ Tây commune in An Giang province, there were 5,000 seasonal migrants reported in 2009 (Nguyen & James,

2013). Between April 2012 and April 2013 there were a total of 121,443 out migrants from the Mekong delta region, with most of them moving to the Southeast region where Ho Chi Minh City is located (General Statistics Office, 2013). As per the above mentioned report, the net migration rates in the Mekong delta region are the same for males and females. Within the Mekong delta region, Bạc Liêu Province reported the highest out migration rates (-14.2 for males and -13.5 for females) (General Statistics Office, 2013).

Similar to migration trends in the Mekong delta region, internal migration in the Bangladeshi GBD is an important demographic and social phenomenon. Environmental shocks combined with economic vulnerability of large strata of the society are the key push factors affecting relatively high out migration rates in coastal districts. A recent report by UNDP pointed out that 40 out of 64 districts have been identified to be environmentally at risk (Marshall & Rahman, 2013). High out migration, in particular from rural locations contributes to creation of large slum areas and informal settlements in cities. Because of limited or no income generating opportunities, migration to cities is often perceived as a coping strategy for the rural poor. In addition, crop losses or damage caused by natural hazards further exacerbate the existing social vulnerabilities. In Bangladesh, the number of life time migrants increased from 950 thousand in 1950 to 12,773 thousand in 2004 and out migration from rural to urban areas grew from 7.3 per 1,000 in 1984 to 25.9 per 1,000 in 2010 (BBS, 2011b). As is the case in other delta regions, climate change, and in particular sea-level rise, are projected to have negative impact on households' livelihoods, which is likely to increase the volume of out migration in the future (Mallick & Vogt, 2012).

Migration dynamics in the Amazon delta show interesting patterns. Based on the analysis of the data for the period 2001-2007 originating from the National Household Survey (PNAD), the state of Pará has consistently experienced high levels of out-migration. In contrast, migration patterns in Amapá have been highly volatile with only some years showing net out-migration flows (Ferreira-Filho & Horridge, 2010). Nevertheless, recent research reports that over 28% of the current population in Amapá originates from outside of this state which may explain the rising trends in population growth (Viana et al., 2014). Another body of research highlights that in the

Amazon delta, similar to other delta regions, migration dynamics are largely intertwined with urbanisation. The difficulty of categorising and quantifying these migration trends is related to the fact that a large proportion of migration includes circular movements (Padoch et al., 2008).

5. CONCLUSIONS AND POLICY IMPLICATIONS

This study aimed to investigate the dynamics of population change across three delta regions: the Ganges-Brahmaputra, the Mekong and the Amazon deltas, as defined in section 2. In order to achieve this goal, we analysed the trends in population growth, population structure and specific components of population change (fertility, mortality, migration). Several conclusions can be drawn. Firstly, our results suggest that, consistent with national averages, fertility rates in the delta regions have been steadily declining, falling below replacement levels in some geographical areas, such the Khulna and Barisal districts in south-western Bangladesh. This trend, combined with increasing life expectancy, improving child mortality rates and migration dynamics might imply that in the longer term population in delta regions are likely to stabilise or even decline, as recently projected for several coastal districts in Bangladesh (Szabo et al., 2015). This is contrary to general expectations of expanding coastal populations and coastal cities (Neumann et al., 2015), and hence is worthy of investigation in other deltas. Secondly, while overall the demographic trends in the deltas follow national trends, important differences exist within study areas.

As highlighted above, total fertility rates vary considerably within the same regions, with some geographical areas, such as the Khulna district in the GBD, already experiencing below replacement fertility rates. Additionally, our results show important differences in migration dynamics across the study areas, which will influence future population size and distribution at the regional and national levels. Thirdly, our findings suggest that all delta regions have been experiencing shifts in population structure resulting in aging populations, with the most rapid changes occurring in the Mekong delta. Finally, while environmental impacts on population trends and dynamics in the delta regions are hardly contestable, they remain difficult

to quantify. Future research should therefore consider ways in which these associations could be modelled (Nicholls et al., 2013, Lazar et al., 2015).

Although the present study advances knowledge in the area of population and environment, at least two caveats should be acknowledged. First, this study did not account for the differences between internal and international migration, and these differentials will have implications for sustainable development. In addition to the impacts of changes in population distribution, the migrants' destination has important consequences, including in terms of remittances they are likely to send home. Second, the paper does not provide population projections for the deltas. This is an important element in terms of preparing mitigation and adaptation strategies. Future demographic research should therefore explicitly consider conducting robust demographic projections based on a range of scenarios, including environmental factors.

The results of the analysis presented in this study have important policy implications. These delta regions will have to increasingly concentrate on addressing the needs of growing elderly populations and ensuring provision of care. This can be a challenging issue in developing countries where pension systems are often either weak or non-existent. The changing population structures will also have implications in terms of labour supply. Coupled with out migration, this will imply that specific policies will have to be designed to tackle potential shifting from labour surplus to labour shortages in certain sectors and geographical areas. Additionally, environmental stressors, such as relative sea-level rise, could entail large population displacements, including across national borders (Smajgl and Ward, 2013). With an aging population, disaster preparedness programmes will have to be appropriately adapted.

Changes in occupational structure are also likely to be linked to internal migration and resulting urban growth. Addressing potential labour shortages in the farming sector is likely to be a challenge given that delta regions are food baskets for many nations (Foufoula-Georgiou et al., 2013). Given the key role of demographic and environmental issues for sustainability of tropical deltas, as well as their wider interlinkages with other phenomena affecting sustainable development, such as public

health and good governance, it is critical to undertake thorough assessments of specific population-environment dynamics on a case-by-case basis. Interlinked population and environmental changes will have different consequences depending on the delta. Policies related to the sustainable development of these three deltas and future research on the deltaic systems should thus concentrate on further disentangling population-environment associations, including through stakeholder engagement initiatives and dynamic/statistical modelling.

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