

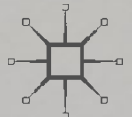


# **ECOSYSTEM SERVICES FOR WELL-BEING IN DELTAS**

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## **Integrated Assessment for Policy Analysis**

**Edited by Robert J. Nicholls, Craig W. Hutton, W. Neil Adger,  
Susan E. Hanson, Md. Munsur Rahman and Mashfiqus Salehin**



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Editors

# Ecosystem Services for Well-Being in Deltas

Integrated Assessment for Policy  
Analysis

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# 5

## Recent Trends in Ecosystem Services in Coastal Bangladesh

John A. Dearing and Md. Sarwar Hossain

### 5.1 Introduction

The Bangladesh coastal zone is a highly dynamic system. Recorded statistics list 174 natural disasters during the period 1974–2007 (Rahman et al. 2010), and an estimated one million deaths as a consequence of cyclones in the period 1960–1990 (Ericksen et al. 1996). Floods in 1998 caused losses of buildings and infrastructure worth two billion United States dollars (USD) (Chowdhury 2001). The area of land lost through riverbank erosion through the period 1996–2000 led to financial losses totalling 540 million USD (Salim et al. 2007). The world's largest mangrove forest, the

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The original version of this chapter was revised. The second author's name was incorrect. The chapter has been updated with the correct name of the author. An erratum to this chapter can be found at [https://doi.org/10.1007/978-3-319-71093-8\\_30](https://doi.org/10.1007/978-3-319-71093-8_30)

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Sundarbans, provides a livelihood for around three million people (Iftekhar and Islam 2004; Iftekhar and Saenger 2008) and protects more than ten million people from cyclonic storms. But the forest is vulnerable to cyclone damage, as in 2007 when around 36 per cent of the mangrove area was severely damaged leading to losses of livelihood (CEGIS 2007). Food security has also been severely compromised by climate extremes. Around one million tons of food grain were lost to drought in 1997 and 50 per cent of all grain in 1982 was damaged by flood (Islam et al. 2011). These catastrophic impacts serve to underline the vulnerability of the zone to extreme events but give only a partial picture of the longer-term interactions between society and the environment that may affect the zone's resilience. For example, there are major concerns about the individual and combined effects of shrimp farms, irrigation and flood dykes on regional salinity levels that may in turn constrain freshwater availability and crop productivity.

Hence, long-term perspectives are a prerequisite for understanding social-ecological system dynamics, developing and testing simulation models, and defining safe operating spaces for the region as it moves towards meeting the Sustainable Development Goals (SDGs—UN 2015) by 2030. This chapter reviews historical trends in ecosystem services and changes in human development over the past few decades that underlie these statistics (Hossain et al. 2016a, b). The chapter summarises social-ecological dynamics including preliminary analyses of trade-offs between economic growth, well-being and ecosystem services.

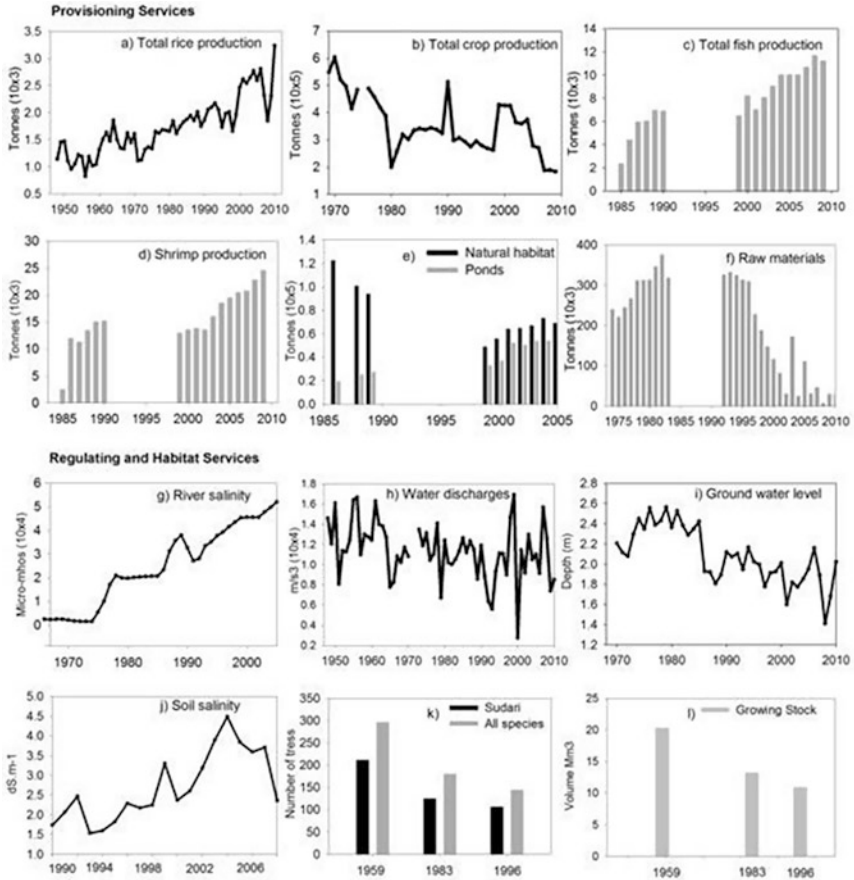
## 5.2 Location and Data Sources

The south-west coastal zone as defined in this study comprises the modern districts of Satkhira, Khulna, Bagerhat, Pirojpur, Barguna, Jhalokati, Patuakhali, Barisal and Bhola within the divisions of Barisal and Khulna (see Chap. 4, Figs. 4.1 and 4.2). The zone covers an area of ~25,500 km<sup>2</sup> with a total population of around 14 million and population densities ranging from 400 to 800 people/km<sup>2</sup> (BBS 2012). The Sundarbans mangrove forest (a UNESCO World Heritage Site) extends across 6,000 km<sup>2</sup> of the southern parts of this area.

Indicators of ecosystem services across the zone (Table 5.1 and Fig. 5.1) are classified as provisioning services or regulating and habitat services. Different

**Table 5.1** Data sources for ecosystem services and specific indicators. Where possible, aggregate district-level data collected since 1985 from the nine districts are aggregated into three sets that are equivalent to the three larger ‘greater districts’ or ‘regions’ of Barisal, Khulna and Patuakhali, which existed before 1985. T = traditional varieties. HYV = high-yielding varieties (see Hossain et al. 2016a for data sources)

Ecosystem services	Indicators	Temporal scale	Data sources
<b>Provisioning services</b>			
Food production	Rice (T-and HYV-Aus, T-and HYV- <i>Aman</i> , T-and HYV- <i>Boro</i> )	Total rice 1948–2010 Rice varieties 1969–2010	Bangladesh Bureau of Statistics
	Vegetables		
	Potato		
	Sugarcane, jute, onion, spices (garlic, ginger, turmeric and coriander)		
	Fish		
	Shrimp		
Forest products	Honey		Department of Forest, Khulna, Bangladesh; Zmarlicki 1994; Chaffey et al. 1985
	Timber types (Glopata, Goran, Gewa)	1974–2010	
<b>Regulating services</b>			
Water quality	Surface water salinity	1964–2006	Uddin and Haque 2010; Islam 2008
	Soil salinity		
Local climate	Temperature and precipitation	1949–2007	Bangladesh Meteorological Department
Water availability	River discharge	1934–2010	Bangladesh Water Development Board
	Groundwater level		
Natural hazard protection	Crop damage (due to cyclones, flooding, water logging and excessive rainfall)	1970–2010	Bangladesh Bureau of Statistics
Erosion protection	Fluvial erosion and accretion	1963–2009	Mapped data; Rahman et al. 2011
<b>Habitat services</b>			
Maintenance of biodiversity	Mangrove density	1960–1997	MoEF 2002; FAO 1999; Khan 2005; MoEF 2010; FAO 2007; Dey 2007; Chowdhury 2001; Helalsiddiqui 1998; Hendrichs 1975; Gittins 1980
	Mangrove volume		
	Mangrove area		
	Mangrove floristic composition		
	Tiger numbers		
	Deer numbers		
<b>Cultural services</b>			
Recreational services	Number of tourist visitors	2000–2009	IUCN 1997; Department of Forest, Khulna



**Fig. 5.1** Provisioning, regulating and habitat ecosystem services over recent decades: (a) total rice production, (b) total crop production, (c) total fish production, (d) shrimp production, (e) aquacultural production from natural wetlands and artificial ponds, (f) production of natural forest materials, (g) monitored salinity in the Poshur river at Mongla (Khulna), (h) mean annual river discharge in the Lower Meghna-Ganges river at Hardinge Bridge, (i) monitored depth to groundwater at Dacope (Khulna), (j) average monitored soil salinity at seven sites in Khulna and Patuakhali, (k) monitored tree numbers at an experimental plot in the Sundarbans, (l) estimated volume of growing mangrove in the Sundarbans (see Hossain et al. 2016a for data sources)

food and forest produce, such as rice, fish and timber, are selected to show the trajectories of provisioning services. Water salinity, river discharge, groundwater levels, crop damage and erosion and accretion rates are used as indicators of regulating services. Tree density and growing stock data for main two mangrove species (*Heritiera fomes* and *Excoecaria agallocha* known locally as *Sundri* and *Gewa*, respectively) and all species of the mangrove are selected for biodiversity indicators along with the numbers of two globally endangered mammal species (Royal Bengal tigers and deer) in the mangrove forest. External environmental drivers (Fig. 5.3) include mean annual temperature and rainfall, sea level and data for cyclone frequency and magnitude. Data are drawn from annual official data available for the nine districts and the Sundarbans National Park, and partly from *ad hoc* time-series of monitored point data or sequences of mapped data from hydrological, climatological and agricultural organisations and other scientific studies.

The list of human well-being indicators (Table 5.2 and Fig. 5.2) are selected according to the Millennium Development Goals for Bangladesh (MDG 2015). Data for income, sanitation, electricity, safe drinking water, crop production and production cost at the household level are drawn from Household Income and Expenditure Survey (HIES) datasets collected by the Bangladesh Bureau of Statistics and World Bank in 1995/96, 2000, 2005 and 2010. Data for child and infant mortality, maternal health, education and access to media come from the Demographic and Health Surveys collected in 1993, 1996, 2000, 2004, 2007 and 2010.<sup>1</sup> Although the Demographic and Health Survey data are at divisional level, two divisions (Khulna and Barisal) have been used for analysing the indicators as the study area covers all districts of Barisal division and around 65 per cent of the total area of Khulna division. Continuous series data are normalised (z-scores) to allow comparisons of curve shapes. Full details of these and other data analyses are available in Hossain et al. (2016a, b).

## 5.3 Ecosystem Services and Drivers

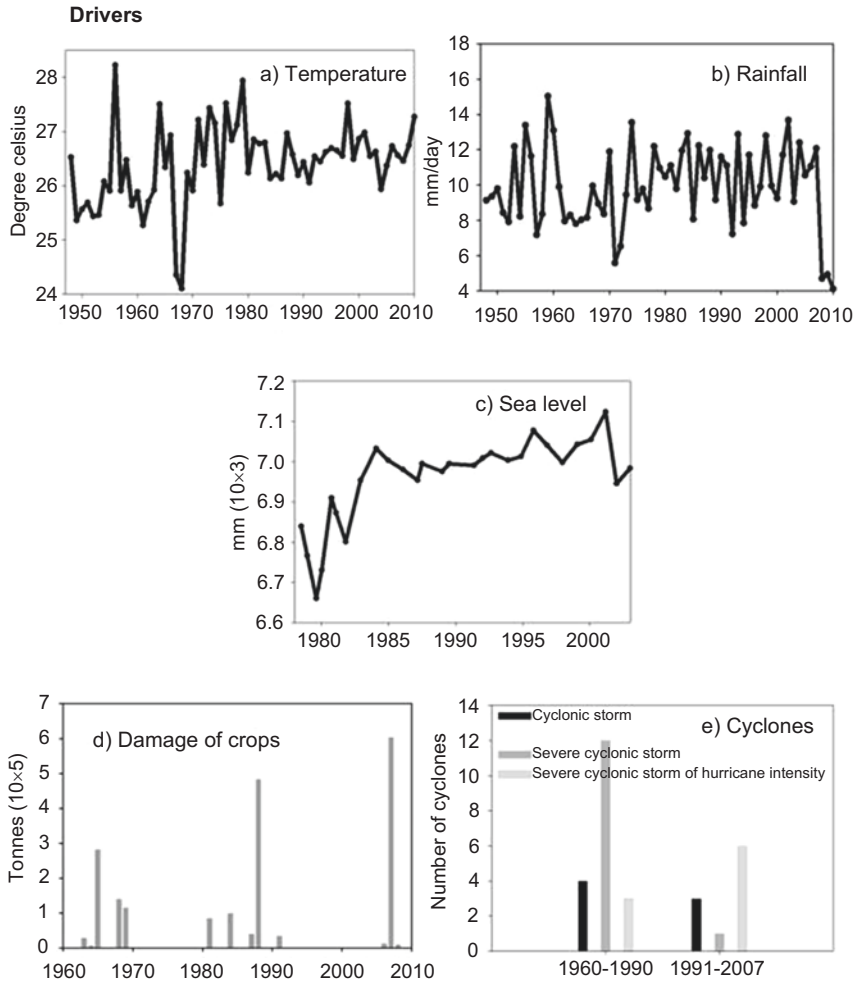
### 5.3.1 Provisioning Services

Food production is mainly derived from agricultural and aquacultural goods with a small amount directly from natural goods (e.g. wild fish, honey). Since 1970, the cultivated crop area has fluctuated between



**Table 5.2** Human well-being indicators based on MEA (2005) and OECD (2013) classifications (see Hossain et al. 2016a for details of data sources)

Dimension		Indicators	Temporal scale	Data source
MA	OECD			
Health	Quality of life	Child mortality (probability of dying before the first birth day) Infant mortality (probability of dying between the first and fifth birth day) Proportion of births attended by skilled health personnel (%)	1993–2011	Demographic health surveys
Material	Material condition	Sector-wise household income Production cost	1995–2010	Authors' own calculations from household income and expenditure survey Income from shrimp farms and production cost; (Islam 2007)
		Gross domestic product (GDP)	1974–2005	Bangladesh Bureau of Statistics
		Poverty—percentage of people living below the upper and lower poverty thresholds	1983–2010	Bangladesh Bureau of Statistics (Wodon 1997)
Security	Quality of life (personal security)	Access to electricity, sanitation, drinking water source	1995–2010	Authors' own calculations from Household Income and Expenditure Survey data
Freedom of choice and action	Quality of life	Education (% of people completed primary education)—man and women Access to mass media (television and newspaper)	1993–2011	Demographic health surveys



**Fig. 5.2** Selected indicators of environmental drivers: (a) mean annual temperature, (b) mean annual rainfall, (c) averaged annual sea level curve (Hiron Point and Khepupara; Brammer 2014), (d) damage to crops, (e) cyclone frequency and intensity (see Hossain et al. 2016a for data sources)

10,000 and 12,000 km<sup>2</sup> and in 2009 represents around 47 per cent of the total land area. Despite this relatively stable crop area, regional rice production (Fig. 5.1a) rose five-fold between 1969 and 2010 as traditional rice varieties were replaced by high-yielding varieties. Similar records for

sugarcane and jute production show declining trends since the 1970s, whilst production figures for both summer and winter vegetables and spices have risen since the 1990s. About 100,000 tonnes (t) of fish and shrimp are produced each year, around 30 per cent from rivers and estuaries, five per cent from the natural wetlands, with the majority (65 per cent) from artificial ponds and fish farms. However, since the 1990s, data show that annual shrimp production has increased from 5,000 t to more than 25,000 t, and fish production from ponds has risen from 22,000 to 60,000 t (Fig. 5.1c, d). Production from rivers and estuaries has declined dramatically, reflecting the increased production from artificial ponds and shrimp farms that continues to the present (Fig. 5.1e). Current shrimp and fish production figures are significantly higher in Khulna (>20,000 t) than Barisal (<50 t) and Patuakhali (<900 t). Trends in timber and other natural materials from the Sundarbans reached a maximum in the 1980s before declining steeply after 1997 (Fig. 5.1f). Honey collection shows relatively low values in the 1970s and 1980s, but has increased by 1.7 t per year over the period 1974–2010.

### 5.3.2 Regulating and Habitat Services

Current concerns about regulating and habitat services mainly revolve around water quality, especially salinity and nutrient levels, water availability in terms of availability as river discharge, and water drainage in terms of high groundwater levels. Additionally, some riverside and coastal areas are losing land to erosion processes, and there are concerns that biodiversity, especially across the Sundarbans, is declining. Although only a few long-term records of salinity are available, making extrapolation or averaging of data across the region difficult, some datasets point to general trends. For example, annual mean river water salinity in the Poshur river at Mongla in Khulna (Fig. 5.1g) increased steadily from approximately <5 deciSiemens per metre (dS/m) in the early 1970s to approximately >50 dS/m in 2005. Similar salinity levels were found in rivers in the Rampal and Paikgacha areas until 1995 (Hossain et al. 2016a), but these were followed by a steep decline in the late 1990s. Soil salinity measured during dry (Dec.–May) and wet seasons (June–Nov.) in Khulna

and Patuakhali since the 1990s shows contrasting records (Hossain et al. 2016b). In Khulna, three sites show salinity values increasing from  $<5$  dS/m to reach peak values  $>10$  dS/m in the 2000s, with maximum annual figures exceeding 20 dS/m. Four sites in the Patuakhali region show lower absolute values ( $<5$  dS/m), even though it is closer to the coast than Khulna, with only slightly rising trends towards the present. Averaging all the records suggests rising salinity values from the 1990s until 2004 with recent values falling back (Fig. 5.1j). There are no data for actual fertiliser applications, but modelled nutrient loading (total fertiliser and manure input) for three locations in the study area (using the Global NEWS model<sup>2</sup>) suggests more than a doubling in the application of fertiliser and manure between 1970 and 2000: 18 t/km<sup>2</sup>/year in 1970 to 39 t/km<sup>2</sup>/year in 2000 (Hossain et al. 2016b). Construction of the Farakka Barrage on the Ganges in India in 1975 has caused mean annual discharge measured downstream at Hardinge Bridge to the north of the region (Fig. 5.1) to gradually decline (Fig. 5.1h). In particular, dry season river discharge has effectively halved from 2,000–4,000 m<sup>3</sup>/s before 1975 to  $<1,000$ –2,000 m<sup>3</sup>/s afterwards: an overall rate change only reversed temporarily by extreme flood events in 2000–2001 and 2007. Groundwater levels show markedly different trends. At one site in Khulna (Fig. 5.1i), and another in Barisal, the groundwater levels have been rising (depth below ground decreasing) since the 1980s and now come within 1.5 m of the surface in the post-monsoon season. But at two other sites, groundwater levels are fairly constant at one and gradually deepening at another (Hossain et al. 2016b). In terms of land losses, geomorphological mapping along the major rivers since the 1970s shows that erosion has been greater than accretion in all decades except the 1980s. Mean erosion rates have decreased from 23 km<sup>2</sup>/year in the 1970s to  $<10$  km<sup>2</sup>/year in the 2000s, while mean accretion rates have also declined from 9 to 3 km<sup>2</sup>/year over the same period. The most recent estimate of net land loss in the study area adjacent to the rivers is around 6 km<sup>2</sup>/year. However, there is also evidence that accretion rates around the Meghna estuary show a land gain of approximately 3 km<sup>2</sup>/year since 2001. The total area of mangroves has increased over the period 1959–2000, while mangrove tree density and numbers (Fig. 5.1k) appear to have declined substantially leading to a halving in the estimated growing stock

(Fig. 5.11). Numbers of deer in the mangrove forest show fluctuating figures (between 50,000 and 95,000) since 1975, but numbers of tigers seem to have peaked at 450 in 1982 and 2004 with a decline to 200 in 2007. Data for the total number of tourists visiting the Sundarbans between 1996 and 2004 show around 5,000 visitors/year from 1996 to 2004 growing to 25,000 per year in the period 2010–2011.

### 5.3.3 Environmental Drivers

Local climate has changed significantly over past decades. Mean annual temperature data from three stations since 1948 show a significantly increasing trajectory in all four seasons (Fig. 5.2a). Averaged mean daily rainfall figures show no major trend and are generally in the range 8–12 mm/day (Fig. 5.2b) with extreme lows (<5 mm/day) in Khulna in 1971 and 2008–2010 and extreme highs (>45 mm/day) in Barisal in 1955 and 1960, and in Patuakhali in 1983. Monsoon and post-monsoon seasonal rainfall trends generally increased from the mid-1960s to the 1990s followed by sharply declining trends since 2007. There is some evidence for a shift in rainfall from the monsoon to the post-monsoon period after the 1990s, but all seasons show a decline after 2007 (Hossain et al. 2016b). The mean sea level from two coastal sites shows a gradual rise since the 1980s (Fig. 5.2c) threatening the ecosystem services at the coast particularly in concert with cyclones. The doubling in the frequency of severe cyclonic storms over the period 1991–2007 compared to 1960–1990 (Fig. 5.2e) is particularly noteworthy. Crop damage from natural disasters (Fig. 5.2d), including flooding, cyclones and waterlogging, since 1963 shows recorded damage in 35 per cent of the years with three clusters around 1963–1969, 1981–1991 and 2006–2009. The last two of these disasters are linked to the impacts of the extreme floods in 1987–1988 and super-cyclone Sidr in 2007.

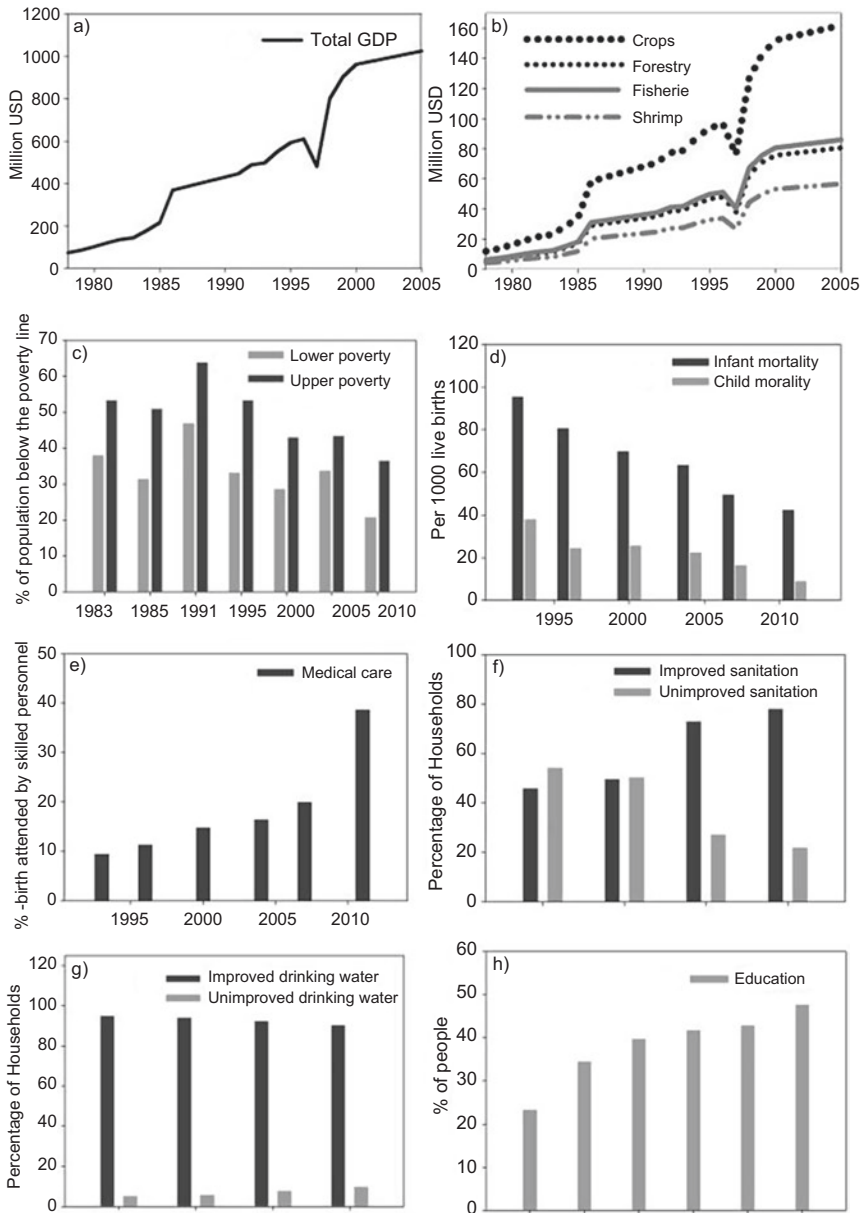
## 5.4 Social Trends and Well-Being

The population of the coastal zone of Bangladesh was approximately 14 million in the 2011 census with 80 per cent designated as rural population. The total population decreased marginally between 1974 and 1991

to around eight million before rising to the current level. Total gross domestic product (GDP) across the zone has also increased from 74 million USD to around 1025 million USD in the period 1978–2005 with two periods of sharply rising trends in the 1980s and late 1990s (Fig. 5.3a). Barisal, Khulna and Patuakhali all show similar trends, but Patuakhali currently has a significantly lower GDP (less than 400 million USD) than the others (>1,000 million USD). Per capita income has also risen over the past decades with figures for 2005 showing highest income in Khulna (559 USD/person) followed by Patuakhali (393 USD/person) and Barisal (358 USD/person). Despite crop production accounting for the largest share of total GDP (Fig. 5.3b), fishery and non-ecosystem-based livelihoods (e.g. manufacturing) have seen the largest rises in median income (76 and 8 per cent, respectively), while median income from solely agricultural livelihoods has decreased by 18 per cent. Rising levels of per capita income have resulted in a 17 per cent reduction in the numbers of people classified as living below the upper poverty line since 1995 (Fig. 5.3c). Levels of poverty for Khulna and Barisal in 2010 were 33 and 40 per cent, respectively, of the total population, reductions from 60 and 47 per cent in 1983.

Infant and child mortality have declined 50 and 75 per cent, respectively, in less than two decades (Fig. 5.3d), reflecting the improvement in medical care at births (Fig. 5.3e), access to improved sanitation facilities (Fig. 5.3f) and electricity. Universal access to improved drinking water sources has, however, remained largely unchanged since 1995 (Fig. 5.3g); about five per cent of tube-wells that have been tested across the region show the presence of arsenic, and rising levels of salinity in river and groundwater (see Chaps. 17 and 18) may also be affecting the availability of drinking water (Hossain et al. 2016a). Using the data sources identified in Table 5.2, there has been a significant increase in both male and female education (Fig. 5.3h), although societal participation (as indicated by the percentage of women who read newspapers weekly) has declined two per cent between 1993 and 2010.

Where there are observed improvements in human well-being, they are often associated with the poverty alleviation efforts of government and NGOs that have provided access to sanitation, safe drinking water, better health facilities and free primary education (Chowdhury et al. 2013, 2011). The Bangladesh government received more than 8,500 million USD from 1981 to 2012 in foreign aid to develop health, education



**Fig. 5.3** Selected indicators of well-being: (a) total regional GDP, (b) share of GDP across land production sectors, (c) lower and higher poverty level, (d) infant and child mortality, (e) trained medical care at births, (f) improved and unimproved sanitation, (g) improved and unimproved drinking water, (h) uptake of education (see Hossain et al. 2016a for data sources)

and family planning sectors and now allocates around 20 per cent of the annual national budget each year to these sectors. Other government investment in commercial sectors such as agriculture, industry, energy and rural development has also supported the eradication of poverty (UNDP 2014).

### 5.4.1 Links Between Ecosystem Services and Well-Being

The importance of natural ecosystem products (e.g. timber, honey, wild caught fish) to well-being is probably low and declining yet is an important safety net for the poorest households, as described in Chap. 2. Forest Department records of the total revenue derived from the harvested product (e.g. timber, honey, etc.) of the Sundarbans show a steep decline since the 1990s which, although estimated to represent a small fraction of the value added income from agriculture and aquaculture, represents a significant safety net for poorer populations. Wild fish catches in rivers have also declined substantially in contrast to the rising trend of fish cultivation in ponds (FAO 2014). Over the whole period, provisioning services have increased due to rising agricultural and fisheries productivity. Poverty has however reduced, with many hypothesised explanations emphasising changing access to migration, literacy and health outcomes. The land use shift to value added crops and shrimp farming may have also played a role in poverty reduction. But, as observed previously, in recent times there are contrasts between rising provisioning services and livelihood incomes in different sectors.

For agriculture, the decrease of nearly one-third in the average cultivated area at the household level coupled to a two-fold increase in crop yield points strongly to agricultural intensification. Farmers have adopted high-yielding crops which demand more fertiliser, pesticides and other inputs compared to the traditional local rice varieties (Hossain et al. 2016a, 2013; Ali 1999) resulting in a seven-fold increase in production costs. This increase in production costs and the lack of fair pricing, it is argued, are the main reasons for the falling median incomes of agricultural households (Hossain et al. 2013; IFPRI 2013). However, the situation is complicated. The salinity increase due to shrimp farming also



reduces crop production and creates unemployment for landless farmers because of the low labour demand in shrimp farming compared to crop production (Swapan and Gavin 2011). As a result, farmers are more likely to belong to the poor income groups. This suggests strongly that regional poverty alleviation has not been driven by natural ecosystem products or agricultural intensification but rather incomes generated from aquaculture, especially shrimp farming, non-ecosystem service sectors and the national investment in infrastructure, education and health care.

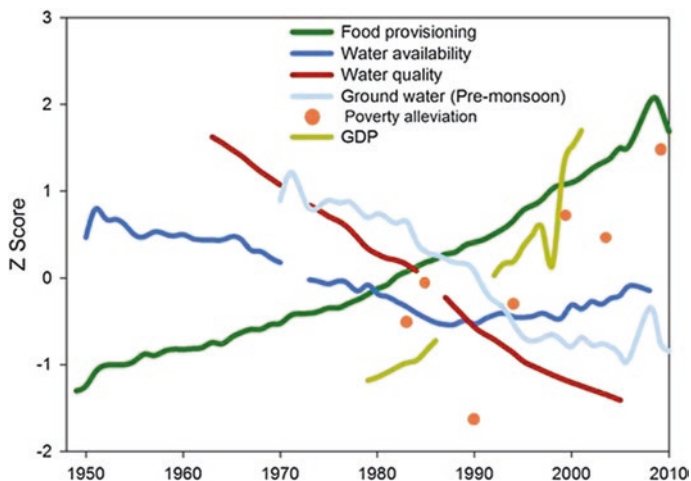
To what extent these multi-decadal changes have been driven by external environmental changes is difficult to quantify or determine with certainty. Within the region there are multiple interacting drivers that include global climate change, the take up of new agricultural methods, national infrastructural developments and local-national policy. Some interactions are strong, direct and linear, while others are weaker, non-linear and may include feedback loops. For example, correlation analysis suggests that climate has directly helped to promote the uptake of high-yielding rice varieties as these are adaptable to rising temperatures and the declining rainfall trend in the pre-monsoon season; traditional varieties are now less viable. In contrast, the conversion of rice fields into productive brackish shrimp farming appears to have been favoured by the rising salinity levels of both soils and water sources. Salinisation is related to the relative rise in sea level and eastwards migration of the main river courses, but has been accelerated by polderisation (Swapan and Gavin 2011; Islam 2006; Mirza and Ericksen 1996) and flood control projects from the 1960s onwards particularly the Farakka Barrage (Mirza 1997, 1998). In turn, shrimp farming tends to increase local soil salinity levels thus generating a positive feedback loop between land use change and environmental degradation (Rahman et al. 2013).

#### **5.4.2 Links Between Provisioning and Regulating Services**

Even though poverty levels among farmers remain high, indicators for average well-being and provisioning services paint a fairly positive picture. In contrast, there is ample evidence to argue that non-food ecosystem

services such as water availability, water quality, biodiversity and land stability have declined, at least in comparison with conditions in the 1960s.

These opposing trends (Fig. 5.4) constitute a trade-off between wealth creation and poverty alleviation and unsustainable land use. It is also clear that this relationship (known as an environmental Kuznets curve, see Dinda 2004) shows no turning point towards lower levels of environmental degradation while poverty continues to lessen as seen in many middle- and high-income countries (Hossain et al. 2016a). Such unsustainable conditions coupled with the clear evidence for later monsoons and higher temperatures should signal a need for proactive adaptive strategies. As Raudsepp-Hearne et al. (2010) have argued, the growing losses of regulating (and supporting) services may eventually be expected to feedback negatively on essential provisioning services, which in coastal Bangladesh would be expected to drive declines in rice, shrimp and fish production. This would impact first on the poorest sector, the rural



**Fig. 5.4** A schematic summary of provisioning services, regulating services, wealth and poverty alleviation 1950–2010. The contrasting curves of normalised data represent a 'trade-off' between rising levels of food production, average wealth and well-being across the region against a background of deteriorating aspects of water (see also Hossain et al. 2016a)

farmers, still dependent on both wage income and subsistence products, before gradually affecting other sectors, the larger landowners and associated processing industries.

## 5.5 Regional Resilience

In dynamical terms, the most striking feature about the data is the dominance of trending rather than stationary curves. The rise in GDP is the most dramatic as it occurs in less than half the timescale of the others. In longer time-series, the shifts towards deteriorating trends in climate drivers and regulating services occurred in the mid-1970s (water availability), mid-1980s (water quality), early 1980s and 2007 (rainfall), mid-1970s temperature and early 1990s (groundwater level). Shifts towards improving trends of provisioning services occurred in the 1980s. The presence of trends over decadal timescales indicates that many variables have an underlying 'slow' component possibly driven by positive feedback loops. But some variables also show fast or high-frequency components over annual and shorter timescales, particularly water quality, rainfall and water availability. System resilience depends upon the interactions between fast and slow variables. The observation that many of the slowly changing non-food ecosystem services that regulate and support key ecosystem processes are deteriorating may indicate weakening resilience within the dependent agriculture and aquaculture sectors. This is especially important because historical analysis shows that flooding and severe cyclones, particularly in 1987–1988, 1991 and 2007, were the major shocks in the past that have impacted negatively on food production and the poorest communities in the past. Lower levels of resilience and projections of higher incidences of climate shocks (e.g. Khan et al. 2000; Ali 1999) raises the prospect of 'perfect storm' scenarios (Dearing et al. 2012) with a greater likelihood of negative impacts in the future. Dynamic and integrated modelling approaches that can guide the selection of adaptation and sustainable management options for the coming decades will be essential to address these concerns.

## Notes

1. available from <http://microdata.worldbank.org>
2. <https://marine.rutgers.edu/globalnews/datasets.htm>

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