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Integrative Analysis for the Ganges-Brahmaputra-Meghna Delta, Bangladesh

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4.1 The Ganges-Brahmaputra-Meghna Delta and Study Area

The Ganges-Brahmaputra-Meghna (GBM) delta is one of the world's most dynamic and significant deltas. Geologically, the delta covers most of Bangladesh and parts of West Bengal (India) and has a total population exceeding 100 million people (Ericson et al. 2006; Woodroffe et al. 2006). The Ganges and Brahmaputra rivers rise in the Himalayas (collectively with catchments in five countries: China, Nepal, India, Bhutan, Bangladesh) and ultimately deposit their freshwater and sediment in the

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R. J. Nicholls et al. (eds.), *Ecosystem Services for Well-Being in Deltas*,
https://doi.org/10.1007/978-3-319-71093-8_4

GBM delta and the Bay of Bengal (Fig. 4.1). The Meghna River has a smaller Bangladesh and Indian catchment. The delta has historically supported high population densities through provision ecosystem services—highly productive farming and fishing systems.

The aggregate population of Bangladesh increased four-fold between 1950 and 2013, from 38 to 157 million, and is projected to exceed 200 million by 2050 with continued significant urbanisation (UN 2013). Land use and population distribution in the delta have also been changing rapidly over the past few decades, in particular a growing urban population in major cities such as Dhaka and Chittagong (and Kolkata in neighbouring India) and land use changes such as expansion of export-led saline shrimp aquaculture. Gross domestic product (GDP) per capita has risen significantly from US$410 in 2000 to US$1,360 by 2016, driven primarily by industrial-led growth in manufacturing, including garments and remittance income from international migration and from economic growth across service and non-farm sectors.

The study area considered for this research, shown in Fig. 4.2, represents a politically, socially and environmentally coherent region, within the defined Coastal Zone of Bangladesh. It is the seaward part of the delta within Bangladesh, south of Khulna and west of the Meghna River to the Indian border. There are numerous islands near the Meghna River, isolating many communities, although transport links are being improved. It also includes the Bangladeshi portion of the Sundarbans, the largest mangrove forest in the world. Excluding the cities of Khulna and Barisal, the study area is largely rural with extensive agriculture, aquaculture and capture fisheries.

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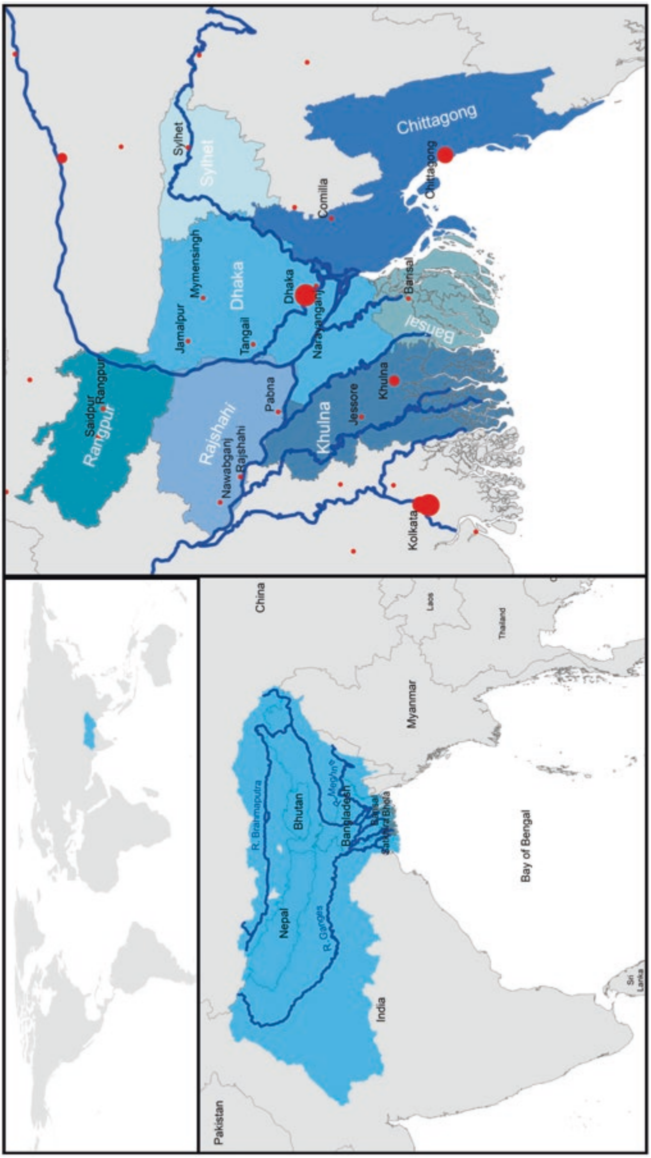

Fig. 4.1 Catchment area of the Ganges, Brahmaputra and Meghna rivers (left), and major distributaries, seven national Divisions (of Bangladesh) and urban centres (red dots) (right)

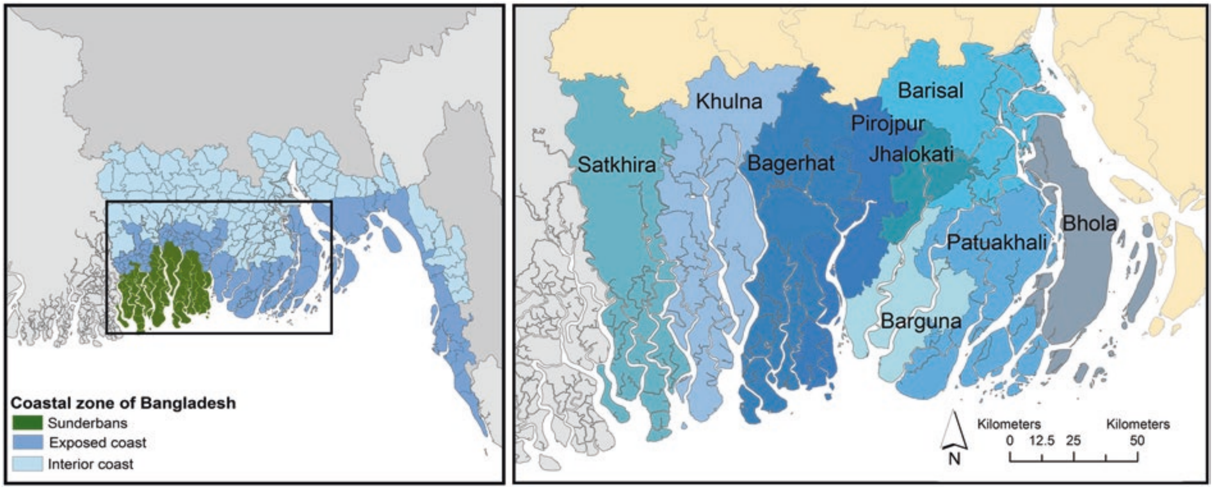

Fig. 4.2 The study area is located within the Coastal Zone of Bangladesh (left) and is comprised of nine districts (right)

Comprising nine districts within two Divisions (part of Khulna and all of Barisal Divisions), the population of the study area is approximately 14 million based on the 2011 census, representing approximately ten per cent of the national population (BBS 2012). Demographic projections suggest that by 2050 the area will have an ageing stable or declining population, somewhere between 11 and 14 million people with migration and mobility critical drivers of demographic outcomes. Migration trends in the delta mirror well-established global trends, with a general increase in urban populations in coastal areas due to migration to coastal cities (de Sherbinin et al. 2011; Seto 2011). Although the study area is essentially rural, it does gain population from this trend. The rural to urban transition sits alongside episodes of involuntary out-migration as both direct and indirect consequences of environmental risks such as salinisation and cyclonic storm surges (Black et al. 2011; Gray and Mueller 2012; Martin et al. 2014). The incidence of poverty is similar or higher than the national average (31 per cent), being 32 and 39 per cent, respectively, in the Khulna and Barisal Divisions (BBS 2011). Savings or access to finance is limited for most of Bangladesh's population (Mujeri 2015), making households vulnerable to economic shocks.

The study area covers one of the world's largest lowlands with an elevation up to three metres—one metre above normal high tides—and it is subject to tidal exchange along numerous north-south channels. It is the area within Bangladesh most exposed to sea-level rise (Milliman et al. 1989; Huq et al. 1995; World Bank 2010), and settlements are subject to tidal flooding, riverine flooding, arsenic in local water supplies, seasonal and longer-term salinisation of water supplies and soils and water logging. Cyclones and associated storm surges have historically caused substantial damage. For example, Cyclone 'Sidr' in 2007 caused several thousand fatalities and significant economic consequences.

Dynamic processes such as flows of water, floods, elevation and the supply of sediments shape the delta. In addition to global sea-level rise, there is a broad regional subsidence of two to three millimetres a year, with localised hotspots exhibiting higher subsidence rates (Brown and Nicholls 2015). Some areas of land are eroded while accretion increases others: there has been a net overall *gain* of land in Bangladesh over the past few decades reflecting a continued current sediment supply, despite upstream damming over the past century (Brammer 2014; Wilson and Goodbred 2015). River floods mainly occur during the wet season (monsoon), when a large volume of water is received from the upstream catchments. This typically results in 20–60 per cent inundation of Bangladesh annually (Salehin et al. 2007), although in the study area such flooding is limited by an extensive system of coastal embankments and polders. Flood risk is projected to increase over the incoming decades, given increased overall discharge projections for the Ganges and other major Himalayan rivers. For the Ganges and Brahmaputra, Lutz et al. (2014), for example, show increased run-off till mid-twenty-first century due to a combination of increased precipitation and glacier melt in the high upper catchments.

Cyclones and tropical storms regularly make landfall in Bangladesh, typically more than once per year, leading to high winds, extreme sea levels and saltwater flooding (Alam and Dominey-Howes 2015; Mutahara et al. 2016). This can damage crops and properties with consequences for life and livelihoods, creating social vulnerability for the study area population. The economic and health consequences of these events are highly significant, and virtually all analyses show that the consequences for economies and societies will increase with projected climate change, with impacts falling disproportionally on poor and vulnerable populations and acting as a brake on development (Hallegatte et al. 2017).

Yet interventions and governance processes can make dramatic differences to vulnerability, poverty and the trajectories of development in the delta. Improved disaster risk management, for example, through the growth of flood warnings and cyclone shelters has greatly reduced the death toll during extreme floods and cyclones compared to the large mortality in 1970 and 1991 (Shaw et al. 2013; Lumbruso et al. 2017). The aspirations of the Bangladesh government are towards economic growth and poverty alleviation, as directly articulated in their planning processes:

> a Bangladesh which, by 2021, will be a middle income country where poverty will be drastically reduced where, our citizens will be able to meet every basic need and where development will be on fast track, with ever-increasing rates of inclusive growth. (Government Vision 2021, (CPD 2007))

The Bangladesh government has also initiated the Bangladesh Delta Plan 2100 (BanDuDeltAS 2014) as part of the strategy for long-term economic sustainability. The Plan is an integrated process that takes a long-term view of the development of Bangladesh and recognises the interconnectedness of environmental sustainability and social progress. The Plan is part inspired by similar integrated planning processes such as for the challenges of sustaining large proportions of low-lying land in the Netherlands (Delta Commissie 2008; Van Alphen 2016).

4.2 Research Challenges in the Ganges-Brahmaputra-Meghna Delta

Ecosystem services in the delta are strongly interconnected, and there are significant trade-offs between different ecosystem services such as the trade-off and even conflict between freshwater agriculture, especially rise paddy, and brackish shrimp aquaculture. Coastal Bangladesh has a system of polders started in the 1960s, where the land is surrounded by coastal embankments with flapgate drains to regulate water levels and enhance agriculture. However, over time, polderisation both prevents sedimentation and promotes subsidence due to drainage (Auerbach et al. 2015), and there has been sedimentation of the riverbed. This degrades soil quality unless artificial fertilisers are used, encourages waterlogging and increases potential flood depths if the embankments fail. Controlled flooding and sedimentation termed 'tidal river management' is an experimental response which might find widespread application (Amir et al. 2013; Nowreen et al. 2014). The balance between sea water and freshwater is a critical issue in the study area (see Chaps. 24 and 28; Clarke et al. 2015; Lázár et al. 2015). This varies seasonally and saltwater pushes far inland during the low river flow period between the annual monsoon rains, and cyclones can also cause saltwater flooding by generating extreme sea levels. If the land becomes too saline, traditional agriculture is degraded. If this persists there are limited options: moving to salt-tolerant crops (which are being continuously developed but add cost) or converting to shrimp aquaculture which is usually for export and providing much lower levels of employment (Ali 2006; Islam et al. 2015; Amoako Johnson et al. 2016).

Upstream water use and diversion to irrigation and other uses also enhances salinisation, as exemplified by the effects of the Farakka Barrage on dry season flows down the Ganges into Bangladesh. The Sundarbans are an important buffer against cyclones, but are threatened by sea-level rise and other stresses (e.g. pollution). They provide a range of ecosystem goods which are available to the poorest, as well as tourism based around the Bengal tiger, an iconic but endangered species.

Explaining social outcomes of ecosystem service use within the GBM delta requires consideration of (i) the magnitude and mobility of ecosystem services and associated populations, (ii) seasonality and other short-term temporal dynamics of ecosystems, (iii) social structures such as the debt economy, (iv) capital accumulation and reciprocity in economic relations and (v) the distribution issues associated with ownership and access to land and resources such as fisheries. These mechanisms are persistent and engrained in social-ecological systems and their governance. They have been used to explain the continued presence of poverty, social exclusion and patterns of uneven development in many contexts (Hartmann and Boyce 1983; Bebbington 1999; Ribot and Peluso 2003). The social mechanisms are manifest in measurable outcomes: notably the material well-being and incomes of populations, their nutritional status and health outcomes and, in so-called subjective well-being, how people perceive their present and futures (Camfield et al. 2009).

This scientific body of evidence further shows that the well-being and health status of populations coming from ecosystem services do not depend on individual elements of ecosystems, but rather on bundles of ecosystems that collectively produce desirable and socially useful outcomes. The people, ecosystems, services and mechanisms used to access these services together combine to create distinct social-ecological systems, unique to each bundle of services. Hence, social-ecological systems form the basis for much of the analysis. The characteristics of co-production of ecosystem services at the landscape scale lead to significant trade-offs between types of ecosystem services (Raudsepp-Hearne et al. 2010). In the GBM delta, such trade-offs are apparent, with Hossain et al. (2016) demonstrating how land use intensification over the past 50 years has significantly increased provisioning ecosystem services per capita, but with a concurrent decline in natural habitats and regulating services.

The dynamics of deltaic social-ecological systems are such that trends are not easily identifiable if simple deterministic relationships are assumed. For the GBM case, for example, populations in poverty persist despite the presence of diverse, highly productive ecological systems. This raises the question of whether access to ecosystem services really can alleviate poverty as opposed to simply maintain a baseline level of welfare (Adams et al. 2013). Similarly, land conversion to shrimp and prawn aquaculture produces high-value commercial products, yet has not transformed the economic fortunes of the localities in which it is practised. Rather aquaculture is co-located with areas of persistent poverty, with the health and economic well-being of associated populations being negatively affected by salinisation (Amoako Johnson et al. 2016).

4.3 Aims and Objectives of This Research

The research described in this book builds on the diverse facets of the current challenges for low-lying deltas such as the GBM, new knowledge on ecosystem services and on human well-being in Bangladesh with an explicit aim of generating findings relevant for long-term planning and policy processes in the delta.

The overall aim is to provide substantive and rigorous results as well as usable and accessible methods and tools to evaluate ecosystem services and livelihoods in coastal Bangladesh, emphasising where and when policy processes and interventions can make a difference. The three main supporting objectives are (i) to engage ecosystem service science for policy analysis and application to coastal and delta system; (ii) to integrate social, physical and ecosystem sciences for the first comprehensive analysis of delta systems and the challenges of the future and (iii) to advance new integrated models linking ecosystem services to all aspects of human well-being and poverty.

The research effort aims to embed participatory and co-production processes from inception through to generating policy lessons. Lessons from diverse stakeholder processes show that key parameters for successful engagement (as indicated by long-term continued use of scientific evidence) include recognising the position and constraints on existing governance institutions, the limitations of scientific evidence for policy, and the critical role of autonomous action and engagement by the governance institutions themselves (Sterling et al. 2017). The research reported here builds on those principles, striving to make the science as useful and salient as well as practical. Hence, stakeholders help to shape and identify problem definition, scenario development and results assessment and interpretation. This gives a strong sense of ownership of the research in Bangladesh.

Integration is also embedded from the start, and the construction of an integrated model is a key aim and outcome of the project. This model aims to couple a range of biophysical processes together with household livelihood information derived from the analysis of census and detailed household survey results. The coupled nature of the integrated model is unusual if not unique as the influence of biophysical changes on livelihoods and human well-being are calculated directly.

As this research developed so the Bangladesh Delta Plan 2100 (BanDuDeltAS 2014) emerged as a key policy process which informed this research. It defined issues such as timescales of analysis, a main focus to 2050 but broader interest in possible biophysical trends to 2100. It also defined possible development interventions, such as the benefits of the proposed Ganges Barrage which is designed to increase dry season flows into the study area.

4.4 The Research Approach

To answer the research questions, key insights from the science of ecosystem services and system analysis in general form a foundation. In deltas, ecosystem services include the processes that bring freshwater, sediments, productive and biologically diverse wetlands and fisheries, and productive land for agriculture. Based on the categories identified in the Millennium Ecosystem Assessment (MEA 2005), a host of (i) supporting, (ii) provisioning, (iii) regulating and (iv) cultural ecosystem services can be identified (Table 4.1 and see Chap. 1, Fig. 1.2). Here the major focus is on the provisioning ecosystem services, although other types of service are considered where relevant, such as the buffering of storms provided by mangroves (a regulating service).

Table 4.1 The ecosystem services considered in this book (with chapter numbers), based on the Millennium Ecosystem Assessment (2005)

Ecosystem service	Related issues addressed in this book (and relevant chapter numbers)
Supporting services	
Nutrient cycling	Agriculture, sediment/morphology (15, 18, 20, 24)
Soil formation	Agriculture, sediment/morphology (15, 18, 20, 24)
Primary production	Agriculture, sediment/morphology, fisheries (14, 15, 18, 20, 24, 25)
Provisioning services	
Food	Fisheries, agriculture (20, 24, 25)
Fuel (wood)	Mangroves (26)
Freshwater	Catchments, salinity (13, 17, 18)
Regulating services	
Water regulation	Legal and policy frameworks, catchments (6, 13)
Erosion control	Sediment/morphology (15)
Water purification	Catchments (13, 17, 18)
Disease control, human	Household survey (22, 23)
Disease control, pest	Agriculture (24)
Natural hazard regulation	Catchments, floods, sediment/morphology, salinity, subsidence, mangroves (8, 13, 15, 16, 17, 18, 21, 26)
Cultural/aesthetic services	
Recreation/ecotourism	Mangroves (26)
Cultural diversity	Household survey (22, 23)

Analysing the future of ecosystem services and human livelihoods in coastal Bangladesh is a complex multi-disciplinary problem. The core issues when integrating the social, physical and ecological dynamics of deltas is the identification and measurement of the mechanisms by which the system components interact to produce human well-being and, importantly, whether these relationships are stable and hence predictable over time. The conceptual framework of the research is, in essence, the diverse social-ecological systems within the GBM delta, and an explanation of how social phenomena and environmental drivers combine to constrain well-being health and pathways of development. A framework that focuses on the mechanisms that link ecosystem services with social outcomes is therefore developed. These mechanisms are core to all the research tasks, including the design of the integrated model, the Delta Dynamic Integrated Emulator Model (ΔDIEM) (Chap. 28).

The analysis is inevitably multi-scale, reflecting the multiple processes shaping the delta. An integrated framework is adopted to be able to represent individual processes, their interactions and how they affect populations and livelihoods. Each topic is considered independently, and this is drawn together using the common framework and scenarios. Four distinct scales are considered: (i) global concerning issues such as climate change; (ii) regional, including the river basin and Bay of Bengal; (iii) national (Bangladesh) and (iv) sub-national, focussing on the study area and the political units that make it up, down to Unions (Fig. 4.3).

Figure 4.4 summarises the overall approach adopted. Governance analysis and stakeholder engagement are continuous throughout and are essential due to the research's participatory nature. This incorporates issue identification, scenario development and discussion of results, including consideration of possible responses and development measures to explore in the integrated assessment (see Chap. 10). This involved an innovative scenario development process combining climate emissions and social-economic change which aimed to generate a dialogue across institutions and sectors to creating a shared future vision and addressing challenges in a holistic, shared and integrated way (Chap. 9).

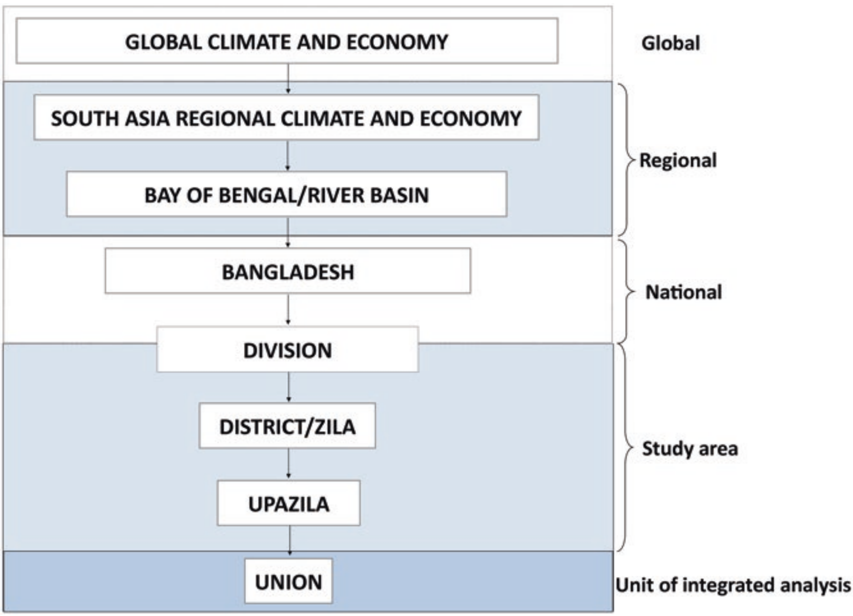

Fig. 4.3 Scales of analysis in this book

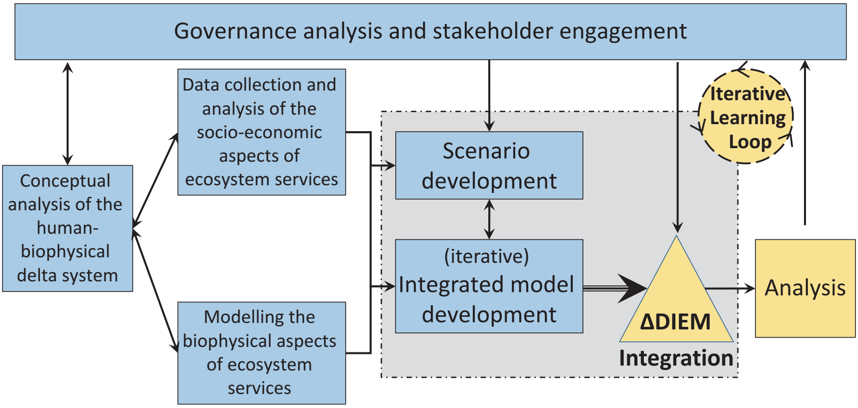

Fig. 4.4 The overall approach and flow of information in the analysis

A preliminary qualitative analysis was essential to test and develop the detailed questions and approaches that were required. In particular, the relationship between ecosystem services and livelihoods was poorly understood at the beginning of the analysis. This process identified a set of seven distinct social-ecological systems (SESs) within the study area, reflecting both the nature of the ecosystem services and human access and their exploitation: (i) rainfed agriculture, (ii) irrigated agriculture, (iii) freshwater prawn aquaculture, (iv) saltwater shrimp aquaculture, (v) eroding islands (charlands), (vi) Sundarbans mangrove forest and (vii) offshore fisheries (Adams and Adger 2016; see also Chap. 22).

This was followed by more detailed social-economic analysis and data collection, including an innovative household survey which collects empirical seasonal data on ecosystem services and livelihoods (Adams et al. 2016; see also Chap. 23). In parallel there is a major effort to analyse and simulate a range of biophysical and social-economic processes with consistent assumptions. This included catchments (Chap. 13), the Bay of Bengal (Chap. 14), sedimentary and morphodynamic processes (Chap. 15), mangrove processes (Chap. 26), flooding and various hydrological processes (Chap. 16), including salinisation (Chaps. 17 and 18) and census-based mapping (Chap. 21). Using their own expertise but co-working where possible, research into specific ecosystem services is also undertaken: health (Chap. 27), fisheries (Chap. 25), agriculture (Chap. 24) and mangroves (Chap. 26). To support these activities and encourage integration, a range of exogenous and endogenous scenarios were developed (see Chaps. 9, 10, 11, and 12), including extensive stakeholder participation in the endogenous scenario development (Chaps. 9 and 10). Preliminary scenarios were available for the early phases of analysis, and developed further to feed into the overall integrated assessment. Hence, integration was built in throughout the project culminating in the development and application of the integrated model (ΔDIEM). ΔDIEM is applied using a range of scenarios to explore possible trajectories of the study area to 2050 and discuss possible policy and development interventions (Chap. 3).

4.5 Linking to the Policy Process

The research was explicitly linked to national scale policy on the basis that policy influence at this scale could have widespread benefits. This includes the innovative iterative learning process where stakeholders

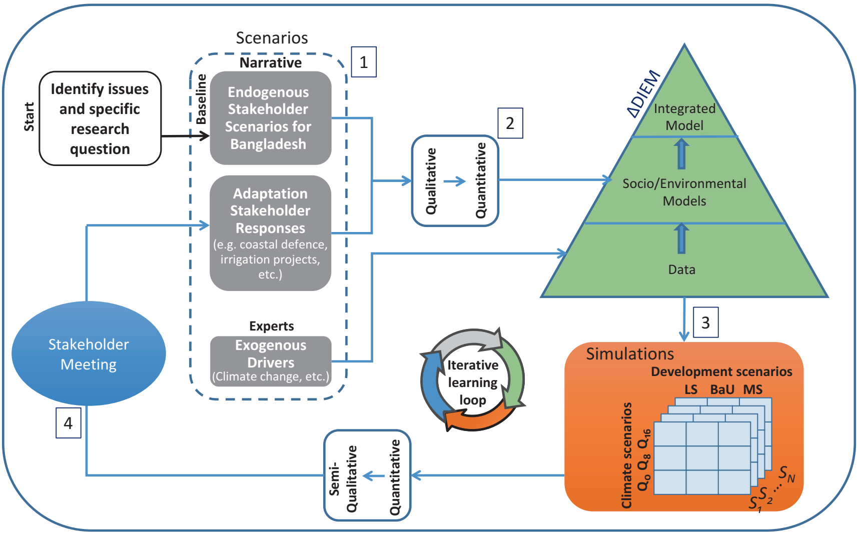

Fig. 4.5 An iterative learning loop using ΔDIEM for policy analysis, comprising (1) scenario development, including adaptation responses, (2) qualitative to quantitative translation to ΔDIEM inputs, (3) simulations using ΔDIEM and (4) stakeholder review of the simulations, which can lead to a new cycle of analysis (Reprinted with permission from Nicholls et al. 2016)

(from government to civil society) are involved in all stages of the research ensuring stakeholder trust, maintain interest in and are willing to participate (see Fig. 4.5). This also helps to provide a process for decision makers to engage and adaptively explore outcomes of the implementation of individual policies or rafts of policies into the future. The iterative loop can be repeated many times, allowing co-learning concerning problems and possible solutions, including trade-offs. This process is considered in more detail in Chaps. 9 and 28. In addition, to help increase understanding and inform the wider population beyond the policy community, research outcomes are disseminated using multiple methods, including a bespoke 'Pot Song' (Chap. 29).

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