



# 3

## The Mahanadi Delta: A Rapidly Developing Delta in India

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### 3.1 The Mahanadi Delta

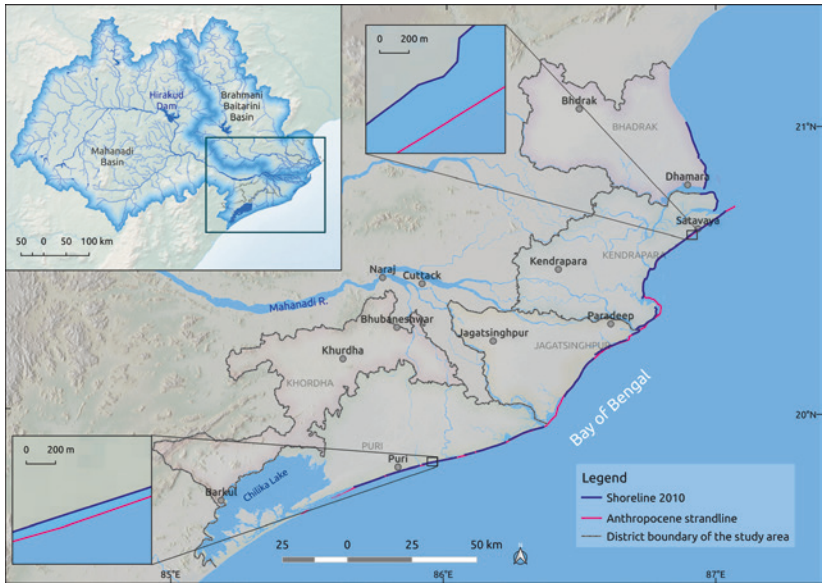
The Mahanadi Delta (Fig. 3.1), located in the state of Odisha on the east coast of India, is a composite delta fed by water, sediments and nutrients from a network of three major rivers: the Mahanadi River (and its distributaries; the Devi, Daya, Bhargavi, Kushbhandra and Parchi) and the adjoining Brahmani and Baitarini Rivers (Kumar and Bhattacharya 2003). The 851 km long Mahanadi River has one of the largest drainage basin on the east coast of India (Fig. 3.1 inset)

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**Fig. 3.1** Mahanadi Delta showing the extent of the catchment basin (inset) and the five coastal districts, with shoreline positions mapped in 1950 and 2010

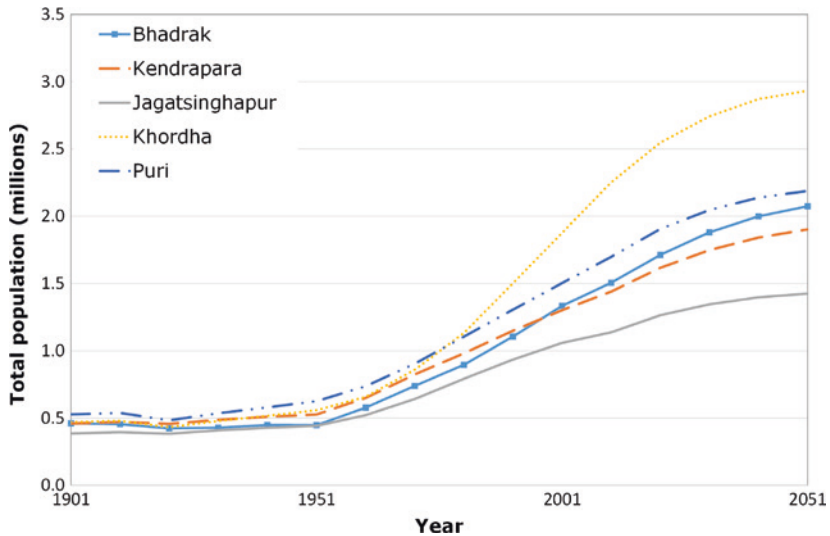
covering 141,589 km<sup>2</sup> (WRIS 2011), 45% of which lies in the state of Odisha. The coastline of the delta is approximately 200 km long, extending from the Chilika lagoon in the south to the Dhamara River in the north. It has five coastal districts (Puri, Khordha, Jagatsinghpur, Kendrapara and Bhadrak) which constitute 83% of the delta area and have large areas below the five metre contour where floods due to cyclones and sea-level rise are expected to be important. These districts form the focus of the research presented here.

## Indicators of the Anthropocene

During the Holocene period the delta shows evidence of substantial progradation and growth. The onset of the Anthropocene (post 1950) was indicated when this growth rate declined significantly, in line with a period of intense dam building (Somanna et al. 2016). This started with the construction of the multipurpose Hirakud Dam on the Mahanadi

River near Sambalpur in 1957, and has resulted in a total of 254 mainly small and medium scale dams within the drainage basin (WRIS 2014). The decline in sediment supply has been significant, amounting to 67% for the Mahanadi River and around 75% for the Bramhani River (Gupta et al. 2012). As a consequence, over 65% of the coastal margin is presently experiencing moderate to severe erosion, with increasing rates from south to north (Mukhopadhyay et al. 2018). For example, between 1990 and 2015, the Anthropocene shoreline (as mapped in 1950, see Fig. 3.1) receded at a rate often exceeding 10–15 m/year. Near the Mahanadi estuary, the rate has exceeded 50 m/year. Hence, erosion is now a key feature of the once prograding delta (Dandekar 2014; Mukhopadhyay et al. 2018).

Since the 1950s, the coastal districts of the delta have also witnessed rapid increase in population (especially Bhubaneswar city), growth of a port, industrial development along with increased groundwater extraction, small- and medium-scale irrigation projects and deforestation of mangroves. Based on the Census of India (2011a, b), the population in each coastal district has accelerated rapidly (see Fig. 3.2) reaching eight million in 2011 across the five coastal districts. The associated high population density is around 600 persons per km<sup>2</sup>, growing at an estimated annual rate of 1.4% over the last two decades. Population projections anticipate this growth to continue until at least 2050 (Whitehead et al. 2015), although spatial variation in population distribution is noticeable (Fig. 3.2); Khordha is the most populated district with a population of 2.25 million (52% male and 48% female), whereas Jagatsinghpur district has the lowest population (1.13 million, 51% male and 49% female). The increase in population is allied with rapid urbanisation. The coastal city of Puri is famous for religious tourism and experiences an annual 10% rise in temporary population largely due to foreign tourists (Das 2013). On the outer fringe of Mahanadi Delta, the capital city of Bhubaneswar, established in 1948, registered the highest population growth rate in India during 1961–1971 with significant ongoing urban growth (Pathy and Panda 2012). Along with tourism, business and IT industries, education and health services make the area among the top three investment destinations in India (*The Economic Times* 2015). The port city of Paradip on the Mahanadi River, in



**Fig. 3.2** Historical and projected decadal population growth for the five districts within the Mahanadi Delta (1901–2051) showing acceleration in the Anthropocene (post 1950s)

Jagatsinghapur district, is also emerging as a hub for major petroleum, chemicals and petrochemical investment regions.

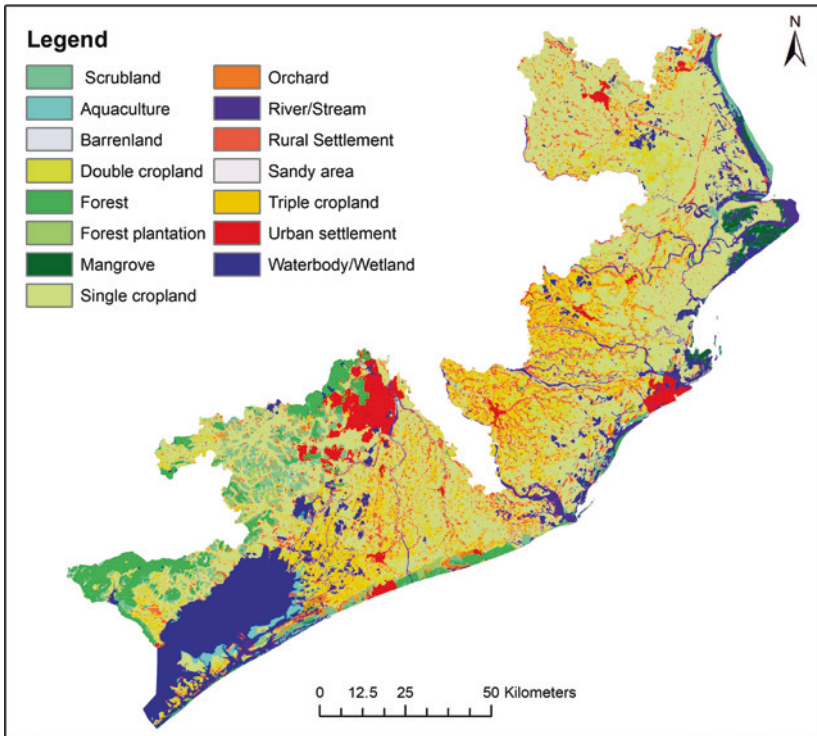
As a consequence, the Mahanadi River system has experienced a substantial increase in the amount of untreated sewage and industrial effluent and rising levels of pollution (Radhakrishna 2001; Sundaray et al. 2006). During the peak monsoon discharge, high levels of organic pollution are indicated by Nitrogen and Phosphorus loading (Sundaray et al. 2006). Substantially low dissolved oxygen conditions have also been reported (Pradhan et al. 1998; Nayak et al. 2001) leading to more acidic conditions (Borges et al. 2003) with extremely low levels of pH being reported at various stations along the Mahanadi River in recent times (Panda et al. 2006; Sarma et al. 2012; Behera et al. 2014). The most strikingly low pH values have been observed in the Atharbanki creek water near the port at Paradip (pH=3.2) with negligible seasonal variability (Sundaray et al. 2006). Such steady acidic input has a potential to affect agricultural productivity and contributes to the acidification of the Mahanadi Estuary with consequences for fisheries, aquaculture

and tourism (Sarma et al. 2012; Bhattacharyya et al. 2015). Plastics, another key indicator of the Anthropocene period, are increasingly found in sediments and water bodies endangering fish, marine mammal and bird populations (e.g. in the Chilika lagoon [Sahu et al. 2014]).

More than 57% of the land area of the Mahanadi Delta is under cultivation. Agriculture currently (in 2011) occupies 68% and, with a subsidiary occupation of capture and culture fisheries, provides the subsistence for the predominantly rural population of the delta. The net area sown and gross cropped area are 0.64 million hectares and 1.12 million hectares respectively (DAFP 2014). Agricultural intensity has been and is still being promoted by converting existing monocrop areas to grow two or three crops per year using irrigation water and chemical fertiliser input to boost crop production and yield (Ghosh et al. 2012; Srivastava et al. 2014; Pattanaik and Mohanty 2016).

The rapid urbanisation and development in agricultural practice over recent decades have left a mark on the environment. Land use analysis finds that between 2001 and 2011 alone, the delta has lost 4600 hectares of agriculture land and 360 hectares of pristine mangrove forest to urban/rural settlements and aquaculture. A probabilistic land cover change assessment for 2030 (Fig. 3.3) under a Business as Usual (BAU) scenario (see Kebede et al. 2018) suggests that the double and triple crop areas in the delta are likely to increase by 12 and 21%, respectively, with substantial (48% when compared to 2011) reduction in mangrove areas (and associated unique ecosystem services). This change in agriculture is reflected in the economics of the delta with the agriculture and animal husbandry sector contributing only 17% (2012–2013) to the Gross State Domestic Product (GSDP) at current prices and the share of the agricultural sector in the states gross domestic product declining over the last decade (P & CD 2014, 2015). Lower profitability of agriculture coupled with reducing yield per hectare is considered the major reason for this decline. Climate change and associated hazards have the potential to further reduce agricultural yield by 2050, affecting food security and reducing the GDP of the delta population by around 0.27% (Cazcarro et al. 2018) (see Chapter 8).

Fisheries, both marine capture and culture, are another important livelihood option for the people in the delta. Before the 1950s,



**Fig. 3.3** Projection of land cover change in the Mahanadi Delta for 2030 under a Business as Usual scenario

people used to depend on subsistence fishing in the river and the estuaries using boats to supplement their daily protein requirements. In the capture fisheries sector, motorised boats were introduced in the late 1950s but only became popular with the increasing availability of outboard engines during the 1980s. This is reflected in the increase in average annual marine catch from 5000 tonnes (1950s) to 120,000 tonnes (1990s). However, in spite of the introduction of technology in the form of improved engines and fishing gears, the marine catch still shows abrupt fluctuation due to variability of the monsoon, river discharge and other oceanographic parameters. Over the last two decades, while the catch of prawns (*Penaeid* and non *Penaeid* species) or Ribbon

fish showed a steady increase, the prize catch of Hilsa, Silver Pomfret, Bombay Duck or Indian Spanish Mackerel showed a wide variation. For the future, the impact of climate change on marine fisheries of northern Bay of Bengal analysed using integrated modelling (Fernandes et al. 2016a, b; Cazcarro et al. 2018; Lauria et al. 2018) is expected to reduce marine fish production in the Bay of Bengal region between 3 and 9% by 2100 under a BAU scenario. The socio-economic implications of this decline indicate that, if combined with unsustainable fishing practices, there would be significant loss in the GDP of the Mahanadi Delta region by 2050 (Lauria et al. 2018).

### Extreme Events and Climate Change

Climatic extremes have a potential to affect the delta adversely. Odisha is the fifth most flood-prone state in India with the delta exposed to frequent floods and waterlogging. In addition to heavy rainfall, cyclonic winds and tidal flows also cause flooding in coastal areas with flooding usually lasting for five to fifteen days in the coastal districts. While low to moderate intensity floods are often treated as a boon by the coastal community due to the arrival of high fertility soils, it is the high-intensity floods that adversely affect the lives, livelihood and food security of the coastal community (F & ED 2010, 2018).

The Mahanadi Delta is situated in the most cyclone-prone region of India. Historical data on cyclones in Odisha indicate high disaster losses due to cyclone and surges in the Anthropocene period (Chittibabu et al. 2004) with eight high-intensity flooding events reported during the period 2001–2015 (Ghosh et al. 2019). One of the most extreme events experienced was the 1999 Odisha Super cyclone Kalinga which had an estimated maximum wind speed of 260–270 km/hr generating a surge of more than 6 metres (20 feet) which travelled 20 km inland (Kalsi 2006). This along with heavy rainfall led to substantial loss of life and damage to property. In the five deltaic districts, 9078 lives were lost, 445,595 houses collapsed, 13,762 houses were washed away and around 0.7 million hectares of agriculture land was affected (PCD 2004). In recent times, thanks to the improved cyclone and

flood warning, evacuation and disaster management procedures and community preparedness, loss of life and property can be minimised (Padhy et al. 2015) as evidenced during the very severe cyclonic storms Phailin (2013) and Hudhud (2014). Simulations from a regional climate model suggest that the frequency and intensity of severe cyclones are likely to increase along with extreme sea levels in the later part of this century when compared to a baseline scenario (1961–1990) (Unnikrishnan et al. 2011).

Future climate data from regional modelling (Macadam and Janes 2017) also indicates that precipitation along with high rainfall events may increase significantly in the later part of this century. Using daily discharge simulations from bias corrected CNRM-C5 data between 2021 and 2099, it is observed that the number of high discharge events (those exceeding 20,000 cumec, capable of generating flood in the delta) is likely to increase under a BAU scenario. The greatest impact of these high discharge events and flooding would be on agricultural land along with a number of urban areas across the delta. Table 3.1 shows the likely extent of flooding and coastal inundation of agricultural land in the delta by the end of the century under this scenario.

In addition, the rate of relative sea-level rise in the last decade has increased to nearly 6 mm/year (Mukhopadhyay, personal communication computed from PSMSL data [<http://www.psmsl.org/>]). Forecasting the future coastline for the years 2020, 2035 and 2050, Mukhopadhyay

**Table 3.1** Spatial extent of agricultural area inundation in the Mahanadi Delta by 2100 under a Business as Usual scenario

Blocks/sub-districts	Area of cropland (km <sup>2</sup> )	
	Projected to be flooded in 100 year fluvial floods	Projected to be flooded coastal storm surges
Chandabali	418	421
Basudebpur	298	256
Mahakalpara	290	280
Rajnagar	251	263
Tihidi	212	176
Ersama	211	148
Pattamundai	206	152
Rajkanika	–	183



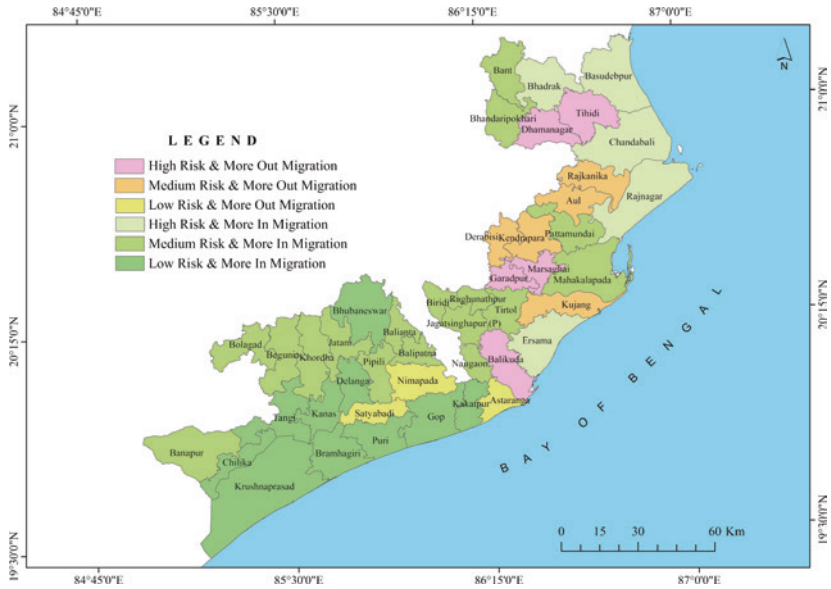
et al. (2018) estimate that about 26 coastal *mouzas* (small administrative blocks) out of 87 (approximately 30%) with average population density greater than 400 per square kilometre would be susceptible to acute erosion by the year 2050 and this may lead to displacement of people from the coast.

## 3.2 Key Issues for the Mahanadi Delta

### Migration

Throughout history, deltas have been a preferred destination for people to migrate and settle thanks to the abundance of natural resources and livelihood opportunities (Szabo et al. 2016). However, the Mahanadi Delta itself has seen a net trend of out-migration. In the state of Odisha, migration (mostly internal) can be permanent, seasonal or circular, and, as it is an ongoing process, it can be difficult to identify causes.

From a study of perceptions of environmental stress of migrant households, it emerges that hazard events such as flooding and droughts act as 'stressors' and motivate individuals/households to consider migration as an option. This is supported by analysis and mapping of risk and net-migration at sub-district level (Fig. 3.4) which includes the common environmental stressors of flooding, cyclone and coastal erosion. Several coastal sub-districts are shown to be adversely affected by climatic hazards, have a low level of economic growth, exhibit high risk and, critically, experience greater out-migration. The sub-districts of Dhamnagar, Ersama, Balikuda and Tihidi are biophysically and socio-economically at very high risk and out-migration dominates (Fig. 3.4) whereas, several sub-districts at comparatively lower risk (e.g. Khordha, Puri) and urban growth centres mostly act as net receiving areas of migrants. Khordha, which is the most urbanised district in Odisha (43% urban population), Puri (famous destination for religious tourism) and Paradip (a growing seaport) emerge as preferred destinations of migrants as they offer economic opportunities for migrants from adjoining rural communities (Das et al. 2016).



**Fig. 3.4** Multi-hazard risk and migration map for the Mahanadi Delta

However, in a household survey carried out in 2016 (see Table 3.2), over 40% of respondents reported that the main reason behind migration is economic, with the majority of migrants moving in search of better employment opportunities. The second most frequently mentioned reason (nearly 20%) is associated with education; to pursue a degree or obtain training. The survey also shows that the dominant nature of migration is seasonal (62%). People migrate to major cities and different states of India once or twice a year depending on the season. Migrants are mostly from agricultural households where monthly income is low and where household size is large (more than 6 members). It is possible that low returns from the existing livelihoods of agriculture and fisheries are triggering migration in the hope to generate alternative livelihoods.

The propensity to migrate is highest in the 21–30 age group and people with secondary and tertiary education generally tend to migrate more than those with lower levels of education. It is most common for single male members of a family to migrate; women either migrate with family members, or remain as female heads of households. Male-headed families

**Table 3.2** Patterns of migration in the Mahanadi Delta based on a household survey carried out in 2016

Characteristics		Responses (%)
Type	Seasonal migration	62.1
Frequency	1–2 times	54.2
Duration	3–6 months	39.7
Scale	Internal migration	99.2
<i>Destination</i>		
State	Odisha, West Bengal, Karnataka, Tamil Nadu	69.7
District	Khordha, Kolkata, Puri	60.4
City	Bhubaneswar, Puri (M), Khordha (M)	75.3
<i>Current migrant's characteristics</i>		
Male migrants		
Age	21–40	60.6
Marital status	Never married	52.9
Education	Secondary	49.7
Livelihood	Factory worker, regular salaried employee, construction worker	78.1
Monthly income	Rs. 10,000 and below	71.6
Female migrants		
Age	21–40	50.0
Marital status	Currently married	54.8
Education	Secondary	43.9
Livelihood	Unpaid home carer, student	88.2
Monthly income	No income	91.8
<i>Reasons</i>		
First	Seeking employment	43.6
Second	Seeking education	19.4
Third	Family obligations/problems	13.5
<i>Remittances</i>		
Type	Money	42.0
Frequency	Monthly	47.4
Amount	Rs. 5000 and below	70.3
Uses of remittances	Daily consumption (food, bills)	71.0

dominate in the delta (1225 [87%] male as opposed to 189 [13%] female), but the increase in the number of female-headed household is emerging as a feature of Anthropocene in the Mahanadi Delta; it is estimated from the household surveys that the number of migrant-sending households will increase in the delta to 38% in the near future resulting in more married women 'left behind' as female heads of households.

These female-headed households often have a more difficult time during the extreme events than male heads due to family care responsibilities, lower incomes, lower resilience or adaptive capacity. A key conclusion from the survey is that female-headed households experienced more monetary losses due to failure of crop, livestock and equipment damages as well as loss of life, during the extreme events than their male-headed counterparts. More than 37% of the female heads have no income and 47% have income less than INR 3000 per month. Sixty per cent of female heads are found to be widowed. In fact, widows, dominantly of mature age (54% are over 60 years old) and with no education (>50%) are often dependent on pension schemes (widow pension, old age pension) provided by the government or are supported by relatives. This suggests that female-headed households living in physically most vulnerable conditions in the delta are socio-economically more vulnerable than the male-headed households.

Monthly remittances sent by migrant family members can alleviate the vulnerable status of households, at least marginally. Remittances enable recipients to pay for daily consumption (food, bills), education and health, and to maintain or improve their standard of living. Households with a migrant member are economically better placed than those without migrants. This is more prominent in the case of female-headed households. Monthly Per Capita Expenditure (MPCE) of female-headed households with migrant members are found to be higher (Rs. 2355) than those without any migrant member (Rs. 1473). More than 60% of total respondents felt migration is beneficial as this improves the socio-economic status of migrants and migrant-sending households. The exchange of money, knowledge and ideas between migrant's place origin and destinations offers further opportunities for reducing the socio-economic and biophysical vulnerabilities for communities within the delta.

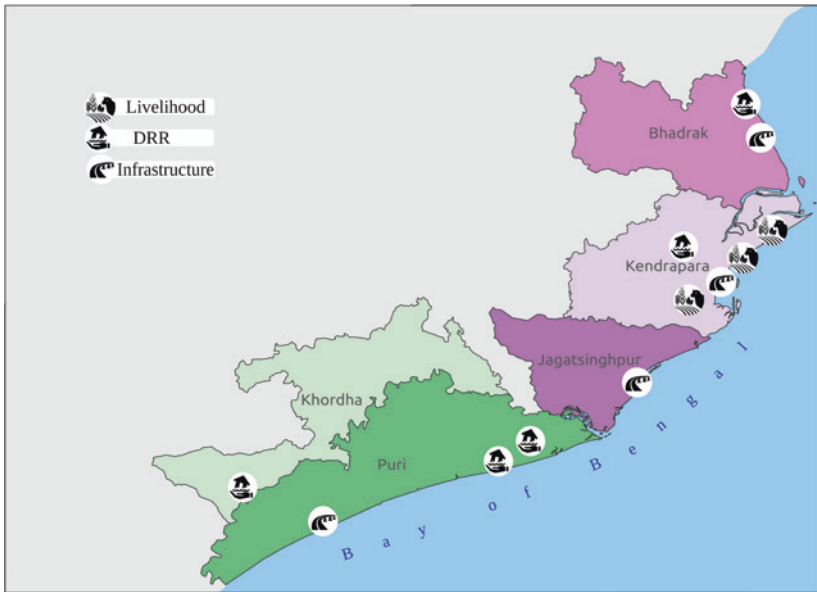
## **Adaptation**

Adaptation activities, both autonomous and planned are taking place in the delta in relation to vulnerability reduction, disaster risk

reduction and building social-ecological resilience to natural hazards and environmental changes (see DECCMA 2018). A notable case of planned adaptation due to environmental change is the Satabhaya Gram *panchayat* of the Kendrapara district in the delta. After a loss of 65% of land area due to erosion, 571 families were identified by the Government of Odisha to be resettled and rehabilitated in Bagpatiya village in 2010 (R & DM Department 2011). However, while more than 50% of families have been resettled, full implementation of the plan is yet to be achieved.

Survey results, at the household level, recorded adaptation activities can be broadly subdivided into three categories: disaster risk reduction, livelihood assistance and infrastructure building. The first category includes capacity building and training in various forms to improve resilience/adaptive capacity of the individual or community for reduction of disaster risk, which is observed to be a dominant mode of adaptation in the Mahanadi Delta (Tompkins et al. 2017); the second category of livelihood related activities include climate tolerant crops, mixed farming, irrigation and water resources augmentation and fishing new breeds; the third category of infrastructure related adaptation involves construction of embankments, house relocation or upgrade and cyclone shelters. The impact of these adaptations is reflected in improved agricultural productivity, food security and efficient management of water resources and enhanced income (Hazra et al. 2016). Use of these techniques is spatially variable across the delta (see Fig. 3.5).

Capacity building and training, climate-tolerant crops, assistance from government and NGOs and structural protection measures like embankment or cyclone shelters were seen to be effective, with loans, cutting down trees and the use of mixed farming methods deemed less successful by those surveyed. For those working at State and District level, the topmost criterion for successful adaptation is the improvement of the capacity of the local institutions to manage environmental disasters and changes. Odisha is exposed to floods and cyclones, and this indicates the need for enhancing capacity to cope with these disasters at all levels across the delta.



**Fig. 3.5** Spatial variability of adaptation activities in the Mahanadi Delta

During the household surveys, the opinion of both male and female respondents were collected on 21 adaptation options that they may/may not practice, the scale of relative success and the preference or intention of the respondents for a particular type (Fig. 3.6 upper). Other than infrastructure and agriculture/fishing (livelihood) related activities, the soft options for disaster reduction related activities such as training, capacity building, assistance, loan, etc. are included in Institutional Support. Migration, returned migration or women working outside the village have been considered under mobility. The responses are also plotted against the percentage of success (abscissa) and percentage preference (ordinate) with the size of the bubble varying with the frequency of practice (Fig. 3.6 lower). From these results it can be observed that there are gender differences in the practiced adaptation activities and often the most practiced adaptation activities are not always the most successful one.

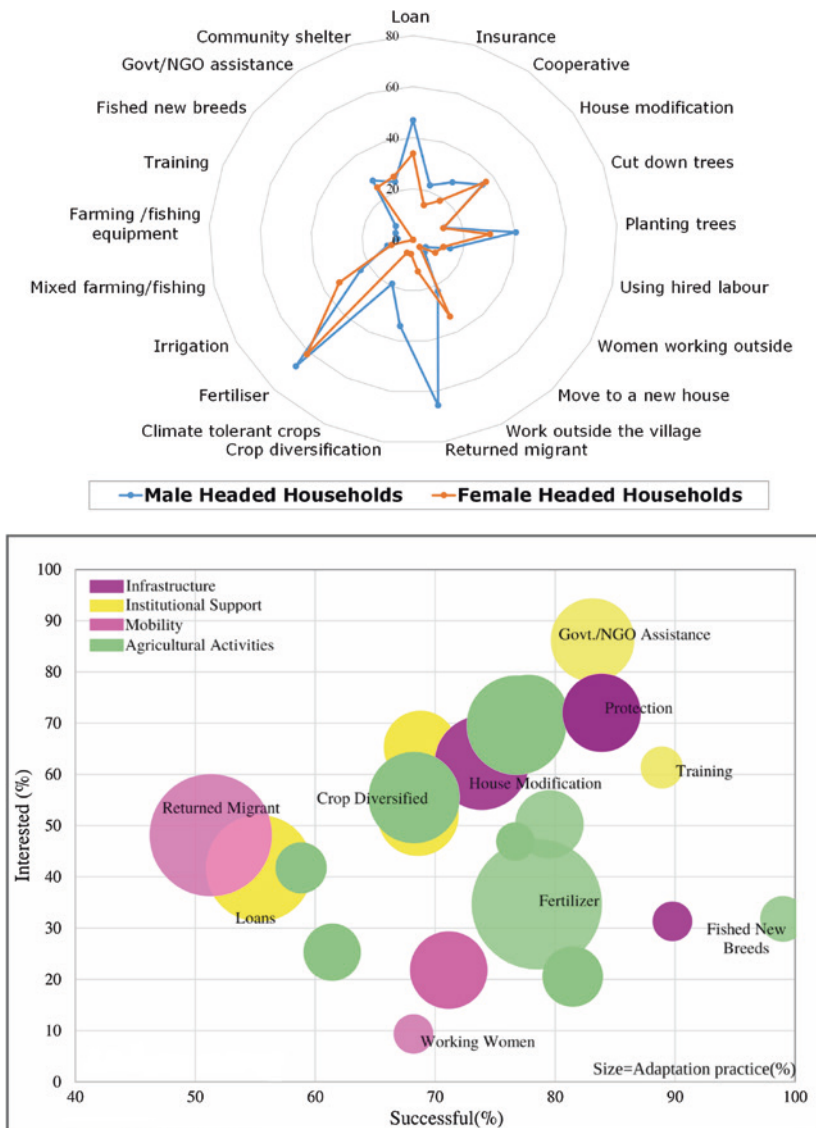


Fig. 3.6 Gender differentiated adaptation activities (upper) and adaptation practice, success and preference (lower)

## Policy

In Odisha, there are no specific policies focussed on the Mahanadi Delta. This part of the State, though both biophysically and socio-economically vulnerable to climatic and demographic changes, have never been addressed as a separate planning unit. The most significant coastal project with a potential long-standing impact on the sustainable development of the delta is the Integrated Coastal Zone Management Project (ICZMP), being implemented in two coastal stretches—Paradeep to Dhamra and Gopalpur to Chilika. However, the investigation of the biophysical sustainability of the delta as a physiographic entity and socio-economic well-being of the deltaic community was not included. The delta coastal districts are also not considered in livelihood generation schemes such as National Rural Livelihood Mission (NRLM)/ Odisha Livelihood Mission (OLM) and employment guarantee programme of Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). The NRLM also reports that in the year 2013–2014 the number of self-help groups in delta districts is less than half of the non-delta districts like Ganjam and Mayurbhanj functioning with government support (P & CD 2015).

No national policy, plan or regulations covering adaptation activities addresses human migration due to climate change and disasters, or the adaptation requirements of vulnerable female-headed households. However, a picture of migration on the delta should not be solely characterised by the concept of a vulnerable population forced to migrate, having failed to adapt to environmental variability. This research identified various benefits of migration in the delta, with remittances being one of them. Data shows that domestic remittances have risen most significantly in Odisha since the 1990s (Tumbe 2011). In 2007–2008, rural Odisha received 14.25 billion dollars as domestic remittances, 6th highest in the country. The benefits of remittances positively contributed to autonomous climate adaptation by the community.

Another inadequacy of present policies of climate change adaptation and disaster risk reduction is the limited consideration of gender in policies and more generally a lack of a gendered database for an effective yet differentiated planning. Such differentiated policies would be



necessary to address the rising number of female-headed households in the delta. Making certain of gender equity in decision-making is very important in migration contexts, especially when the out-migrants are generally adult male members of the family. Empowerment of women through various skill building and other trainings will help in developing the adaptive capacity of this vulnerable group.

### 3.3 The Future for the Mahanadi Delta

In the Anthropocene, where human beings have the capacity to alter the pathway of natural changes, the future is what humans make it. Future projections under a BAU scenario are not encouraging for the Mahanadi Delta. Higher sea surface temperatures (a rise of potentially 2.3–2.9 °C [Fernandes et al. 2016b]) and sea levels along with an increasing number of high rainfall events, particularly in the later part of the century, has a potential for increased number of flood events endangering life and livelihoods of the delta community. Climate change and climatic shocks also have the potential to reduce crop yield in the delta. Based on the IPCC's Shared Socio-economic Pathway 2 scenario for the Mahanadi Delta, Arto et al. (2019) estimated, that, by 2050, the economic loss from agriculture could be about 5% of GDP per capita. However if loss of infrastructure is considered, climate change and climatic shocks (flood, cyclone, etc.) may lead to cumulative per cent loss in GDP per capita of about 11% in the delta (Arto et al. 2019). At the same time, with the projected loss of fisheries production (Fernandes et al. 2016a), the socio-economic integrated model indicates that losses from the fishery sector alone to be around 0.25% of the total GDP in the delta by 2050 (Lauria et al. 2018). These together impose a serious constraint on the livelihood of the delta community in future.

Like most other deltas in the world, Mahanadi Delta, is under threat from sea-level rise and sediment starvation (Chapter 5). The potential consequences of extreme events are illustrated by surge-inundation from the 1999 Super cyclone when the district of Jagatsinghpur suffered over eight thousand fatalities (see Table 7.6 in PCD 2004). As indicated earlier, 65% of the deltaic coast is also currently experiencing

varying degree of erosion, a situation which is expected to worsen by 2050 (Mukhopadhyay et al. 2018), implying compounded threat to the coastal habitations particularly between Puri to Paradip and promoting increased out-migration of people from the coast.

Whether the Mahanadi Delta will be able to withstand adverse environmental hazards in the Anthropocene and develop sustainably will largely depend on global climate change mitigation action (see Brown et al. 2018) alongside regional, national and local adaptation planning. As the latter are currently limited in scope and application, an immediate challenge is to generate management plans which aim to develop holistic pathways to sustainable management of biophysical and human resources of the delta in near future.

### 3.4 Discussion and Conclusion

This research looks at the changes in the Mahanadi catchment basin since the onset of the Anthropocene (i.e., since 1950), focusing on the evolution of the Mahanadi Delta, both in terms of biophysical and socio-ecological change over time including delta management and policy evolution. The once prograding delta of the Holocene is now retreating due to sediment starvation and sea-level rise, and experiencing accelerated population growth, decline in income from agriculture or fisheries, increasing pollution in the river system with potential of acidification of estuaries, proliferation of plastics in the environment, degradation of mangroves with loss of biodiversity and human migration. Thus the Mahanadi Delta is now shrinking and a more challenging situation is emerging. The most vulnerable communities often suffer disproportionately at times of natural disasters with potential loss of life, livelihoods and assets. The people living in the Mahanadi Delta are forced to cope with frequent disasters, but recent progress in warnings, evacuation and shelters seems to have reduced losses. Urban areas in the delta are expanding and there is rural to urban migration which can be expected to continue. These urban areas will have important implications for the future of the delta.

For policymakers at both the State and District level, the topmost criterion for successful adaptation is the improvement of the capacity of the local institutions to manage environmental disasters and changes. This research indicates a positive correlation between perceived success of adaptation activity and people's intention to undertake them. However, the most practiced adaptation activities are not always the most successful in the Mahanadi Delta. Adaptation activities are not always gender-sensitive with the effect that men are benefiting more than women. Thus it has to be ensured that the most vulnerable groups including the elderly, the severely poor, the physically challenged and women are involved in the development of migration-related adaptation as stakeholders. All stakeholders need to be involved for proper planning and implementation of adaptation plans and for accrual of benefits from there.

This research has the following three key observations for the Mahanadi Delta: (i) assessing the Mahanadi Delta region as a unit of planning and implementation offers opportunities to enable coherent policy responses to reduce the risk of climate change to populations by supporting gender-sensitive adaptations; (ii) a variety of types of adaptations should be used to reduce climate change risk; and (iii) to encourage migration as an adaptation, targeting trapped populations with skill development (as observed in Pattamundai, Kendrapara district) can improve their migration capability. Alternatively, designing income-generating opportunities like skills training, livelihood programmes and development initiatives for those who remain behind in areas affected by disasters/climate change will reduce their vulnerability and increase their ability to cope during an extreme weather event.

In the Anthropocene, the major challenge for the rural areas of the Mahanadi Delta is to restore or maintain the natural delta dynamics as far as possible, to combat the cumulative threat of sea-level rise and land subsidence and address the water-sediment-pollution-biodiversity interactions, while maintaining the socio-economy of the delta in an integrated and inclusive way to make the delta sustainable for the future generations. The interactions of the rural delta areas with the urban delta areas also need to be considered.

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