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VALUATION OF COASTAL AND MARINE ECOSYSTEM SERVICES IN INDIA: MACRO ASSESSMENT

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Preface

"Valuation of Coastal and Marine Ecosystem Services in India: Macro Assessment" has been prepared as part of the project, Assessment of Coastal and Marine Ecosystem Goods and Services: Linking Coastal Zone Management to Ecosystem Services in India, funded by National Centre for Sustainable Coastal Management (NCSCM), Chennai.

Three consortium partner institutes – NCSCM, Madras School of Economics (MSE), and Goa University (GU), have contributed to this assessment. The three research teams contributed to different components of the paper. The NCSCM team contributed to the valuation of marine fisheries, seaweeds, coastal minerals, and coastal salt; the MSE team contributed to the valuation of seawater desalination, industrial cooling, coastal shipping and coastal protection; and the GU team contributed to the valuation of coastal recreation. The valuation of carbon sequestration has been carried out by the MSE team with inputs from the NCSCM team. The final compilation of the report was coordinated by the MSE team.

The three research teams gratefully acknowledge the financial support provided by NCSCM and thank Prof. R. Ramesh, Director, NCSCM for his guidance throughout out the project period. The research teams acknowledge the helpful comments provided by the review committee consisting of Prof. B. R. Subramanian (Chairman), Prof. D. Chandramohan, Prof. R. Maria Saleth, Dr. Ahana Lakshmi, and Dr. D. Asir Ramesh at the meeting held on 24th June 2015 at NCSCM, Chennai. The research team would also like to place on record the help extended by Dr. Purvaja and Dr. Asir Ramesh in the smooth execution of the project.

The MSE team would like to place on record their sincere thanks to the Chairman, the Director and the Administrative Officer of MSE for their help during the project. The secretarial help provided by Ms. Saraswathi and Ms. Geetha of MSE in the preparation of the final report is gratefully acknowledged.

Valuation of Coastal and Marine Ecosystem Services in India: Macro Assessment

EXECUTIVE SUMMARY

Coastal and marine ecosystems, including mangroves, seagrasses, coral reefs, sand beaches and dunes, mudflats, salt marshes, estuaries and marine waters, provide a host of services that are of vital importance to human well-being, health, livelihoods and survival. These include 'provisioning services' (e.g. food, water, raw materials), 'regulating services' (e.g. coastal protection, carbon sequestration), 'recreational services' (e.g. coastal tourism) and 'habitat services' (e.g. nursery services). The aim of this study is to value, in monetary units, coastal and marine ecosystem services in India. The reasons for doing so are two–fold: i) the destruction and degradation of coastal ecosystems necessitates the accounting for ecosystem service losses in terms of the benefits foregone to human beings, such that appropriate decisions and actions regarding the extent to which coastal ecosystems are to be conserved may be taken; and ii) very few studies exist in the literature that have comprehensively valued coastal and marine ecosystem services in India.

Three methods have been used to estimate coastal and marine ecosystem services in this study, including: i) the direct market valuation approach (that includes the avoided cost approach) that uses market information to estimate a price or cost times quantity value; ii) the travel cost method that uses information on time and various types of travel expenses to arrive at a recreational value; and iii) benefit transfer in which values estimated in other studies are adjusted to the present study's context. A summary of the coastal and marine ecosystem service values estimated for the year 2012-13 in billions of rupees, along with the methodologies used to arrive at the same, are presented in the table below.

S. No.	***Service Valued***	***Method of Estimation***	***Value Range Min.***	***Value Range Max.***	***Average Value***
I.	PROVISIONING SERVICES				
1.	Marine Fisheries	Direct Market Pricing	-	-	294.48
2.	Seaweeds	Direct Market Pricing	-	-	0.09
3.	Coastal Minerals	Direct Market Pricing	-	-	12.47
4.	Coastal Salt	Direct Market Pricing	-	-	12.40
5.	Seawater Desalination	Direct Market Pricing	18.01	22.21	20.11
6.	Seawater – Industrial Cooling	Direct Market Pricing	2.58	4.76	3.67
7.	Coastal Shipping	Avoided Cost	15.88	63.80	39.84
	Total Provisioning		-	-	383.06
II.	REGULATING SERVICES				
8.	Coastal Protection (Mangroves)	Benefit Transfer	560.38	754.04	653.98
9.	Carbon Sequestration (Mangroves)	Direct Market Pricing	0.76	1.65	1.21
10.	Carbon Sequestration (Seagrasses)	Direct Market Pricing	0.01	0.04	0.03
	Total Regulating		561.16	755.73	655.21
III.	RECREATIONAL SERVICES				
11.	Coastal Recreation	Travel Cost	-	-	452.92
	Total Recreational		-	-	452.92
	GRAND TOTAL				1,491.19

The total value of the provisioning services estimated amounts to Rs. 383 billion. The total value of the regulating services estimated is roughly 1.7 times that of the provisioning service value at Rs. 655 billion with a value range of Rs. 561 – 756 billion. The total coastal recreational value is estimated at Rs. 453 billion. The total value of coastal and marine ecosystem services in India is approximately Rs. 1.5 trillion, of which provisioning services account for 26 percent, regulating services account for 44 percent and coastal recreation accounts for 30 percent of the total value. The estimated mean total coastal and marine ecosystem service value for India (Rs. 1.5 trillion) is approximately 3.2 percent of Net National Product (NNP) in 2012-13.

It must be noted that the total estimated coastal and marine ecosystem service value for India is an underestimate due to the following two reasons: i) all coastal and marine ecosystem services were not included in the valuation exercise; and ii) the estimates do not include the consumer surplus value of the service and thus they represent a conservative underestimate of the total economic value of the service. However, where the direct market pricing method was used to estimate services, the input costs were not subtracted from the final value and hence these values may be upwardly biased. Overall, the first-cut values of coastal and marine ecosystem services in India reported here could be upwardly revised in due course with improvements in the valuation methodologies as well as inclusion of more ecosystem services.

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INTRODUCTION

1.1 Context and Motivation

Coastal and marine ecosystems (hereafter referred to as 'coastal ecosystems'), found along continental margins, are ecologically sensitive regions of extraordinary biological productivity and high accessibility. They include mangroves, coral reefs, seagrass beds, sand beaches and dunes, mudflats, salt marshes, estuaries and marine waters. Coastal ecosystems provide a host of services that are of vital importance to human well-being, health, livelihoods and survival. The benefits people obtain from coastal ecosystems are known as coastal ecosystem services. Some of these services include the provision of food, water, timber and fibre ('provisioning services'), coastal protection, carbon sequestration, waste recycling, water purification and erosion control ('regulating services'), recreational, aesthetic and spiritual fulfilment, and education ('recreational and cultural services'), and the provision of genetic diversity and nursery services ('habitat services'). The human civilisation is fundamentally dependent on the steady flow of these services. Despite the multitude of services that coastal ecosystems provide us, however, their degradation and the subsequent loss of biodiversity continues at an unprecedented rate. This undermines coastal ecosystem functioning and resilience and thus threatens the ability of coastal ecosystems to continuously supply the flow of services for present and future generations. These threats are expected to increase as a result of climate change and a growing world population that has increasing consumption needs. They can, therefore, no longer be considered as inexhaustible resources.

The decision regarding the conservation vis-à-vis the degradation of coastal ecosystems and their associated services hinges on the true value of the flow of coastal ecosystem services to society. This could either be in terms of the benefits enjoyed by society from the provision of these services or the losses suffered by society in the absence of the same. Attaching a positive value to coastal ecosystem services implies that they can no longer be treated as free 'goods'. Moreover, causing irreversible damage to coastal ecosystems implies that the services they provide will come to a halt leading to huge losses in terms of the benefits forgone to human beings.

The importance of coastal ecosystems to human society has many dimensions, namely ecological, socio-cultural and economic. However, expressing the value of coastal ecosystem services in economic terms or more specifically, in monetary units, is important. This is because it not only helps raise awareness among citizens of the (relative) importance of these resources, but it also assists policy-makers in the efficient use of limited government budgets by identifying where protection and restoration is economically most important and can be provided at least cost. Monetary values of coastal ecosystem services are also useful in providing incentives for their conservation and sustainable use (for example in a Payment for Ecosystem Services scheme). Further, they can also help determine the extent to which compensation should be paid for the loss of coastal ecosystem services in liability regimes.

To stimulate public debate and policy action, a number of studies valuing ecosystem services (both coastal and terrestrial), at both the macro- and the micro-level, have been conducted in recent years. Nevertheless important gaps in the literature remain. While most terrestrial ecosystems (e.g. forests) are covered relatively well in the valuation literature both across services and across geographical regions of the world, most coastal ecosystems are still understudied in those respects. For some coastal ecosystems like, mangroves and near-shore coral reefs, monetary values have been estimated for almost all services provided by them, whereas for other coastal ecosystems like, seagrasses and sand beaches and dunes, very few value estimates across services currently exist. Moreover, many of the important benefits of coastal ecosystems have not been estimated reliably, and even for those services that have been valued, only a few dependable studies have been conducted. Further, the geographical spread of coastal ecosystem service values is uneven with a large number of values coming from studies conducted in North America, North Europe and South-East Asia and very few values coming from studies conducted in South Asia and the rest of the world. More primary valuation studies across these regions are needed. There is therefore an urgent need to bridge this gap in the valuation of coastal ecosystem services across the different types of coastal ecosystems, services and geographical regions in order to improve their management as well as to design better policies.

This study on the valuation of coastal ecosystem services in India is an attempt to bridge this gap in the literature. Values for terrestrial ecosystem services have already been estimated at the all-India level by TEEB-India but values for coastal ecosystem services have not been estimated before at the macro-level in a comprehensive manner[1]. More importantly, India is a peninsular nation that boasts a coastline spanning some 7500 km (including its Island territories), along which 25 percent of the population

[1] World Bank (2013) recently has estimated the value of biodiversity and ecosystem services in India. The study, among other things, estimated the value of services provided by mangroves and coral reefs. The literature review section below provides further details.

resides, many of whom are directly dependent on the services provided by coastal ecosystems (e.g. protection from extreme weather events, livelihoods, etc.). Not to mention the other three-fourths of the population that also benefits from a variety of coastal ecosystem services (e.g. food (fish), freshwater, recreation, etc.). Thus, the valuation of these services will aid effective policy formulation in the context of coastal development within the Integrated Coastal Zone Management plans of the Government of India.

The report is structured as follows: The rest of this chapter provides a brief review of literature on global and national estimates of the value of ecosystem services with a special focus on coastal ecosystems. The next chapter briefly discusses the scope of coastal ecosystem valuation undertaken in this report along with the broad approach/methodology followed. Chapters 3 to 12 provide detailed discussion on the valuation of various coastal ecosystem services in India, including provisioning, regulating and recreational services. Finally, Chapter 13 reports the consolidated value of coastal ecosystem services in India and provides concluding remarks.

1.2 **Literature Review**

Costanza et al. (1997) estimated that the annual value of ecosystem services across the globe ranged from $16 trillion to $54 trillion, with a mean estimate of $33 trillion that was, at that time, significantly higher than the global GDP. This generated a great deal of interest and criticism about the value of global ecosystem services, including services provided by marine and coastal resources. Although the Costanza et al. (1997) paper was criticized for the valuation approach followed, their study promoted subsequent research interest on the contribution of ecosystem services, specifically ocean and coastal wetland ecosystem services, to human wellbeing (Christie et al., 2012). Over the last decade there has been an exponential growth in literature focussing on several dimensions of non-market environmental valuation vis-à-vis economic-ecological modelling, policy instruments and management, spatial analysis and valuation databases. As per the database generated by Harte Research Institute for the Gulf of Mexico Studies, the number of research papers on coastal ecosystem service valuation generated between 1997 and 2013 has increased by more than two fold compared to papers published between 1980 and 1997. These publications cover a large number of ecosystems focussing on different services, different temporal and spatial specifications and valuation approaches.

There are several ecosystem service databases online that offer a wealth of information on the monetary values of various ecosystems including marine and coastal ecosystems. The databases serve as a point of valuable reference for any preliminary assessment that needs to be carried out for the chosen site and ecosystem. The values of a particular ecosystem service in such databases may vary to a great degree as the methods of valuation, scale of the study, location, physical status of the ecosystem, the political and economic conditions and policy context may all differ. Thus, it is important to fully understand the underlying assumptions of each value before they are put to use in the analysis. In most cases these values are used as benchmarks with which the actual values derived from the assessment are compared, or they are used in a meta-analysis/value transfer approach provided the spatial and temporal context for value estimates are similar to the ones in the study. Table 1.1 provides a list of online databases containing references to and results of ecosystem valuation studies from around the world. Without getting into the details of the various valuation exercises, the review here is restricted to looking at the global and India specific coastal and marine ecosystem valuation exercises.

The first global assessment of the value of ecosystem services carried out by Costanza et al. (1997) estimated the value of 17 ecosystem services for 16 biomes. Costanza et al. (1997) showed that almost 63 percent of the estimated value of $33 trillion is contributed by marine systems and in particular by coastal systems (about 32 percent of the total value). In a subsequent exercise, de Groot et al. (2012) reviewed approximately 1350 valuation estimates to assess the value of ecosystem services of ten main biomes. The analysis reported by de Groot et al. (2012) is an extension of TEEB (2010). The monetary value of the ecosystem services for the marine and coastal biomes have been estimated as (expressed in $/ha/year, in 2007 prices): open oceans – 491; coral reefs – 352,915; coastal systems – 28,917; and coastal wetlands – 193,845.

Costanza et al. (2014) used the unit values estimated by de Groot et al. (2012) to re-assess the value of ecosystem services at the global level. Apart from the upward revision of the unit values of most of the ecosystem services, Costanza et al. (2014) argue that the areas have changed between the original estimate in 1997 and the recent assessment. Accounting for the changes in both unit values and area, Costanza et al. (2014) estimate the value of ecosystem services from the marine system as $49.7 trillion (expressed in 2007 prices) – with the open ocean contributing 44 percent of the value and the coastal systems accounting for about 56 percent. Unlike the 1997 assessment, the contribution of marine ecosystems to the total ecosystem service value in 2011 stood at about 40 percent. Overall, Costanza et al. (2014) estimate that the global ecosystem service value in 2011 was 2.7 times more than the original 1997 estimate and stood at $124.8 trillion (expressed in 2007 prices).

There are very few aggregate estimates of the value of ecosystem services in India. Green Indian States Trust (GIST, 2008) has made an attempt to estimate the aggregate impact of natural resource degradation on the Indian economy. The resources covered included depletion of forest resources, biodiversity loss, agricultural and pasture land degradation, and loss in ecological services. The gain/loss due to the change of these resources are estimated across the major states of India and expressed with reference to the Net State Domestic Product (NSDP) in 2002-2003:

- In terms of loss due to the depletion of timber, fuelwood, and non-timber forest products, Bihar is estimated to have incurred a significant burden – about 5 percent of its NSDP, followed by Himachal Pradesh (2 percent of its NSDP) and Orissa (1 percent of its NSDP). At an all India level, the losses are estimated at about 0.5 percent of NDP.
- With regards to loss due to the depletion and degradation of agricultural and pasture land, Rajasthan, Madhya Pradesh and Orissa registered high losses (4 percent, 3.5 percent and 3 percent respectively of NSDP).
- Himachal Pradesh, Uttar Pradesh and Kerala registered significant losses in terms of biodiversity loss from forest degradation.

Recently Mani et al. (2012) provided an estimate of social and financial costs of environmental damage in India by focusing on urban air pollution, indoor air pollution and inadequate water supply, poor sanitation and hygiene. The study estimated the total annual cost of environmental degradation in India at 3.75 trillion rupees, equivalent to 5.7 percent of Gross Domestic Product (GDP) in 2009.

World Bank (2013) has put together the value of ecosystem services from the major biomes in India. The total value has been estimated as Rs. 1.4 trillion in 2009 – which is about 3 percent of India's GDP in that year. It may be noted that although the atmosphere provides a 'provisioning' ecosystem service in the form of clean air and water, the ecosystem service valuation exercises (including World Bank, 2013) do not typically account for such services. This partly explains the divergence between the cost of environmental degradation and the value of ecosystem services estimated for India in 2009. Among the ecosystems and their services valued in World Bank (2013), wetlands, including coastal wetlands, account for the highest percentage (48 percent), followed by coral reefs (22 percent).

Table 1.1: Ecosystem Valuation Databases

Database	***Details***
Marine Ecosystem Services Partnership (MESP)	MESP is a virtual centre for information and communication on the human uses of marine ecosystems around the world, including an extensive database of marine and coastal valuation studies with nearly 2,000 value estimates.
Harte Research Institute - Texas A&M University-Corpus Christi	The two main goals of the GecoServ database are to allow for the distribution and sharing of information about ecosystem valuation studies and to identify current gaps in the ES literature. The studies summarized here are for habitats that are relevant to the Gulf of Mexico region even though they may have been conducted elsewhere.
National Ocean Economics Program (NOEP)	NOEP provides economic and socioeconomic information on changes and trends along the U.S. coast, and will soon expand its scope internationally. NOEP includes databases on market and nonmarket values of coastal and marine resources.
Environmental Valuation Reference Inventory (EVRI)	EVRI is a searchable storehouse of more than 2,000 empirical studies on the economic value of environmental benefits and human health effects. It has been developed as a tool to help policy analysts use the benefit transfer approach.
The Economics of Ecosystem and Biodiversity (TEEB)	Ecosystem Service Valuation Database (ESVD), initially developed for the TEEB initiative, contains more than 1,300 data points from more than 300 case studies on both marine and terrestrial ecosystem services.
Lincoln University, New Zealand	This database provides users with a large (850+) bibliography of valuation studies. The economic value of many of these studies is also analysed and reported. These values have been standardized temporally and spatially so that the application of the values is adequately robust.
Beijer Institute of Ecological Economics	The Valuation Study Database for Environmental Change in Sweden (ValueBaseSWE) was developed at the Beijer Institute of Ecological Economics within a project funded by the Swedish Environmental Protection Agency. The database is the result of a survey of empirical economic valuation studies on environmental change in Sweden.

Chapter 2
METHODOLOGY

In the environmental economics literature, the total value of ecosystems is generally divided into two categories of value, namely use- and non-use values. Use values from ecosystems are the benefits individuals derive from the direct or indirect use of ecosystem services. Non-use values on the other hand reflect the satisfaction individuals derive from knowing that ecosystems services are maintained and that others will have access to them. In the current valuation exercise, only the use values of coastal ecosystem services are estimated whether they relate to the benefits obtained from the direct or indirect use of ecosystem services. Among the direct use values estimated in this study, the values of fish, seaweeds, minerals, salt and seawater used for desalination and industrial cooling fall under the extractive or consumptive use category while those of coastal shipping and coastal tourism fall under the non-extractive or non-consumptive use category. Either way, both categories of direct use values are reflected in market transactions (at least partially in some cases). Indirect use values are usually associated with regulating services such as coastal protection and carbon sequestration, both of which have also been estimated in this study. These may be seen as public services which are generally not reflected in market transactions.

As often done in the ecosystem valuation literature (see, Costanza et al., 1997), this study estimates the value per unit area of each ecosystem service using either of the following conceptualizations of the value: (a) the sum of consumer and producer surplus; or (b) the producer surplus; or (c) price times the quantity as a proxy for the economic value of the service[2].

Several techniques have been developed over the years to value environmental resources and ecosystem services. They are commonly categorised into three broad approaches, namely direct market valuation approaches, revealed preference approaches and stated preference approaches. Direct market valuation approaches use market information to value ecosystem goods or services where markets for these goods/ services exist. Revealed preference approaches use information on prices that individuals are willing to pay in markets for related goods to value ecosystem services that may not be directly bought or sold in markets. Stated preference approaches use surveys to ask

[2] Assuming that the demand for the ecosystem service approaches infinity as the quantity available approaches zero (or some minimal level), price times quantity as a proxy for the economic value of the ecosystem service reflects a conservative underestimate of the true value of the ecosystem service.

people directly what they are willing to pay for an environmental service based on a hypothetical scenario. This approach is used when ecosystem services are neither traded in markets nor are they closely related to any other marketed goods such that people cannot 'reveal' what they are willing to pay for them through their market purchases or actions.

In this study, three methods have been used to estimate coastal ecosystem services. They are:

a. Direct Market Valuation Approach
b. Travel Cost Method
c. Benefit Transfer

Where markets for ecosystem services exist, individuals' preferences for ecosystem services are directly reflected in data from actual markets. Thus, in such cases, market data such as price, quantity and cost information has been used to value coastal ecosystem services. This is commonly referred to as the direct market valuation approach and may be further divided into the market price-based approach and the cost-based approach depending on whether price or cost information is used to value to the ecosystem service in question. Market prices can be good indicators of the value of ecosystem services since they reflect individuals' preferences and the marginal cost of production. The values of provisioning services such as fish, seaweeds, minerals, salt and seawater used for desalination and industrial cooling have been obtained by multiplying the price of the service with the quantity produced in a given year. Costanza et al. (1997) note that the true total economic value of a resource is captured by the sum of the producer and consumer surplus (excluding the cost of production) since the former is the benefit accruing to the producer over and above the cost incurred and the latter is the welfare the consumer receives over and above the price paid. Thus, it is important to note that the price times quantity estimate is a proxy for the true economic value of the ecosystem service, which may be greater or less than the true economic value.

Cost-based approaches are based on estimations of costs that would be incurred if ecosystem benefits needed to be recreated through artificial means (TEEB, 2010). One of the techniques for valuing ecosystems within this approach is the avoided cost method, which relates to costs that would have been incurred in the absence of ecosystem services. The value of the sea as a means for transporting goods across the country via shipping has been estimated using the avoided cost method. More specifically, the benefits of coastal shipping are the costs avoided by transporting goods via sea as opposed to transporting them by alternative modes of (land) transportation such as road or rail.

The travel cost method, which is a revealed preference approach, has been used to value coastal tourism in this study. The rationale behind this method is that the time and travel cost expenses that people incur when visiting a particular tourist site (i.e. opportunity costs of time and direct expenses) represents a lower bound on the value of the recreational experience. Then, based on the number of trips that people make at different travel costs (i.e. based on the demand function for visiting the site), individuals' willingness to pay to visit the site and associated consumer surplus can be estimated. Moreover the demand function can be used to infer the value of a change in the quality or quantity of a particular tourist site as a result of changes in the ecosystem. In this study, the coastal tourism value includes an estimate of the sum total of actual travel expenses, accommodation and food expenses and the opportunity costs of time that were incurred by all domestic tourists who visited various coastal destinations in India during the year 2012-13. As such, the estimated coastal tourism value is a base value as it does not include consumer surplus received by recreational visitors. However consumer surplus values have also been estimated and reported separately.

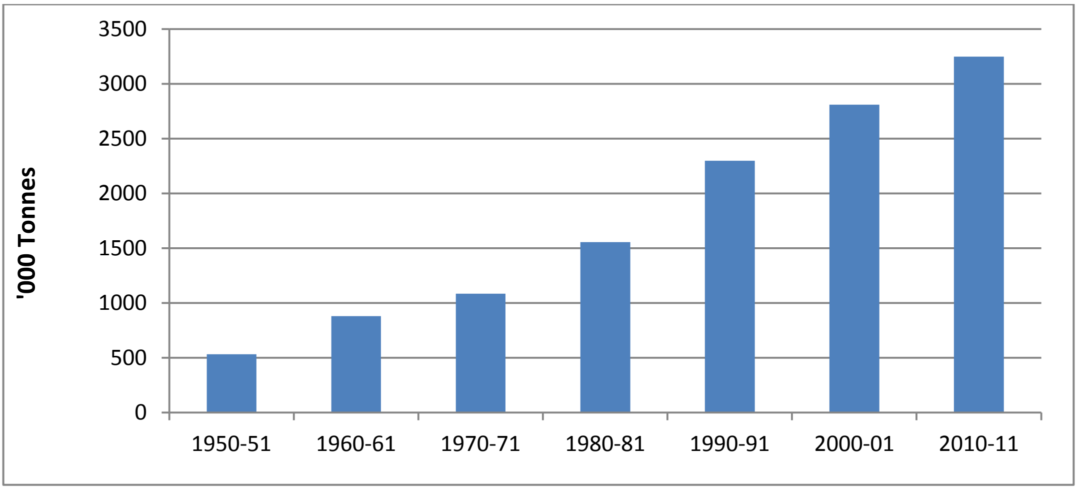
The third approach that has been used to value coastal ecosystem services in this study is benefit transfer, which is the method of transferring values estimated in one study, location and/or context to another. The advantage of using benefit transfer is that it overcomes the need for undertaking a new ecological and economic study which is often expensive and time consuming. The value of coastal protection (provided by mangroves) has been estimated using benefit transfer. The unit value of coastal protection estimated by Das (2007a) for Kendrapada District in Odisha has been scaled-up to the all-India level after adjusting for differences across coastal States and Union Territories in terms of: a) physical characteristics of cyclone activity; b) probability of occurrence of severe storms; c) mangrove quality; and d) income.

Chapter 3

VALUE OF MARINE FISHERIES

Fish is a valuable resource provided by the sea since it is an important source of food and nutrition for human beings. Total marine fish production in India was 3,321 thousand tonnes in 2012-13 (DADF, 2014). Marine fish production has grown rapidly over time; increasing by a factor of six over the period 1950-51 to 2010-11 (see Figure 3.1).

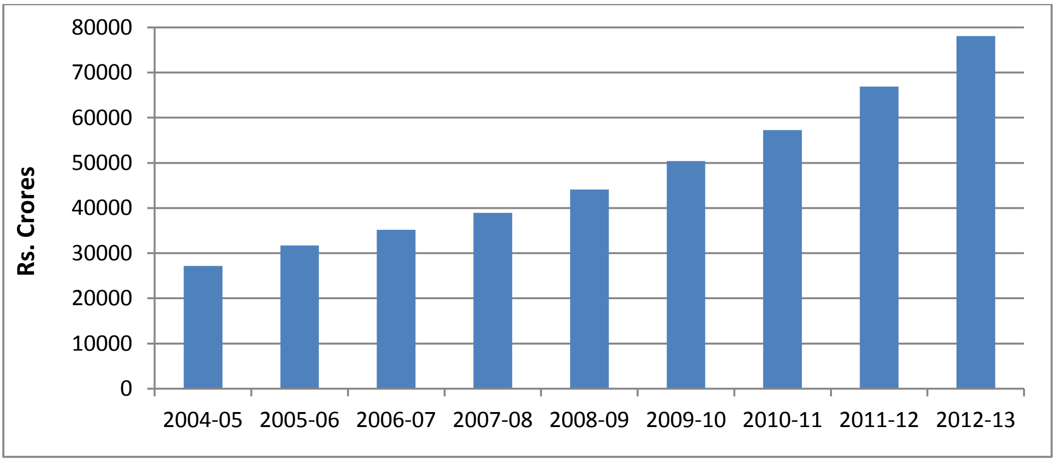
Figure 3.1: Total Marine Fish Production in India (in '000 Tonnes)



Source: DADF (2014).

The gross value added of the fisheries sector (both marine and inland) has also been steadily increasing over the last ten years or so (see Figure 3.2). In 2012-13, fishing accounted for 0.8 percent of total GDP at constant 2004-05 prices. This implies that fish is an important provisioning service provided by the sea and here the monetary valuation of marine fish is undertaken.

Figure 3.2 Gross Value Added of the Fishing Sector in Current Prices (in Rs. Crores)



Source: MoA (2015).

3.1 Methodology

The direct market pricing approach is used to value marine fish as a source of food. The data used in this exercise comes from the Central Marine Fisheries Research Institute (CMFRI) that publishes information on the quantities of various types of fish as well as their prices at the fish landing centres[3]. The marine fish landings for the country (except Andaman and Nicobar and Lakshadweep islands) were estimated as 3.78 million tonnes in 2013 which represent a drop of 4 percent from the previous year (CMFRI, 2013).

For each species of fish, an average price was estimated based on 2014 prices of the respective species across all major fish landing centres. For few species, such as Bombay duck, which were not listed at the major ports; state departments provided an annual average price for 2014. The fish prices for each species were standardized to 2012-13 prices using the GDP deflator provided by the World Bank so that values are comparable across services and ecosystems. It must be noted that the landing prices are used rather than the market prices for each species in order to estimate the gross value of output rather than the gross value added. In other words, the value of inputs and the marketing costs have not been excluded from the final value. Using the direct market pricing method, each fish species' value is estimated by multiplying its annual landing quantity across India by its standardised annual average price for 2012-13. Finally the sum total of all values was estimated for each category and for total marine fisheries.

[3] See http://www.cmfri.org.in/fishwatch.php

3.2 Data Sources

The catch statistics published by CMFRI are used (CMFRI, 2013), and the same classifies marine fishery resources into three broad categories:

- Demersal: Demersal finfish generally live on or near the ocean floor usually at depths of more than 20 meters.
- Pelagic: Pelagic fish can be categorized as coastal and oceanic fish, based on the depth of the water they inhabit. Coastal pelagic fish inhabit sunlit waters up to about 655 feet deep, typically above the continental shelf. In other words, these are fish types living predominantly in the upper layer of the ocean.
- Shellfish: Shellfish are water-dwelling animals including various species of molluscs, crustaceans, and echinoderms. These aquatic invertebrates are used as food.

Table 3.1 gives details of marine fish species under each of the three broad categories of fish type.

Table 3.1: Fish Species under each Category of Marine Fish Type

Type	***Class***	***Species***
DEMERSALS	ELASMOBRANCHS	Skates Rays Sharks
	EELS	
	CATFISHES	
	LIZARD FISHES	
	PERCHES	Rock cods Snappers Pig-face breams Other perches Threadfin breams
	GOATFISHES	
	THREADFINS	
	CROAKERS	
	SILVERBELLIES	
	WHITEFISH	
	POMFRETS	Black pomfret Silver pomfret Chinese pomfret
	FLAT FISHES	Halibut Flounders Soles
SHELLFISH	CRUSTACEANS	Non-penaeid prawns Lobsters Stomatopods

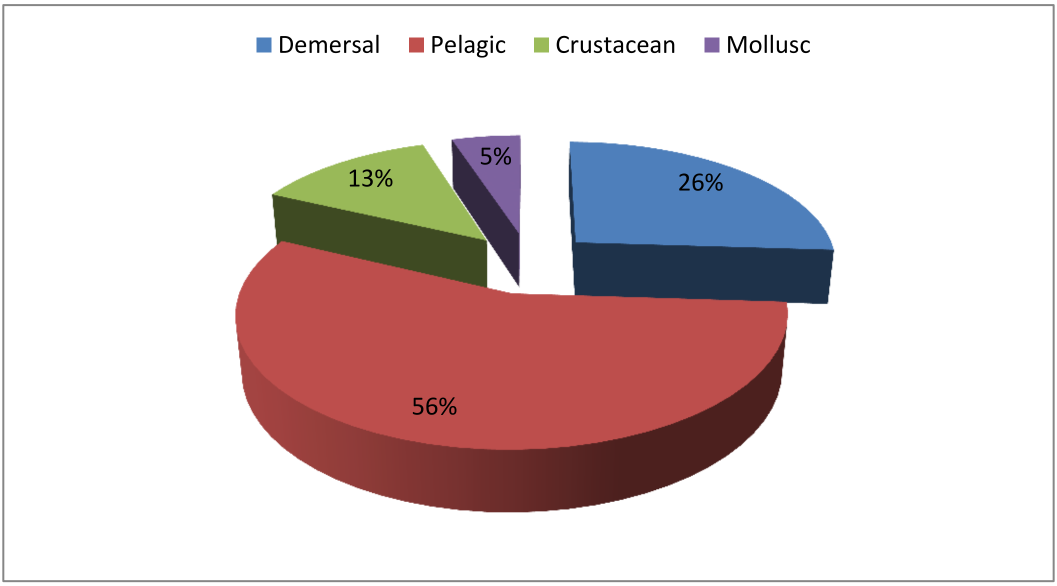
(Contd… Table 3.1)

Type	***Class***	***Species***
		Penaeid prawns Crabs
	MOLLUSCS*	
	CEPHALOPODS	Squids Octopus Cuttlefish
PELAGIC	CLUPEOIDS	Oil sardine Hilsa shad Wolf herring Other sardines Other shads Coilia Setipinna Stolephorus Thryssa Other clupeids
	BOMBAYDUCK	
	HALF BEAKS & FULL BEAKS	
	FLYING FISHES	
	RIBBON FISHES	
	CARANGIDS	Horse Mackerel Scads Leather-jackets Other carangids
	MACKERELS	Indian mackerel Other mackerels
	SEER FISHES	*Scomberomorus commerson* *Scomberomorus guttatus* *Acanthocybium* spp.
	TUNNIES	*Euthynnus affinis* *Auxis* spp. *Katsuwonus pelamis* *Thunnus tonggol* Other tunnies
	BILL FISHES	
	BARRACUDAS	
	MULLETS	
	UNICORN COD	

Note: * Including bivalves such as Oysters, Mussels, Clams.
Source: CMFRI (2013).

Figure 3.3 shows the components of marine fish landings in India in 2013. Pelagic species, including some of the most common fishes such as oil sardines, mackerels and tunas, dominate the fish landings with 56 percent. Demersal resources contributed to over 26 percent of 2013 landings. Shellfish including crustaceans, which comprise of the most sought after resources like prawns and lobsters, and molluscs, encompassing resources such as clams, oysters and squids, together contributed 18 percent to 2013 landings.

Figure 3.3: Components of Marine Fish Landings in India in 2013



Source: CMFRI (2013).

3.3 Results and Discussion

The total estimated value of marine fish is approximately 295 billion in 2012-13 which is 1.4 times lower than the Central Statistical Organisation's value of marine fish in 2012-13, which is Rs. 407 billion[4]. This underestimate in value is due to the fact that fish cured (both by salting and sun-drying) as well as subsistence fish have not been accounted for in the valuation. CSO includes raw fish as well as cured and subsistence fish in its estimation, which would at least partly explain its higher value for marine fish output. Note that since the value of inputs has not been deducted from the estimates in Table 3.2, these represent an overestimate in marine fish value. Shellfish is the most highly valued at Rs. 117 billion, followed by Pelagic at Rs. 93 billion and then Demersals being Rs. 85 billion.

[4] CSO's Gross Value of Output (GVO) for marine fisheries is Rs. 21,549 crores in 2012-13 at constant prices (CSO, 2014). The conversion from constant to current prices was undertaken by using a multiplication factor of 1.89, which was arrived at on the basis of the CSO's total Gross Value Added (GVA) estimates of fisheries (both marine and inland) at current versus constant prices in 2012-13.

Table 3.2: Value of Marine Fish (in 2012-13 Rupees)

Fish Type	***Value (Rs.)***	***% of Total Value***
Demersal	84,489,631,983	29
Shellfish	117,203,000,026	40
Pelagic	92,791,927,933	31
Total	**294,484,559,941**	**100**

Shellfish contribute forty percent to the total value estimate of marine fish even though the shellfish landings on the coast account for only 18 percent of total landings (See Figure 3.3). This is due to the fact that shellfish are high valued species and are thus more costly when compared to Pelagic and Demersal resources. Pelagic species contribute 31 percent to the total value of fish followed by Demersals, which contribute 29 percent.

Chapter 4
VALUE OF SEAWEEDS

Seaweed is an algae that is either harvested naturally or cultivated. For the purpose of commercial use, it is usually collected by fishing communities and then further processed to obtain by-products which are then used in different industries. The cultivation of seaweeds is undertaken along the Gulf of Mannar and Palk Bay in Tamil Nadu, Gujarat, Andaman-Nicobar islands and in other coastal regions of the country (Reddy et al., 2006). Natural seaweeds occur mainly in Tamil Nadu, Odisha and Gujarat (Rao and Mantri, 2006).

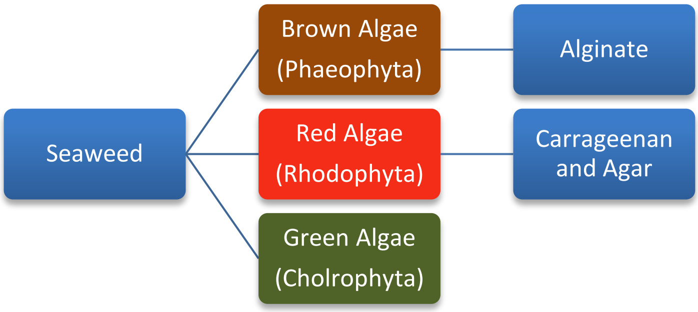
In India, CSIR (Council of Scientific and Industrial Research), CSMCRI (Central Salt and Marine Chemicals Research Institute) and ICAR (Indian Council for Agricultural Research) are creating awareness and promoting the cultivation of seaweed due its commercial potential as a natural resource. Seaweed can be consumed as edible food. It is also a source of fish/animal feed. It is further processed and used in the pharmaceutical, food and cosmetic industry. It is also used as a raw material for biofuels, fertilizers and soil conditioners. Thus, seaweed is an important resource provided by the sea that needs to be valued.

4.1 Description of Seaweeds

There are essentially three primary types of seaweed - red (*Rhodophyta*), green (*Chlorophyta*), and brown (*Ochrophyta*) varying in colours and pigmentation (See Figure 4.1). Seaweed is mainly composed of proteins, lipids, carbohydrates, moisture and is also rich in vitamins and iodine (Baghel et al., 2014). Seaweed is commercially processed to manufacture processing agents such as agar, alginate and carrageenan that are used in the pharmaceutical, food and fertilizer industries (Kaliaperumal et al., 2004; McHugh, 2003).

In India, agar is used as a gel in food products such as processing jelly, dairy products, biopolymers and many others. It has specific properties that are suited for its use in solidifying agents to help manufacture pharmaceuticals and disinfectants, nutraceuticals, veterinary medicines, tablet coatings and food supplements. Agarose - a component of agar - is also used as an essential raw material in the pharmaceutical and food processing companies.

Figure 4.1: Types of Seaweed and Agents Extracted



Saragassum and Turbinaria are agents obtained from the Alginate which have numerous uses in the manufacturing of pharmaceuticals, cosmetic creams, paper, cardboard and processed food products (Chapman, 1970).

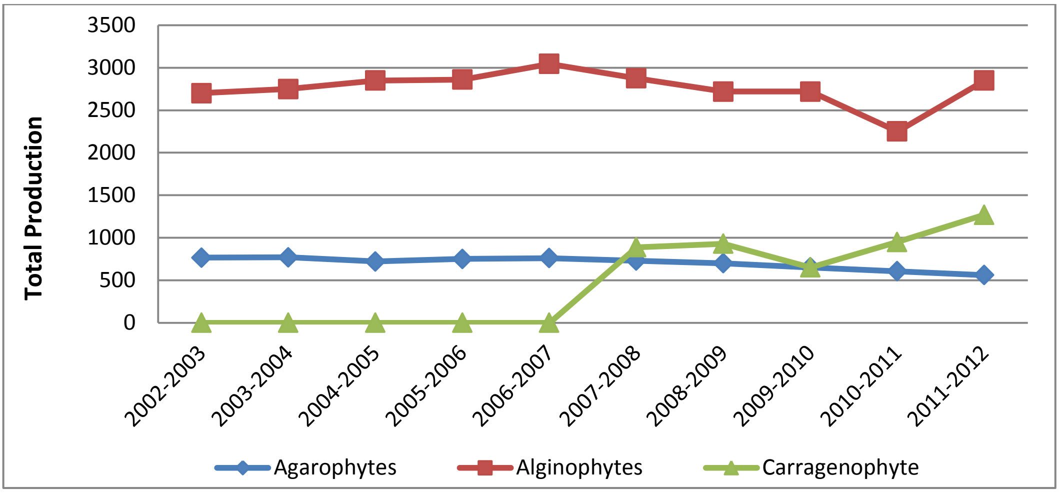
There are three main types of Carrageenan derived from red algae - lambda, kappa and iota - each having their own gel characteristics. The culturing of Kappaphycusalvarezii was introduced due to its commercial viability in the Indian market. It is used as a clarifying agent for beer and heavily used in the dairy industry for stabilization of ice-creams, flavouring of milk and evaporating milk products. The first attempt to culture seaweed on a commercial scale was initiated by PepsiCo Holdings India Ltd in 2000, which was also subsequently undertaken by CSMCRI in Bhavnagar, Gujarat (Krishnan and Narayanakumar, 2010).

4.2 Data Sources

In India, most of the literature on seaweeds focuses mainly on its industrial uses. In addition to The Seaweed Industry Association, an international trade association based in Seattle, USA, is up to date with the developments in the seaweed industry across the world. Thus with production and price data from the Seaweed Association and CSIR-CSMCRI, the total value generated by seaweeds as a provisioning service has been estimated.

Figure 4.2 illustrates the growth in total production of seaweed from 2002 to 2012. There is a clear indication of the rise in carragenophyte cultivation from 2007, and a relatively stable production in agar in spite of growing costs of harvest and production. The production of alginophytes is the highest as it is widely used domestically as well as exported across the world.

Figure 4.2: Quantities of Seaweed Production in India (Dry wt. in tonnes), 2002-12



Source: CSIR-CSMCRI (personal communication).

A list of companies was prepared with the help of the Seaweed Association and CSIR-CSMCRI. The data was also collected directly from the companies on their total production and the prices determined at the landing sites. An annual average of the prices across different seaweed collectors and companies was used in the estimation.

Table 4.1: Average Prices of Seaweed in India (in 2011-12 Rupees)

Seaweed	***Price at seashore (Rupees/Dry wt. in ton)***	***Final price at Industry (Rupees/Dry wt. in ton)***
Gracilariaedulis (Agarophyte)[1]	30,000	35,000
Gelidiellaacerosa (Agarophyte)[1]	72,000	90,000
Sargassum spp. (Alginophyte)[2]	9,000	13,000
Turbinaria spp. (Alginophyte)[2]	9,000	13,000
Kappaphycusalvarezii (Carrageenophyte)[3]	35,000	35,000

Source: [1] Seaweed collectors, [2] Seaweed Phycocolloid industries, [3]Cultivated material, CSIR- CSMCRI.

Data on the cost of collecting seaweed has not been included in the estimation of value due to the lack of this information in the literature and in secondary data sources. The price and quantity data has been collected at the primary stage of the production cycle to avoid double counting. Further, prices are standardised to 2012-13 prices by using the World Bank GDP deflator.

4.3 Methodology

In the context of the present study, the revenue stream associated with the major fish landing centres was considered. In order to estimate the value (revenue) of seaweed produced in India by using the direct market pricing methodology, the prices of seaweed at major landing centres along with the data on production were used. The gross revenue of seaweed was estimated based on the species-wise quantities and their respective sales prices at the fish landing centres.

4.4 Results and Discussion

A value of approximately Rs. 92 million (in 2012-13 prices) was estimated for dry seaweed at the base level of production (see Table 4.2).

Table 4.2: Value of Seaweed as a Raw Material (in 2012-13 Rupees)

	Seaweed	*Price at seashore (Rs./Dry wt. in tonnes)*	*Quantity produced (Dry wt. in tonnes)*	*Total Value (Rs.)*
[1]Agarophyte	Gracilariaedulis	26897.69	190	5,110,561
	Gelidiellaacerosa	64554.46	370	23,885,149
[2]Alginophyte	Sargassum spp. & Turbinaria spp.	8069.30	2850	22,997,526
[3]Carrageenophyte	Kappaphycusalvarezii	31380.64	1270	39,853,412
TOTAL			**4680**	**91,846,648**

Source: CSIR-CSMCRI; Quantity- [1]Bose, Sivas Chemicals, Madurai, Personnel communication, [2]Nehemiah, SNAP, Ranipet, Personal communication, [3]Shanmugam, Personal communication. Price- [1]Seaweed collectors, [2]Seaweed Phycocolloid industries, [3]Cultivated material.

Chapter 5

VALUE OF COASTAL MINERALS

The 7500 km long coastline of India has some of the largest and richest shoreline deposits, which are an accumulation of valuable minerals formed during sedimentary processes due to gravity separation. The beaches and coastal sand dunes contain several heavy minerals, primarily ilmenite, rutile, garnet, zircon, sillimanite and monazite.

These minerals provide provisioning services and are very important to the economy from an industrial and strategic point of view. The Indian Minerals Yearbook published by the Indian Bureau of Mines (IBM, 2012) gives the annual availabilities and extractions of these minerals among others.

5.1 Data Sources

The Indian Mineral Year Book published by the Indian Bureau of Mines provides comprehensive literature and data on various aspects of the Indian mineral industry such as policy and legislation, permits and licenses, research and development and also production quantities and prices. In terms of the prices of minerals, the year book provides a complete break up of prices for various metallic and non-metallic minerals for both domestic and international markets. The handbook also provides yearly production quantities of minerals, specifically fuel, metallic and non-metallic, in India. Among the minerals extracted for uses in various industries, there are 7 minerals that are primarily extracted from coastal areas - Ilmenite, Leucoxene, Rutile, Garnet, Sillimanite, Zircon and Monazite.

5.1.1 Ilmenite, Leucoxene and Rutile

Ilmenite and rutile are the two main minerals of titanium. Leucoxene, also known as brown ilmenite, is an alteration product of ilmenite. The quantity of reserves of ilmenite (including leucoxene) and rutile present in the Indian coasts in the year 2011-12 was estimated to be 334.24 million and 28.91 million tonnes respectively (IBM, 2012). Both minerals were found in coastal states such as Andhra Pradesh, Kerala, Odisha and Tamil Nadu while Illmenite was also found in Maharashtra. Andhra Pradesh holds the highest reserves of Illmenite with 103 million tonnes while Maharashtra holds the least with just 3 million tonnes. Similarly, rutile is found mostly in Andhra Pradesh, while Tamil Nadu has the lowest reserves of the same. States like Odisha and Tamil Nadu produce only around 0.8 percent and 0.2 percent (respectively) of their reserves annually.

Table 5.1: Availability of Ilmenite (including Leucoxene) on Indian Coasts

State	*Reserves (million tonnes)*	*Production (million tonnes)*	
		2010-11	*2011-12 (p)*
Andhra Pradesh	102.90	-	-
Kerala	79.00	0.11	0.086
Maharashtra	3.04	-	-
Odisha	87.82	0.21	0.188
Tamil Nadu	61.48	0.34	0.476

Table 5.2: Availability of Rutile on Indian Coasts

State	*Reserves (million tonnes)*	*Production (million tonnes)*	
		2010-11	*2011-12 (p)*
Andhra Pradesh	10.30	-	-
Kerala	7.24	0.0059	0.0056
Odisha	6.06	0.0080	0.0078
Tamil Nadu	5.31	0.0120	0.0030

5.1.2 Garnet

Garnet is not a single mineral, but a group of minerals containing closely related, isomorphous minerals that form a series with each other. Primarily known for their use as gemstones, garnets, with high hardness, are also used as abrasives in industries. Both these types of garnets are available in the country. A total of 56.81 million tonnes of garnet was available on the Indian coasts in the year 2011-12 (IBM, 2012). Tamil Nadu currently has one of the highest reserves of Garnet in the country with 33.82 million tonnes of the mineral. Kerala, on the other hand, has the least reserves of the mineral with just 0.2 million tonnes. Tamil Nadu and Andhra Pradesh, the states with the most reserves of Garnet, produced close to 5 percent and 0.3 percent of their total reserves, respectively, in 2011-12.

Table 5.3: Availability of Garnet on Indian Coasts

State	*Reserves (million tonnes)*	*Production (million tonnes)*	
		2010-11	*2011-12 (p)*
Andhra Pradesh	19.06	0.15	0.06
Kerala	0.20	-	-
Odisha	3.53	0.018	0.019
Tamil Nadu	33.82	1.95	1.74

5.1.3 Sillimanite

Sillimanite is an alumino-silicate mineral. Sillimanite is used to manufacture refractory products like dense and insulating bricks. Sillimanite refractory bricks are extensively used in steel and glass industries. They are also used in ceramics, cement kilns, heat treatment furnaces and petrochemical industries. A total of 66.98 million tonnes of sillimanite was available in the country in 2011-12. Out of this, 49.02 million tonnes of sillimanite was reported to be available on the Indian coasts in 2011-12 (IBM, 2012). Tamil Nadu and Odisha have some the highest reserves of Sillimanite in the country with a combined reserve of over 30 million tonnes. Andhra Pradesh, with its reserve of 9.64 million tonnes, had the highest production quantity in 2011-12 with 0.031 million tonnes being extracted.

Table 5.4: Availability of Sillimanite on Indian Coasts

State	***Reserves (million tonnes)***	***Production (million tonnes)***	
		2010-11	***2011-12 (p)***
Andhra Pradesh	9.64	0.017	0.031
Karnataka	0.98	-	-
Kerala	7.15	0.0082	0.0075
Maharashtra	0.20	0.0046	0.0009
Odisha	13.10	0.0178	0.0174
Tamil Nadu	17.95	0.0001	-

5.1.4 Zircon

Zircon is found usually as a constituent in heavy mineral sand assemblages, which include ilmenite, rutile, leucoxene, monazite and garnet in varying proportions. Colourless specimens of zircon which exhibit gem like quality are popularly demanded as a substitute for diamond. They are known as Matura Diamond. A total of 32.28 million tonnes of Zircon was reported on the Indian coasts in 2011-12 (IBM, 2012). The production of zircon decreased to 25,996 tonnes in 2011-12 from 33,209 tonnes in the preceding year. The state-wise break-up of zircon production for the year 2011-12 is not available from the Indian Minerals Yearbook.

Table 5.5: Availability of Zircon on Indian Coasts

State	***Reserves (million tonnes)***	***Production (million tonnes)***	
		2010-11	***2011-12***
Andhra Pradesh	12.60	-	-
Kerala	6.52	0.010	-
Maharashtra	0.07	-	-
Odisha	3.16	0.0059	-
Tamil Nadu	9.46	0.016	-

5.1.5 Monazite

A radioactive phosphate mineral containing rare earths, monazite is an important ore of thorium. This makes it very important from a strategic point of view as thorium is essential for harnessing nuclear energy. A total of 11.93 million tonnes of monazite was reported in the country (as on May 2013)[5], out of which 10.49 million tonnes was present in the coastal placer deposits. However, there was no production of Monazite in the years 2010-11 and 2011-12.

Table 5.6: Availability of Garnet on Indian coasts

State	*Reserves (million tonnes)*	*Production (million tonnes)*	
		2010-11	*2011-12*
Andhra Pradesh	3.74	-	-
Kerala	1.51	-	-
Odisha	1.85	-	-
Tamil Nadu	2.16	-	-

5.2 Methodology

For the valuation of coastal minerals in India, the amount produced in the year 2011-12 was taken under consideration. Their respective declared average prices were also collected from IBM (2012). The prices for 2011-12 were adjusted for the year 2012-13 using the World Bank's GDP Deflator.

5.3 Results

The valuation of these coastal minerals for the year 2012-13 (adjusted from 2011-12) using the market price method is tabulated below.

Table 5.7: Valuation of the Coastal Minerals (in 2012-13 Rupees billion)

Mineral	*Price (Rs./tonne) (2011-12)*	*Adjusted Price (2012-13)*	*Quantity Produced (tonnes)*	*Value (Rs. Billion) (2012-13)*
Ilmenite	11,174	10,021	751,163	7.52
Rutile	70,610	63,324	16,598	1.05
Zircon	94,546	84,790	25,996	2.2
Sillimanite	8,978	8,052	58,043	0.46
Garnet	743	666	1,824,648	1.21
Monazite	Nil	Nil	Nil	Nil
Total Value of Minerals (2012-13 Rs. billion)				**12.44**

[5] See http://zeenews.india.com/news/eco-news/indias-monazite-reserves-have-gone-up_869100.html

Hence, adjusted for the year 2012-13, more than one thousand crore rupees (Rs. 12.44 billion) worth of coastal minerals were produced. This value excludes the value of monazite, which was not produced by the Indian Rare Earths Limited (IREL) in the years 2010-11 and 2011-12. However, the production of monazite has been resumed by IREL since early 2013 after it received an environmental clearance to set up a 10,000 tonnes/year monazite processing plant which is an upgrade from the already existing plant of 4,500 tonnes/year capacity.

Chapter 6

VALUE OF COASTAL SALT

India is the third-largest producer of salt in the world after China and the USA. The states of Gujarat, Tamil Nadu and Rajasthan are the major salt producers producing over 90 percent of the country's requirements (Salt Department, 2013-14). The rest is produced by the other coastal states as well as Himachal Pradesh in the north.

The major service provided by salt is that of 'provisioning' in terms of food items and industrial purposes like manufacturing pharmaceuticals and chemicals such as caustic soda, soda ash, etc. Apart from providing provisioning services, salt also provides recreational and cultural services. Salt pans, such as those in the Rann of Kutch in Gujarat and Tuticorin in Tamil Nadu have become tourist attractions.

6.1 Data Source

An attempt has been made to arrive at the monetary value of the provisioning services provided by salt produced from the coasts of India, Gujarat and Tamil Nadu being the leading coastal producers.

The Salt Department, Ministry of Commerce and Industry, in its Annual Report (2013-14) reports Gujarat remained the highest salt producing state with more than 19 million tonnes of salt produced in 2012-13. The total production of salt by Gujarat, Tamil Nadu, Karnataka, Maharashtra, Goa, Andhra Pradesh, Odisha and West Bengal was found to be 22.7 million tonnes for the year 2012-13. Out of this 1.37 million tonnes of salt was added to the total salt stock inventory of the country.

In effect, 21.35 million tonnes of salt was sold in the market in various forms such as iodized, common, refined, non-refined, etc. These forms of salt have been differentiated in this study into two major categories – Iodized Salt and Non-Iodized Salt.

6.2 Methodology

The values of total production of salt from the respective coastal states and their prices at the different producing centers were taken from the Annual Report of the Salt Department, Ministry of Commerce and Industry (2013-14). The difference between the stock of salt on 31st March, 2013 and on 31st March, 2014 was calculated for all the coastal states to arrive at the value of the net total quantity of salt that entered the market in 2013-14.

The prices of iodized and non-iodized salt differ, that is, iodized salt is priced higher than non-iodized salt. Their respective prices also vary from state to state and the price difference can be seen even in the same category between different salt producing centres within the same state.

For the purpose of this study, the average prices of non-iodized salt from the respective states have been considered as indicative prices of all salt entering the market in these states, and thus only these prices have been used in the analysis. The prices for iodized salt were not considered because the costs of iodization add to that of non-iodized salt which would lead to an overestimation of salt prices. Further, the national price of coastal salt was calculated by taking an average across the representative state level mean salt prices.

6.3 **Results and Discussion**

A net total of 21.35 million tonnes of salt was produced by the coastal states in the year 2012-13. The national average ex-factory price of coastal salt was found to be Rs. 1318.75 per tonne. Thus, the total value of salt produced in the coastal states of India in the year 2012-13, using the market price technique of valuation, was estimated to be more than 1.2 thousand crore rupees (Rs. 12.4 billion).

Table 6.1: Valuation of Coastal Salt (in 2012-13 Rs. Billion)

State	***Production of Salt (tonnes)***	***Addition to Existing Stock of Salt as on 31st March 2013 (tonnes)***	***Net Total of Salt Sold (tonnes)***	***Average Ex-Factory Price of Non-Iodized Salt (Rs/tonne)***	***Total Value of Coastal Salt (billion Rs.) (2012-13)***
Gujarat	19,423,900	1,264,900	18,159,000	537	9.75
Tamil Nadu	2,670,300	104,300	2,566,000	713	1.83
Karnataka	14,500	1,900	12,600	2,100	0.03
Maharashtra	160,400	-23,700	184,100	1,525	0.28
Goa	1,900	800	1,100	1,525	0.002
Andhra Pradesh	403,300	15,200	388,100	1,150	0.45
Odisha	33,800	13,300	20,500	1,500	0.03
West Bengal	13,900	-6,700	20,600	1,500	0.03
Total	**22,722,000**	**1,370,000**	**21,352,000**	**1318.75 (Average)**	**12.40**

It must be noted that this value is only an underestimate of the actual value of coastal salt since the value from many small scale salt producing industries could not be recorded. Also, the values of the recreational and cultural services provided by coastal salt have not yet been studied. Such estimates could contribute significantly towards the total value of coastal salt in India.

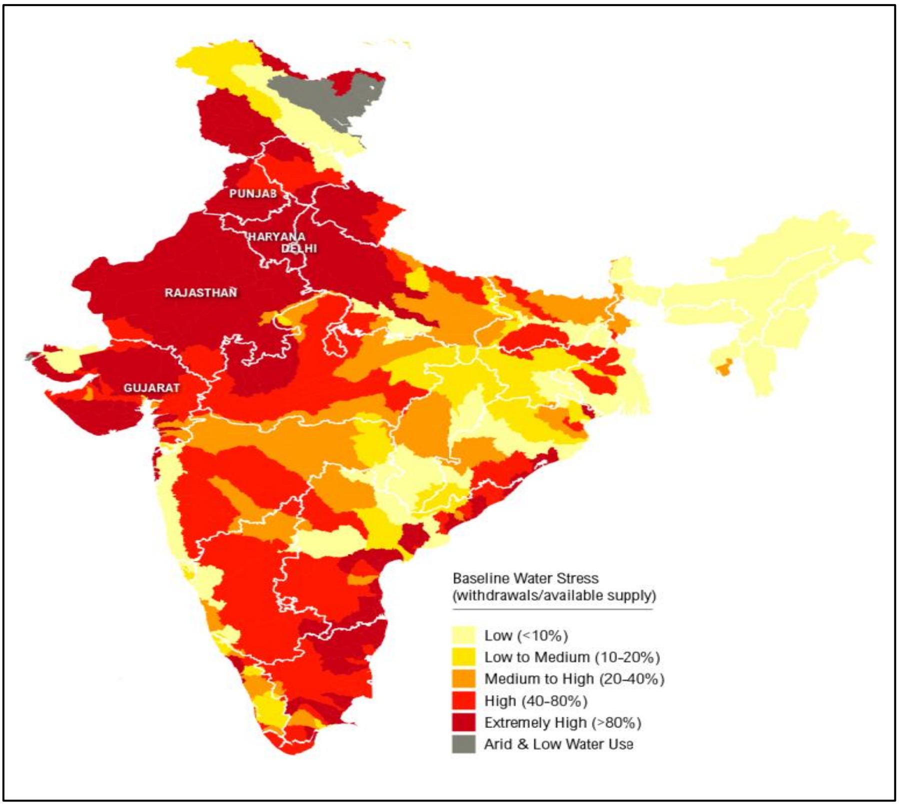
Chapter 7

VALUE OF SEAWATER DESALINATION

Seawater is a valuable resource that is provided by the seas. Other than its direct use in salt production, seawater may be used to produce fresh water that is suitable for domestic consumption, irrigation and industrial use with the help of desalination technologies that essentially remove salt and minerals from saline water.

In a country like India in which droughts, floods and ground water contamination have been common occurrences over the years, the need for an alternative source of freshwater is urgent. Moreover, there are big disparities in water availability and water requirements both across and within Indian States and cities, and seawater desalination offers a solution to bridging this gap. According to WRI, 54 percent of India faces high to extremely high water stress (see Figure 7.1). The growth in population, increase in water disputes among States, increase in food production, growth in industrialisation and urbanisation, problems with monsoon water storage and industrial water contamination imply that States are looking for alternative sources to address the water scarcity issue. In this context, seawater (and brackish water) desalination can play an important role in countering the problem of water scarcity in India.

Figure 7.1: Baseline Water Stress in India



Source: World Resources Institute; http://www.wri.org/blog/2015/02/3-maps-explain-india%E2%80%99s-growing-water-risks

Figure 7.1 shows that water stress in coastal States, particularly in Gujarat, Tamil Nadu and Karnataka, is relatively high compared to other (particularly, Eastern) parts of the country. Coastal States, however, can take advantage of their proximity to the sea by harnessing the abundant seawater resource that is at their disposal in order to produce fresh water. Having said that, the high cost of producing water per litre by using the current available technologies is the main deterrent for adopting desalination as a solution.

Currently seawater desalination technology is the most widely used in the water scarce States of Tamil Nadu and Gujarat. At present, the installed production capacity stands at 2,97,435 m^3 per day in Tamil Nadu, and 2,90,392 m^3 per day in Gujarat (see Table 7.1). Tamil Nadu and Gujarat account for 96.4 percent of the total installed seawater desalination capacity in India (which is 6,09,927 m^3 per day). The biggest desalination plants currently in operation in the country are the Reliance Industries, Jamnagar desalination plant in Gujarat (with a production capacity of 1,60,000 m^3 per day) and the Minjur and Nemmeli desalination plants in Tamil Nadu (each having a production capacity of 1,00,000 m^3 per day) (see Annexure 7.1 for details).

Table 7.1: Current Installed Seawater Desalination Production Capacity in India (m^3 per day)

S. No.	*State*	*Production Capacity (m^3/day)*
1	Tamil Nadu	2,97,435
2	Gujarat	2,90,392
3	Maharashtra	1,100
4	Karnataka	16,200
5	Andhra Pradesh	3,600
6	Pondicherry	1,200
	TOTAL	**6,09,927**

Note: Details of current desalination plants within each State including name, location, production capacity and source of information are presented in Annexure 7.1.

7.1 Methodology

The direct market pricing method is used to value seawater desalination in India, i.e. the value of seawater desalination is nothing but the installed production capacity (as in Table 7.1) multiplied by the price of water. What this price of water is, however, requires some discussion.

Fisher (2002) notes that "it is the scarcity of water and not merely its importance for existence that gives water its value. Where water is not scare, it is not valuable" (pp. 188). Thus, if water shortage justifies desalination, then the monetary value of the water (its scarcity cost) is equal to at least the cost of the new source of supply, i.e. the cost of desalination. Hence, the price of water is nothing but the cost of desalination.

The desalination cost from the Minjur desalination plant is used to value this service. The Chennai Metropolitan Water Supply and Sewage Board (CMWSSB) signed a bulk water purchase agreement (BWPA) with Chennai Water Desalination (CWDL) to purchase water from the Minjur desalination plant at a cost of Rs. 48.66/m^3 (\$1.03/m^3) and it sold the same to industries at a rate of Rs. 60/m^3 (\$1.27/m^3) (in 2005 prices)[6]. These values are consistent with desalination costs from around the world. For instance, Zhou and Tol (2004) suggest a unit cost of \$0.6 per m^3 for desalting brackish water and

[6] See http://www.water-technology.net/projects/minjurdesalination/

\$1.0 per m^3 for seawater as appropriate for the potential application of desalination in China. Thus, the price range used to value this service is Rs. 48.66 – 60 per m^3 (in 2005 prices), which when converted to 2012-13 prices using a GDP deflator is Rs. 80.9 – 99.7 per m^3.

7.2 Results and Discussion

The value of seawater currently used to produce fresh water via desalination in India is presented in Table 7.2. The estimated value of saltwater desalination is in the range of Rs. 18 – 22 billion per year (in 2012-13 prices). The mean value is roughly Rs. 20 billion per year. Since Tamil Nadu and Gujarat have the highest production capacity in the country, together they also account for more than 96 percent of the value.

Table 7.2: Value of Seawater Used for Desalination in India (in 2012-13 rupees billion per year)

S. No.	***State***	***Value Range***		***Mean***
		Lower Bound	***Upper Bound***	
1	Tamil Nadu	8.78	10.83	9.81
2	Gujarat	8.57	10.57	9.57
3	Maharashtra	0.03	0.04	0.04
4	Karnataka	0.48	0.59	0.53
5	Andhra Pradesh	0.11	0.13	0.12
6	Pondicherry	0.04	0.04	0.04
	TOTAL	**18.01**	**22.21**	**20.11**

Note: The above values may be an underestimate since only the major desalination plants have been accounted for in the analysis. Moreover, the desalination capacity is likely to increase in the future. Table 7.3 presents the planned desalination capacity of States, which in total is likely to be an additional 18,49,460 m^3 per day in the future. Thus a fourfold increase in the values presented in Table 7.2 is expected in the coming years.

Table 7.3: Planned Seawater Desalination Production Capacity in India (m^3 per day)

S. No.	***State***	***Production Capacity (m^3/day)***
1	Gujarat	6,86,000
2	Tamil Nadu	8,85,000
3	Andhra Pradesh	1,25,460
4	Andaman & Nicobar Islands	14,000
5	Kerala	4,500
6	Pondicherry	30,000
7	Maharashtra	1,00,000
8	Odisha	4,500
	TOTAL	**18,49,460**

Note: Details of future desalination plants within each State including name, location, production capacity and source of information are presented in Annexure 7.2.

Appendix 7.1: Details of Current Desalination Plants in Operation in India

S. No.	***State***	***Plant***	***Product-ion Capacity (m3/day)***	***Source***
1	Tamil Nadu	Minjur Desalination Plant	100000	http://www.befesa.com/web/en/prensa/historico_de_noticias/2010/bma_20100811.html
2	Tamil Nadu	Nemmeli Desalination Plant	100000	http://www.wabag.com/ru/wabag-projects/nemmeli-desalination/?project_year=&country=india-ru&branch=desalination-ru&cat=all.municipal-ru.industrial-ru.sludge-treatment-ru.sea-and-brackish-water-ru.ground-water-ru.surface-water-ru.water-reuse-ru.&search=&search_button=Search
3	Tamil Nadu	Ramanathapuram Desalination Plant	3800	http://www.doshion.com/uploads/downloads/19/Download_DOSHION_Corporate_Profile.pdf; http://shodhganga.inflibnet.ac.in/bitstream/10603/16610/7/07_chapter2.pdf
4	Tamil Nadu	CPCL, Thiruvallur	26400	http://www.ionindia.com/download/newsletters/IEI_June2010.pdf
5	Tamil Nadu	NTPC, Vallur	19800	http://www.ionindia.com/pdf/IEI%20News%20Volume%20No.%2080%20July%202013.pdf
6	Tamil Nadu	PPN CCPP, Pillaiperumalnallur	10455	http://www.aquatech.com/wp-content/uploads/27.-PPN-SWRO.pdf
7	Tamil Nadu	CEPL, Tuticorin	13000	http://www.aquatech.com/press-releases/aquatech-awarded-desalination-project-for-a-thermal-power-facility-in-tamil-nadu-india/
8	Tamil Nadu	KKNPP, Kudankulam	7680	http://www.barc.gov.in/egreport.pdf; http://www.dianuke.org/water-balance-sheet-of-koodankulam-nuclear-power-plants-kknpp/#_edn1
9	Tamil Nadu	MAPS, Kalpakkam	6300	http://www.barc.gov.in/publications/tb/desalination.pdf
10	Tamil Nadu	Sesa Sterlite Ltd., Tuticorin	10000	http://lntecc.com/homepage/multislug/demos/images/water/water_brochure.pdf
11	Gujarat	Reliance Industries, Jamnagar	160000	http://www.ide-tech.com/wp-content/uploads/2013/09/Reliance-India-Project.pdf
12	Gujarat	Essar Project, Jamnagar	65000	http://www.ide-tech.com/wp-content/uploads/2013/09/Essar-India-Project.pdf
13	Gujarat	GMDCL, Akrimota, Kutch	2400	http://www.wabag.com/ru/wabag-projects/akrimota-kutch-thermal-desalination-2/?project_year=&country=india-ru&branch=desalination-ru&cat=all.municipal-ru.industrial-ru.sludge-treatment-ru.sea-and-brackish-water-ru.ground-water-ru.surface-water-ru.water-reuse-ru.&search=&search_button=Search
14	Gujarat	Nirma, Bhavnagar	10800	http://pds.magichome.co.kr/board/encoss/seawatercase.pdf; http://www.thermaxglobal.com/Fileuploader/Files/Case_Study_Sea_Water_Desalination.pdf
15	Gujarat	Adani Power SEZ, Mundra, Kutch	7000	http://www.ionindia.com/download/newsletters/IEI_June2010.pdf
16	Gujarat	Gujarat Anjan Cement Ltd, Kutch	6000	http://www.ionindia.com/download/newsletters/IEI_June2010.pdf
17	Gujarat	GEB, Sikka, Jamnagar	4392	http://www.membranesindia.com/products/swdp.htm

(Contd …Appendix 7.1)

S. No.	***State***	***Plant***	***Product-ion Capacity (m^3/day)***	***Source***
18	Gujarat	GHCL, Veraval	3600	http://www.membranesindia.com/products/swdp.htm
19	Gujarat	Indian Rayon, Veraval	6000	http://www.membranesindia.com/products/swdp.htm
20	Gujarat	CGPL, Mundra	25200	http://www.aquatech.com/wp-content/uploads/47.-CGPL-SWRO.pdf
21	Maharashtra	Trombay	100	http://www.barc.gov.in/publications/tb/desalination.pdf
22	Maharashtra	Industrial Water	1000	GE Power & Water, Seawater Desalination Solutions. Available at: https://www.gewater.com/kcpguest/document-library.do
23	Karnataka	Udupi Power Corp. Ltd.	16200	http://www.trivenigroup.com/water-solutions/profile/milestones.html
24	Andhra Pradesh	Simhapuri Power Ltd., Nellore	3600	http://www.ionindia.com/pdf/IEI%20News%20Volume%20No.%2079%20May%202012.pdf
25	Pondicherry	Chemplast Sanmar, Karaikal	1200	http://www.ionindia.com/pdf/IEI%20News%20Volume%20No.%2073%20April%202006.pdf

Appendix 7.2: Details of Future Desalination Plants Planned in India

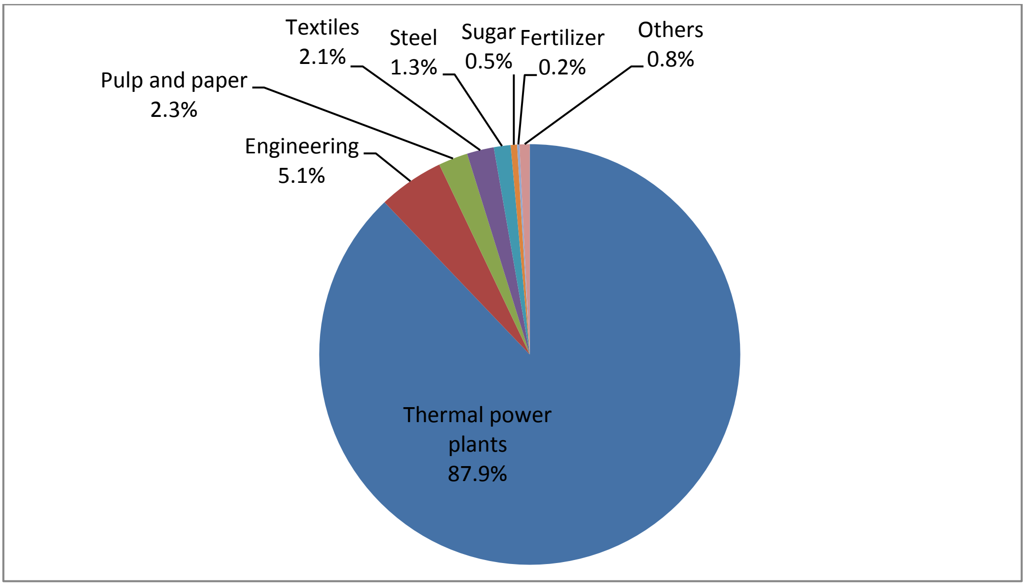
S. No.	*State*	*Plant*	*Production Capacity (m^3/day)*	*Source*
1	Gujarat	Dahej SEZ	336000	http://www.hitachi.com/New/cnews/130111.pdf; http://hyflux.listedcompany.com/misc/mar12/latest.html
2	Gujarat	Kutch Desalination Plant (GIDB)	150000	http://www.gidb.org/Document/NOTICE_INVITING_REQUEST_FOR_QUALIFICATION_CUM_PROPOSAL.pdf; GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
3	Gujarat	Mundra Port SEZ Expansion	200000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
4	Tamil Nadu	Chennai Nemmeli Extension	150000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
5	Tamil Nadu	Chennai 3	200000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
6	Tamil Nadu	Chennai 4 (Perur)	400000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
7	Tamil Nadu	Ramanathapuram	60000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
8	Tamil Nadu	Ramanathapuram (TIDCO)	15000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
9	Tamil Nadu	Tuticorin	60000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
10	Andhra Pradesh	Visakhapatnam Steel Plant	45460	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
11	Andhra Pradesh	Vizag Mobile RO Desal	10000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
12	Andhra Pradesh	Sri City SEZ, Nellore	50000	http://www.aquadesigns.in/documents/1.pdf
13	Andhra Pradesh	Thamminapatnam, Nellore (KWCPL)	20000	http://www.appcb.ap.nic.in/faq/Agenda-7A.doc.pdf
14	A&N Islands	Brookshabad Desalination Plant, Port Blair	14000	http://www.and.nic.in/search/ENglish%20Final%20Report%2002-03-2012/chapter-4.pdf
15	Kerala	Cochin Port Desalination Plant	4500	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
16	Pondicherry	Kalapet Desalination Plant	30000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
17	Maharashtra	Mumbai	100000	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.
18	Odisha	OSCOM Chatrapur	4500	GWI (2015) Global Water Intelligence, Volume 18, Issue 8, August 2015.

Chapter 8

VALUE OF SEAWATER USED FOR INDUSTRIAL COOLING

Water is an important input requirement for the industrial sector as various industries require large quantities of water for their manufacturing process. Water use in thermal power plants, in particular, is significantly higher than that of other industrial sectors in India (see Figure 8.1).

Figure 8.1: Industrial Water Use in India



Source: CSE (2004).

Water is used for many purposes in a power plant including process cooling in the condenser, ash disposal, removal of heat generated in plant auxiliaries, in the demineralisation plant and for various other plant consumptive uses such as drinking water, service water, fire fighting etc. However, among the many processes for which water is used in a thermal power plant, the cooling water system for condenser and plant auxiliaries dominates the consumptive water requirement of a thermal power plant. CEA (2012) notes that more than 80 percent of input water is required for process cooling in coal-based thermal power plants with cooling towers. Ash disposal also consumes a significant amount of water; however this is usually sourced from the cooling water system as blow down water and as such is not considered separately to the water requirements of the cooling tower. Close to 40 percent of the water input into the cooling tower is used for ash disposal.

Delgado (2014) notes that there are two main drivers of water use in power plants, namely –

a. The efficiency of the power plant; and
b. The type of cooling system used.

With regards to the first point, Delgado notes that all the waste heat (or 'loss') from a power plant has to be released into the environment somehow and that the vast majority of this heat is rejected into the environment through cooling systems. Therefore the more efficient a power plant is the less heat it loses and thus lower are its cooling needs. In other words, the higher the rate of conversion of heat to electricity in a given power plant, higher is its efficiency and lower is the amount of waste heat generated that needs to be rejected into the environment via cooling. Efficiencies of power plants in turn depend on the type of fuel used in production as well as the technology adopted. Table 8.1 gives the typical efficiencies of different power plants that are distinguished by the type of fuel they use. In general, the natural gas combined cycle power plant has the highest efficiency and thus it also has the least cooling needs compared to nuclear, solar thermal (Rankine cycle) and the (newer) coal-based power plants, all of which have efficiencies in the range of 30 to 40 percent and thus have higher cooling needs. The older coal-based thermal power plants tend to have the highest cooling needs with efficiencies as low as 20 percent.

Table 8.1: Typical Efficiencies of Different Types of Power Plants

S. No.	***Type of Power Plant***	***Typical Efficiency***
1.	Natural Gas Combined Cycle	~50%
2.	Super Critical Pulverised Coal	~39%
3.	Subcritical Pulverised Coal	~36%
4.	Nuclear	~33%
5.	Solar Thermal (Rankine Cycle)	~32%
6.	Old Coal Power Plants	~20%

Source: Delgado (2012).

With regards to the second point, i.e. the type of cooling system used as being one of the drivers of water use in power plants, there are three main types of cooling technologies that are in use today, namely –

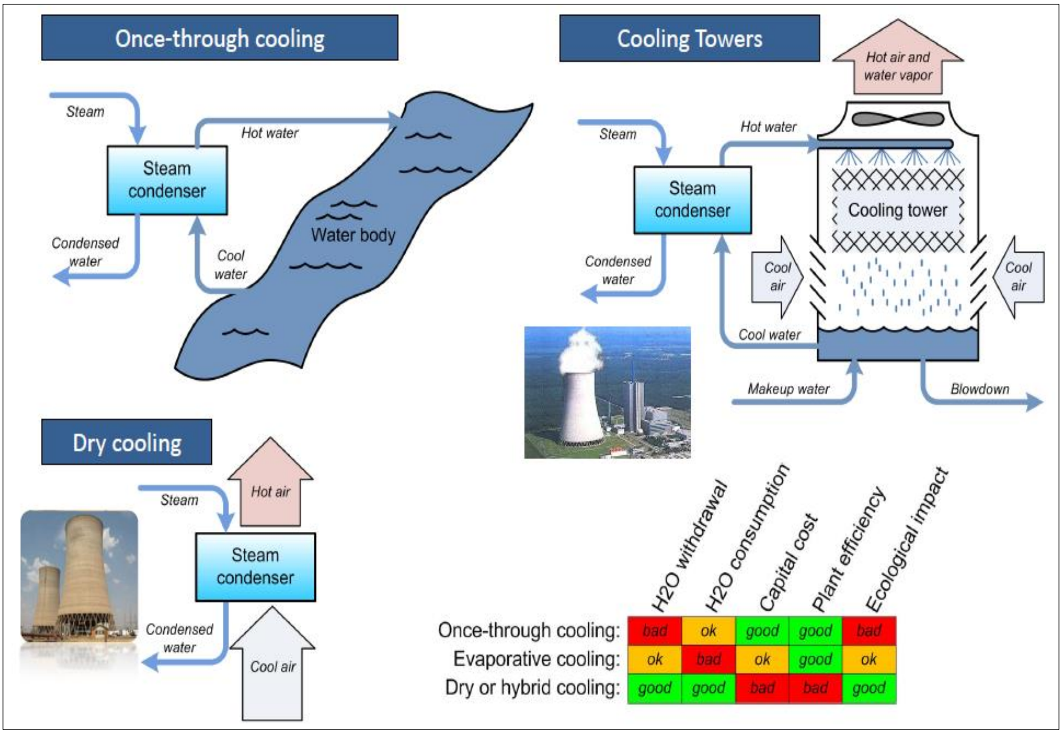
i. Once-through cooling: This system requires the intake of a continual flow of cooling water, which is discharged without recirculation/recycling after heat exchange in the condensers. The water demand of the once-through system is considered to be about 30 to 50 times more than the closed-cycle system (CSE, 2004). Although the use of once-through cooling systems are becoming uncommon across the world, many thermal power plants in India still use this type of cooling system (TERI, 2012).

ii. Closed-cycle cooling/ cooling towers: This system discharges heat through evaporation in cooling towers and recycles water within the power plant. Water is re-circulated many times in a closed loop. Clarified water is added continuously from the raw water treatment plant to make up for evaporative and drift losses as well as for the loss through the 'blow down' carried out to get rid of the high salt content concentrated in the water during the process of re-circulation (TERI, 2012). The water required for cooling in this system is comparatively small since it is limited to the amount lost through the evaporative process (CSE, 2004).

iii. Dry cooling: This system uses air instead of water to cool the steam exiting a turbine. The use of a dry condenser cooling system results in a reduction of plant consumptive water by about 80 percent given that the wet cooling tower is then used only for auxiliary cooling water (ACW) flow. The requirement of plant consumptive water can be further reduced by adopting the dry cooling mode for the ACW flow as well (CEA, 2012).

A graphical representation of the three types of cooling systems and a comparison of all three in terms of water withdrawal, water consumption, capital cost, plant efficiency and ecological impact are both presented in Figure 8.2.

Figure 8.2: Comparison of Different Types of Cooling Systems



Source: Delgado (2014).

It is clear from the above discussion that within the industrial sector, power plants consume the highest quantity of water, and also that the water consumption of any particular power plant is dependent on the plant efficiency (linked to the type of fuel and technology used) and the type of cooling system employed in discharging waste heat. In order to meet the water requirements of power plants, water is obtained from various sources depending on the location of the power plant. For power plants located on the main land, water is generally drawn from a fresh water source such as a river, lake, canal, reservoir or barrage. Treated sewage water may also be used as a source of raw water for power plants located adjacent to cities. For power plants located in coastal areas, water for cooling the condenser and plant auxiliaries is drawn from the sea or creek, which also provides for the water requirement of the wet ash handling system. The requirement of water for other plant consumptive uses is met from an alternative source of water or by installing a desalination plant. Therefore by using seawater for cooling purposes, power plants conserve on scarce freshwater resources that may be put to alternative uses in the agricultural and domestic sectors. The sea thus provides a valuable service in terms of the supply of seawater in order to meet the water needs of power plants located on the coast. Although seawater is not priced and is available for 'free' to the power companies, it is a valuable resource as it saves power companies billions of rupees each year on their water bills, which they would have otherwise had to pay to procure freshwater (which is not available at free of cost). Hence, the aim of this exercise is to value the benefits of using seawater for industrial cooling.

8.1 Methodology and Data Sources

Given that power plants consume the highest quantity of water among all industries, and that among the power plants it is the coal-based thermal power plants and the nuclear power plants that have relatively lower efficiencies and thus have higher water requirements for cooling, this exercise focuses on valuing the benefits of seawater used for cooling in coal-based thermal and nuclear power plants located on the coast in India. Natural gas combined cycle thermal power plants are excluded from the analysis as their water requirements are comparatively lower, and moreover there are very few plants of this type that are located on the coast and that use seawater for cooling in India.

The direct market valuation approach is used to value this service in which the volume of seawater used by power plants is multiplied by the price of raw water or freshwater, in the absence of a price for seawater, to arrive at the monetary value. The value represents the water costs that power companies would have incurred if they did not have access to seawater and had to use freshwater instead. To that effect, this method can also be viewed as the avoided cost method since the benefit power companies derive is the costs they avoid in terms of water purchases by using seawater instead of freshwater. It is important to note however that operation and maintenance costs that are likely to be higher with the use of seawater vis-à-vis freshwater due to corrosion of equipment etc. are not deducted from the total value. Moreover other costs such as capital costs for the cooling water system, water transportation costs etc. that are bound to differ between plants that use seawater and freshwater are not accounted for in the final value. Thus the estimated benefit is a gross value.

The introduction noted that water requirements of power plants vary depending on the type of cooling system they use (i.e. once-through, closed-cycle or dry), which is taken into account in the estimation of the volume of water used by each power plant. More specifically, the benefit of using seawater for industrial cooling is estimated as follows:

$$B_{ij} = V_{ij} \times p \tag{8.1}$$
$$V_{ij} = \alpha_j \times MW_i \tag{8.2}$$
$$\sum_{i=1}^{n} B_{ij} = B \tag{8.3}$$

Where,
i is the type of power plant, i.e. coal-based or nuclear;
j is the type of cooling system used, i.e. once-through, closed-cycle or dry;
B_{ij} is the value accruing to power plant i with cooling system j in rupees per year;
V_{ij} is the volume of seawater consumed by plant i using cooling system j in m^3 per year;
α_j is the seawater requirement of a plant using cooling system j in m^3 per hour per MW;
MW_i is the operating capacity of plant i as of December 2013 in megawatts;
p is the price of raw water in rupees per m^3; and
B is the total value in rupees per year.

Information on the list of power plants operating in India comes from the Central Electricity Authority's monthly generation report that provides monthly sector-wise, fuel-wise and state/region-wise power generation information (CEA, 2013). Since the monetary value is estimated for the year 2012-13, the list of power plants as well as their operating capacities (MW_i) as of December 2013 was used. From the complete list of all power plants operating in India, the coal-based thermal and nuclear power plants operating on the coast (that use seawater for cooling) along with the type of cooling system they employ were identified from information on individual power plants that is available online (i.e. from power company websites, environmental clearance reports etc.). Details of coastal power plants considered for the analysis are presented in Table 8.2.

Table 8.2: Particulars of Power Plants Located on the Coast Using Seawater for Cooling as of December 2013

S. No.	*Location*	*Sector*	*Fuel Type*	*Name of Company*	*Name of Power Plant*	*Type of Cooling System*	*Monitored Capacity (MW)*
1.	Andhra Pradesh	Private	Coal	MEL	Thamminapatnam TPS	Closed-Cycle	300
2.	Andhra Pradesh	Private	Coal	SEPL	Simhapuri TPS	Closed-Cycle	300
3.	Andhra Pradesh	Central	Coal	NTPC Ltd.	Simhadri TPS	Closed-Cycle	2000
4.	Gujarat	State	Coal	GMDCL	Akrimota Lig. TPS	Closed-Cycle	250
5.	Gujarat	State	Coal	GSECL	Sikka Rep. TPS	Closed-Cycle	240
6.	Gujarat	Private	Coal	APL	Mundra TPS	Closed-Cycle	4620
7.	Gujarat	Private	Coal	CGPL	Mundra UMTPP	Once-Through	4000
8.	Gujarat	Private	Coal	EPGL	Salaya TPP	Once-Through	1200
9.	Karnataka	Private	Coal	UPCL	Udupi TPP	Closed-Cycle	1200
10.	Maharashtra	Private	Coal	JSWEL	JSW Ratnagiri TPP	Closed-Cycle	1200
11.	Maharashtra	Private	Coal	RIL	Dahanu TPS	Once-Through	500
12.	Maharashtra	Private	Coal	TATA PCL	Trombay TPS	Once-Through	1400
13.	Tamil Nadu	Private	Coal	IBPIL	Tuticorin (P) TPP	Dry Cooling	150
14.	Tamil Nadu	Central	Coal	NTECL	Vallur TPP	Closed-Cycle	1000
15.	Tamil Nadu	State	Coal	TNGDCL	Ennore TPS	Once-Through	450
16.	Tamil Nadu	State	Coal	TNGDCL	North Chennai TPS	Once-Through	1830
17.	Tamil Nadu	State	Coal	TNGDCL	Tuticorin TPS	Once-Through	1050
18.	Maharashtra	Central	Nuclear	NPCIL	Tarapur	-	1400
19.	Tamil Nadu	Central	Nuclear	NPCIL	Madras (Kalpakkam)	-	440

Source: CEA (2013); Type of cooling system compiled from various online sources.

Nineteen power plants located on the coast were considered for the analysis including seventeen coal-based thermal power plants and two nuclear power plants. Gujarat and Tamil Nadu have the highest number of power plants located on the coast, followed by Maharashtra and Andhra Pradesh. Of the 17 coal-based thermal power plants, 9 have closed-cycle cooling systems, 7 have once-through cooling systems, while only 1 power plant uses a dry condenser cooling system. As per MoEF's stipulation dated 2nd January 1999, the once-through type of cooling system is only allowed in power plants located in coastal regions (using seawater for cooling) and on the condition that the discharged hot water does not lead to the rise in temperature in excess of 7°C over and above the ambient temperature of the receiving water body (CEA, 2012).

Data on the water consumption of coal-based thermal power plants comes from CEA (2012). This study looks at the water requirements of coal-based thermal power plants using different cooling systems and recommends optimal plant consumptive water requirements based on the cooling system employed. The details are presented in Table 8.3.

Table 8.3: Consumptive Plant Water Requirement for 2x500 MW Power Plant (in m^3/h)

S. No.	***Description***	***Inland Plants Using Indigenous Coal***		***Seawater based Coastal Plants (Freshwater Requirement)***
		Plant with Wet Cooling Tower (Closed-Cycle)	***Plant with Dry Cooling System***	
1.	Water requirement for first year of plant operation	3600 (3.6)	750 (0.75)	400 (0.4)
2.	Water requirement during subsequent periods	3000 (3.0)	550 (0.55)	

Note: Figures in parentheses indicate plant water requirement per MW.
Source: CEA (2012).

Table 8.3 gives the suggested water consumption by power plants using different types of cooling systems. Note that plants located on the coast use seawater for cooling but they have additional freshwater requirements to the tune of 400 m^3/h per 1000 MWs. For an inland plant using a closed-cycle wet cooling system, its water requirement is 3600 m^3/h per 1000 MWs in its first year of operation, which is obtained completely from a freshwater source owing to its lack of access to seawater. This implies that during the first year of plant operation, the *seawater* requirement of a plant located on the coast, that uses a closed-cycle wet cooling system, is 3200 m^3/h (i.e. 3600 – 400) per 1000 MWs, assuming everything else remains the same between inland and coastal power plants using closed-cycle cooling systems. The seawater requirements of plants with closed-cycle cooling systems during subsequent time periods and the seawater requirements of plants using dry cooling systems may be calculated similarly. In other words, it is assumed that irrespective of the type of cooling system used, a coal-based power plant consumes 400 m^3/h of freshwater for purposes *other* than cooling, and thus its cooling water requirement is its total consumptive requirement on the basis of the type of cooling system used (as in Table 8.3) minus its freshwater requirement (400 m^3/h) irrespective of its location. Plants located on the coast use seawater to meet their cooling needs whereas plants located inland are forced to use freshwater (or treated sewage/wastewater) for cooling.

Since plants with once-through cooling systems are no longer allowed to operate inland, Table 8.3 does not mention the plant water requirements of inland plants using this type of cooling system. CSE (2004) notes that the water demand for the once-through system is 30 to 50 times that of a closed-cycle system. However this would include the total plant water requirement and not just the plant consumptive water requirement since only about 2.5 to 3 percent of the total water used in a coal-based thermal power plant is consumed (TERI, 2006). Thus, the seawater requirement of a plant using a once-through cooling system is assumed to be 40 percent more than that of a plant operating a closed-cycle system, in line with TERI (2012).

The plant consumptive water requirement for the first year of operation is considered as the upper-bound value and the water requirement during subsequent periods is considered as the lower-bound value in the estimation of the volume of seawater used for cooling. Note that in general, nuclear power plants have water requirements in excess of coal-based thermal power plants, however owing to the lack of specific data on the volume of water they require/consume or the type of cooling system they use; their water requirements are assumed to be the same as those of coal-based power plants with once-through cooling systems. To this effect, the estimated value of seawater-based cooling for nuclear power plants is likely to be an underestimate.

Table 8.4 presents the seawater cooling requirements of power plants with different types of cooling systems (a_j) that have been employed in the valuation exercise.

Table 8.4: Plant Consumptive Seawater Cooling Requirements by Type of Cooling System (in m^3/h per MW)

	Wet, Once-Through Cooling System	***Wet, Closed-Cycle Cooling System***	***Dry Cooling System***
Lower-Bound	3.64	2.60	0.15
Upper-Bound	4.48	3.20	0.35

Source: Own calculations based on CEA (2012) and TERI (2012) as discussed above.

Finally, two prices of raw water are used to compute the ecosystem service value: Rs. 4 per m^3 which is the rate of freshwater procured from the irrigation department as reported in TERI (2012); and, Rs. 6 per m^3 which is the unit cost of raw water as reported in CEA (2012). Prices are in 2012-13 rupees. The lower- and upper-bound values for cooling water requirements combined with the two prices of raw water give four sets of estimates for the monetary value of seawater used for industrial cooling from which a value range for this ecosystem service is established.

8.2 Results and Discussion

The estimated value range of the benefits of using seawater for industrial cooling in India is presented in Table 8.5.

Table 8.5: Value of Seawater Used for Industrial Cooling in India (in 2012-13 Rupees Billion per Year)

Type of Power Plant	***Minimum***	***Maximum***	***Average***
Coal-Based Thermal Power Plants	2.52	4.66	3.59
Nuclear Power Plants	0.06	0.10	0.08
Total	**2.58**	**4.76**	**3.67**

For coal-based thermal power plants located on the coast of India and using seawater for cooling as of December 2013, the annual value ranges from Rs. 2.52 – 4.66 billion. Almost 60 percent of this value accrues to plants using the once-through cooling system and about 40 percent of this value accrues to plants using the closed-cycle cooling system. The value accruing to plants with dry cooling systems is negligible as there is only one power plant with a relatively small capacity that falls into this category. For nuclear power plants located on the coast and using seawater for cooling as of December 2013, the annual value ranges from Rs. 0.06 – 0.10 billion. Thus, the total estimated value for this service ranges from Rs. 2.58 – 4.76 billion per year, with an average value of Rs. 3.67 billion per year. Coal-based thermal power plants account for almost 98 percent of the total value whereas nuclear power plants account for only slightly more than 2 percent of the total value.

It is important to reiterate that since annual operation and maintenance costs etc. have not been subtracted, the final value represents a gross value and thus an overestimate. On the other hand, since the water requirements for coal-based power plants with once-through cooling systems have been adopted for nuclear plants, this value is likely to be an underestimate given that nuclear power plants have bigger water requirements than coal-based thermal power plants. While we can expect some cancellation of the upward and downward bias in estimates, it is unclear what its net effect on the final value is likely to be.

Chapter 9

VALUE OF COASTAL SHIPPING

Among other things, the seas provide us an opportunity to transport goods and people to various destinations via shipping. In India, coastal (domestic) shipping accounted for only 7 percent of the overall cargo movement in 2007-08 (road transport accounted for 54 percent and rail transport accounted for 39 percent; TTS-RITES), which is low compared to other countries such as EU-27, Japan and China in which the share of coastal shipping in domestic freight transportation was 38, 34 and 49 percent respectively (European Commission, 2009, 2010). This is surprising since there are several benefits of transporting goods via coastal shipping vis-á-vis road and rail transport. A KPMG report (2014) that provides insights into water transportation in India has identified these as follows:

a. Lower costs – coast to coast transportation of goods via coastal shipping is about 21 percent of that of road transport and about 42 percent of that of rail transport.

b. Lower consumption of fuel per tonne of cargo – fuel consumption by coastal shipping is 4.83 grams per tonne-kilometre, which is 15 percent of the fuel consumption by road and 54 percent of that by rail.

c. More environment-friendly – Carbon dioxide emissions from rail transport and road transport are roughly two and six times higher than those from coastal shipping, respectively.

d. Lower rate of fatalities – Road and rail movement result in significant loss of lives in India. It is estimated that one life is lost in a road accident every 3.7 minutes in India.

The above factors indicate that there are significant gains to be had in terms of costs saved and damages avoided by transporting goods via sea rather than via other modes of freight transport. Here an attempt has been made to estimate the benefits of coastal shipping in terms of the economic and environmental costs saved with respect to road and rail transport.

9.1 Methodology

The benefits of coastal shipping are valued by using the avoided cost method, which estimates the costs of transportation that would have been incurred in the absence of the sea (and thus, in the absence of coastal shipping). In other words, the benefits of coastal shipping are the costs avoided by transporting goods via sea as opposed to transporting them by alternative modes of land–based transportation such as road or rail.

The benefits of coastal shipping as a means of transportation may be estimated in the following manner:

$$V_{Si} = \sum_{zjk} \left(\left(D_{iz} \times C_{ijk} \times T_{Szj} \right) - \left(D_{Sz} \times C_{Sjk} \times T_{Szj} \right) \right) \tag{9.1}$$

Where,

V_{Si} are the benefits of coastal shipping, *S*, in terms of the costs saved with respect to *i*, the alternate mode of transportation;

i is the mode of transport other than shipping. Only the two major modes of freight transportation namely road and rail transport are considered as alternatives in this exercise;

z represents a pair of maritime zones across which goods are transported, from one zone to another. There are twelve maritime zones and forty eight pairs of maritime zones over which goods have been transported in 2012-13 (more on this in the next section);

j is the type of commodity being transported across maritime zones (e.g. Petroleum Oil and Lubricants (POL), cement etc.). Transportation costs tend to vary by the type of commodity being transported both within and across the different modes of transportation, which is taken into account here. Moreover, different commodities are transported via specific routes only depending on the demand and supply of the same;

k is the category of cost being estimated. Economic and environmental costs alone are considered for this exercise;

D is the distance in km between a representative port in one maritime zone and another. Note that transportation routes and thus distances will vary by the different modes of transportation for the same *z*;

C is the cost in Rupees per tonne-km by commodity. Costs vary not only by the type of commodity being transported but also by the distance travelled in some cases (road transport) as well as other specifics of the route (type of terrain- *ghat*/plain, type of road- national highway/other, type of track- single line/double line etc.) and the mode of transportation itself (whether diesel or electric traction etc.; more on this in the subsequent section); and

T is the tonnes of goods of various kinds that are transported by coastal shipping between the different maritime zones.

Looking at the right hand side of equation (9.1), the first part estimates what it would cost to transport goods actually transported by coastal shipping by another mode of transportation, and the second part estimates what it costs when they are transported by coastal shipping. Thus, the difference between the two are the costs saved by transporting goods via coastal shipping compared to another mode of transportation, i.e. the benefit derived. Since costs saved over two alternate modes of transportation, namely road and rail, are estimated, two values for V_{si} are obtained which gives a range of values for the benefits of coastal shipping.

9.2 Data Sources

The Planning Commission's Total Transport System Study (TTS-RITES) has worked out the economic and environmental costs (in terms of Rupees per Tonne-Km) incurred by different modes of transport including coastal shipping, road transport (highways) and rail transport. The economic costs of transportation comprise of fixed capital costs (including ground facilities, ports, highways, tracks, terminals, workshops etc.), moving capital costs (including rolling stock, vehicles, vessels, trains, equipment at terminals and workshops etc.) and operating and maintenance costs (including fuel expenses, repair and maintenance, running costs, salaries, insurance etc.). Economic costs are nothing but the financial costs that have been adjusted for transfer payments, taxes and subsidies using a shadow pricing factor. Economic costs for coastal shipping are only available for commodities commonly transported by this means of transportation. These include iron ore, POL (product and crude), coal, cement and others (including containers). Thus, although economic costs for railways, primarily, and road transport are available for commodities other than those listed above, averages over respective commodity groups have been taken to represent the commodity-wise economic costs as per the coastal shipping classification of commodities. For railways, TTS-RITES also estimated economic costs on the basis of the type of terrain (whether traversing a plain section or a *ghat* section), type of train traction (whether diesel or electric) and the type of railway line (whether single or double). For the purpose of this study average values over all these categories have been used for each commodity group due to lack of information on the specifics of each journey. For road transport, other than the usual commodity-wise cost estimates, TTS-RITES also estimated costs on the basis of terrain (whether plain, rolling or hilly), road type (national highway, state highway or major district road) and the number of lanes (single, double, four, intermediate and four lane expressway). In addition, economic costs were also estimated on the basis of the distance travelled (i.e. distance slab-wise cost). Since almost all road journeys across maritime zones involve travel on national highways, commodity-specific economic costs for national highways (averaged across the other two categories- terrain and number of lanes) that corresponded to the distance range in question (i.e. range into which the actual road-distances between representative ports falls into) were used for the analysis. All unit costs as reported in TTS-RITES correspond to 2007-08 prices and were converted to 2012-13 prices using a GDP deflator (annual percentage, base year is 2004-05), data for which was obtained from the World Bank's World Development Indicators Database (available online). The commodity-wise economic costs of the three modes of transportation considered in this analysis are presented in Table 9.1. It is evident that the unit economic costs of road transport are the highest and those of coastal shipping, the smallest, across all commodity groups.

Table 9.1: Commodity-Wise Economic Costs of Different Modes of Transportation in Rupees per Tonne-Km (2012-13 prices)

Commodity Group	***Coastal Shipping***						
Iron Ore	0.094						
POL Product	0.497						
POL Crude	0.271						
Coal	0.287						
Cement	0.363						
Others	0.313						
	Railways						
Iron Ore/ Coal	0.741						
POL Product/ Crude	0.814						
Cement	0.736						
Others	0.744						
	Road Transport						
	Upto 200 km	*201 - 400 km*	*401 - 600 km*	*601 - 800 km*	*801 - 1000 km*	*1001 - 1500 km*	*Above 1500 km*
Iron Ore/ Coal/ Cement	1.769	1.623	1.575	1.527	1.551	1.493	1.502
POL Product/ Crude	2.136	1.942	1.879	1.816	1.802	1.771	1.782
Others	1.943	1.800	1.717	1.664	1.663	1.625	1.635

Source: TTS-RITES. Converted to 2012-13 prices.

In addition, the TTS-RITES study also estimated the per unit environment costs that are incurred by the different means of transportation. Environment costs in TTS-RITES were assessed on the basis of the abatement costs of air pollution from road transport in India (as estimated by Chatterjee et al., 2007). Abatement costs for different types of road vehicles, in the Chatterjee et al. study, comprised of the cost of upgrading vehicular technology to make it compatible with Euro III emission standards and the cost of improving fuel quality, i.e. the incremental cost of producing improved petrol and diesel compatible with Euro norms (as reported in the Mashelkar Committee Report, 2002). TTS-RITES used an annualised incremental cost of upgrading road vehicular technology of Rs. 17,212.50 per vehicle and an average incremental cost of improving fuel of Rs. 1.80 per litre to estimate the environment cost per tonne-km for road freight transport. The environment cost for railways and coastal shipping was arrived at in proportion to fuel consumption under these sectors. A fuel consumption norm of 2.54 litres per thousand GTKM under rail and 0.00216 litres per TKM under coastal shipping were adopted.

The environment costs estimated by TTS-RITES represent the costs of air pollution abatement; they do not include Greenhouse gas (GHG) emission costs of the different modes of transportation. It is important to include the latter in the environmental cost calculations to evaluate the GHG emission reduction benefits under coastal shipping as against other modes of transportation. The per unit GHG emissions costs for the different modes of freight transportation were computed by multiplying the estimates of GHG emissions per useful distance travelled for each mode of freight transportation, measured in grams of carbon dioxide equivalent per tonne-kilometre obtained from IPCC-AR5 (Schlömer et al., 2014), with the Social Cost of Carbon (SCC)[7] for India, estimated by Nordhaus (2011) and measured in Rupees per tonne of carbon dioxide. Note that the GHG emissions per tonne-kilometre estimates of the different modes of freight transport from IPCC-AR5 are based on the currently commercially available transport technologies world over and therefore they represent average global values (i.e. they are not India-specific).

The per unit environmental costs, comprising of both the air pollution abatement costs as well as the GHG emission costs, for the different modes of transportation that

[7] SCC is the estimated monetised value of damages caused by an additional tonne of CO_2 emissions or its equivalent released into the atmosphere. Economists and climate scientists often consider SCC as an underestimated value of the damages caused as a result of climate change impacts.

were used in this study are presented in Table 9.2. Note that both the environmental costs for railways represent average values of diesel traction and electric traction. Given that the proportion of freight transported by diesel traction as opposed to electric traction is not known, this is a reasonable assumption.

Table 9.2: Environmental Costs of the Different Modes of Freight Transportation in Rs. per Tonne-Km (2012-13 prices)

Mode	***Air Pollution Abatement Cost*** [a]	***GHG Emissions Cost*** [c]
Road	0.197	0.101[d]
Railways	0.032[b]	0.008[e]
Coastal Shipping	0.029	0.002[f]

Notes: [a] Source: TTS-RITES converted to 2012-13 prices.

[b] Average of diesel traction (Rs. 0.05/t-km) and electric traction (Rs. 0.015/t-km).

[c] Source: Own calculations based on g CO_2eq/t-km from Schlömer et al. (2014) and SCC from Nordhaus (2011) converted to 2013 Indian Rupees; SCC value range used is Rs. 314 – 680 per t CO_2.

[d] g CO_2eq/t-km values for diesel heavy and medium duty trucks used.

[e] g CO_2eq/t-km values for diesel (heavy good) and electric trains used.

[f] g CO_2eq/t-km values for large bulk carriers/tankers used.

As expected per unit environmental costs are the lowest for coastal shipping, followed by railways and they are the highest for road freight transport. The per unit air pollution abatement cost for coastal shipping is only slightly lower than that of railways, however it is approximately seven times lower than that of road transport. The per unit GHG emission cost for coastal shipping is four times lower than that of railways and around fifty times lower than that of road transport. Air pollution abatement costs are roughly twice as high as the GHG emissions costs for road transport. The same are about four and fifteen times higher than the GHG emissions costs for railways and coastal shipping respectively[8].

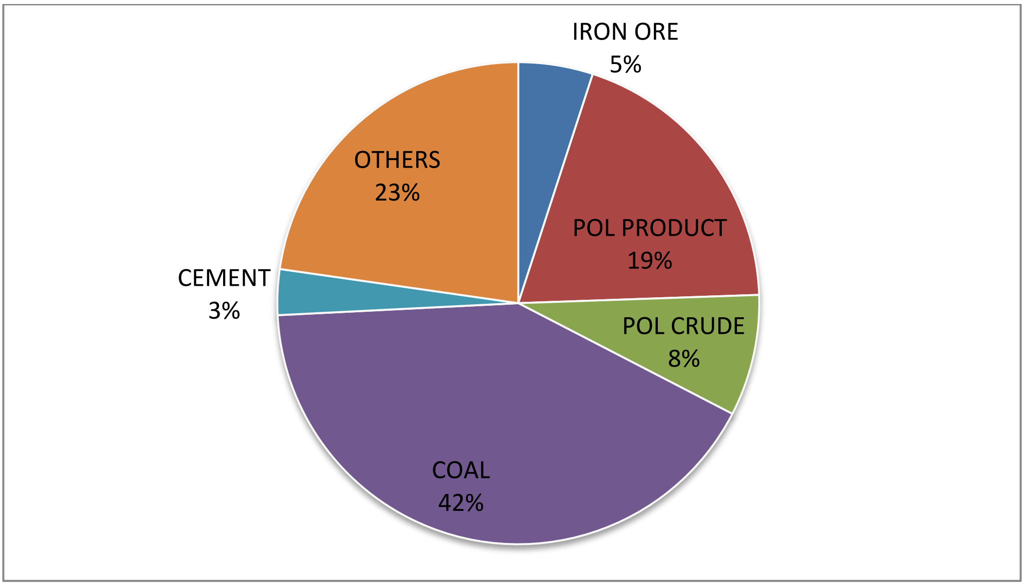
Note that the environment costs are not commodity-specific and hence the environment cost for each mode of transportation is added to the commodity-wise economic costs (the same value for all commodity groups) to arrive at the commodity-wise total costs for each mode of transportation.

[8] It may be noted that the environmental costs associated with air pollution and greenhouse gas emissions have been estimated in two different ways here. In case of air pollution, the environmental costs have been approximated with the cost of complying with emission norms, which in turn would shed light on the avoided social cost of air pollution. In the case of greenhouse gas emissions, on the other hand, the social cost of carbon used provides a direct measure of avoided social cost of greenhouse gas emissions.

Data on the commodity-wise quantity of goods transported across the maritime zones of India (T_{Szj} in equation (9.1)) comes from the annual publication 'Statistics of the Inland Coasting Trade Consignment of India' (DGCI&S, 2012-13). This publication divides up the Indian coast into twelve maritime zones with each of the coastal States forming one zone each, the Islands of Andaman and Nicobar and Lakshadweep forming two additional zones and the Union Territory of Puducherry forming one additional zone, which gives a total of twelve zones in all. The publication gives information on the quantity of each commodity that was transported from one zone to another across all twelve zones but does not specify which port within each zone the goods were transported from and to. All commodities were grouped into the five major commodity groups for which unit cost estimates for the coastal shipping sector exist (as discussed above) and quantities thereof that were transported across the different maritime zones were aggregated. Note that quantity units varied according to the commodity in question and therefore all units were converted to tonnes using commodity-specific conversion factor units from the TTS-RITES study (Special Report 1) to enable such aggregation across commodities.

The cargo mix of commodities transported via coastal shipping (by quantity) in the year 2012-13 is depicted in Figure 9.1. The bulk of goods transported along coastal waters were coal (some 12.8 MT), followed by POL (approximately 8.5 MT) and other commodities (about 7 MT), which include food grains, fruits and vegetables, salt, inorganic chemicals, plastic, rubber, wood, ceramic and iron and steel articles, electrical machinery and equipment, road vehicles, boats and barges, parts of aircrafts, among others. The total quantity of goods transported was roughly 30.8 MT in 2012-13.

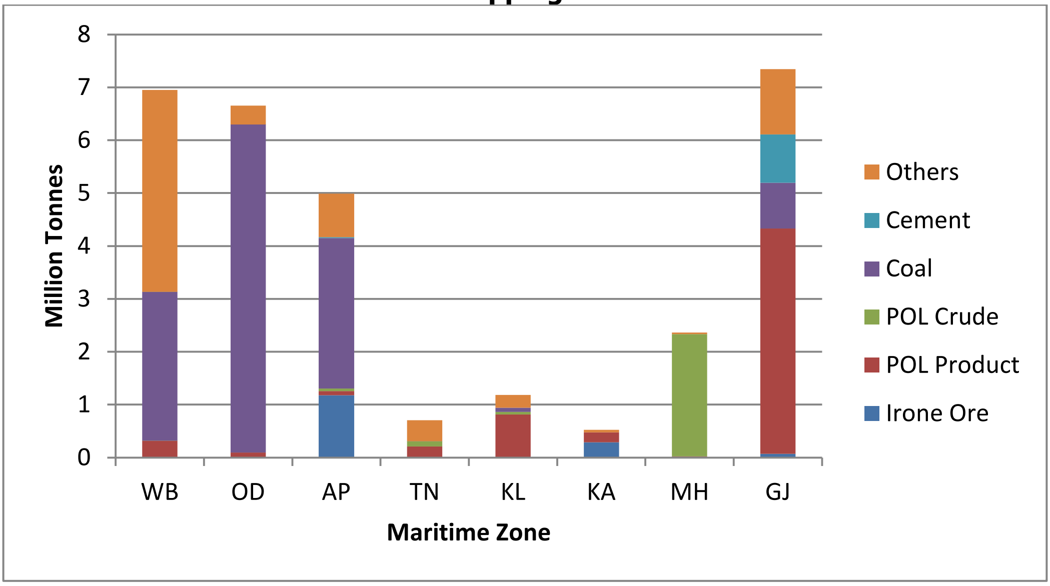
Figure 9.1: Cargo Mix of Commodities on Coastal Shipping (by weight) in 2012-13



Source: DGCI&S (2012-13).

In terms of the quantity of total goods that were sent outwards from each maritime zone to the others, Gujarat transported the highest quantity of goods during 2012-13, followed by West Bengal, Odisha and Andhra Pradesh (see Figure 9.2). Goa, Puducherry and Andaman and Nicobar Islands transported less than twenty thousand tonnes each and were thus excluded from the figure below. Lakshadweep did not transport any goods to other maritime zones during this period.

Figure 9.2: Commodity-Wise Quantity of Goods Sent by Maritime Zone via Coastal Shipping in 2012-13

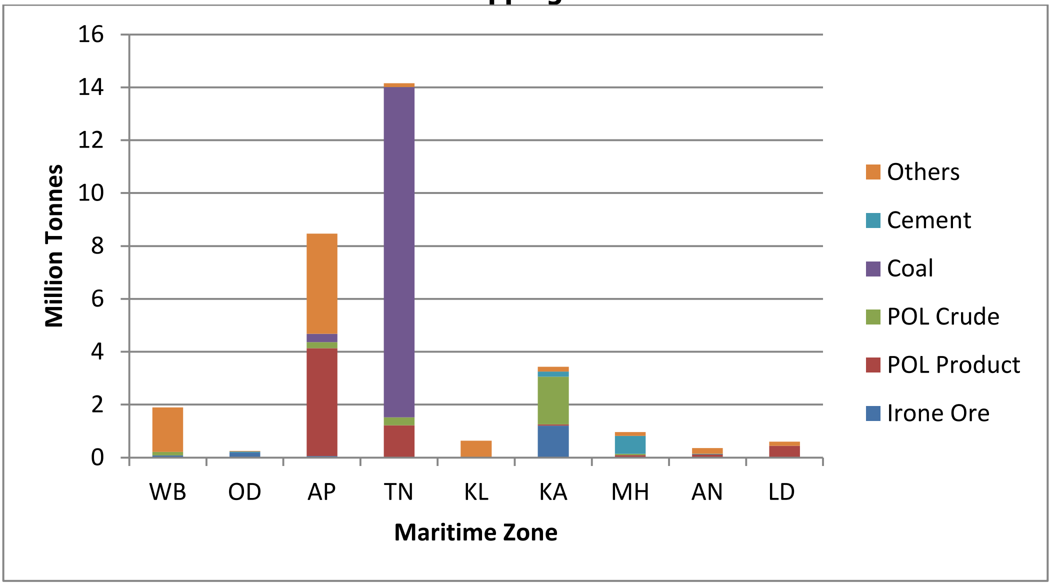


Source: DGCI&S (2012-13).

Figure 9.2 also shows that the highest quantity of POL product and cement that was transported was sent from Gujarat (almost 4.3 and 0.9 MT respectively); the highest quantity of Coal transported was sent from Odisha (approximately 6.2 MT) followed by West Bengal and Andhra Pradesh (about 2.8 MT each); the highest quantity of POL crude transported was sent from Maharashtra (close to 2.3 MT); the highest quantity of Iron ore transported was sent from Andhra Pradesh (almost 1.2 MT); and, the highest quantity of other goods transported to other maritime zones was sent from West Bengal (about 3.8 MT).

Looking at the maritime zone that received the highest quantity of goods that were transported via coastal shipping, Tamil Nadu received close to 14 MT of goods, which is significantly higher than the quantity of goods received by any other maritime zone via coastal shipping (Figure 9.3). No goods at all were shipped to Gujarat, Goa and Puducherry in 2012-13. The destination for almost all of the coal transported via coastal shipping is Tamil Nadu (some 12.5 MT). Andhra Pradesh was a major destination for the transportation of POL product and other goods (approximately 4.1 and 3.8 MT respectively); Karnataka for iron ore and POL crude (almost 1.2 and 1.8 MT); and, Maharashtra for cement (about 0.7 MT).

Figure 9.3: Commodity-Wise Quantity of Goods Received by Maritime Zone via Coastal Shipping in 2012-13



Source: DGCI&S (2012-13).

Given that the information on the port of origin and port of destination of goods transported within maritime zones is missing from the DGCI&S data, a representative port was selected in each of the twelve maritime zones and the distance (D_z in equation (9.1)) between that representative port in a particular maritime zone and the representative ports in other maritime zones was calculated for each mode of transportation. A representative port in each maritime zone was chosen on the basis of the amount of total coastal traffic it handled (i.e. the highest quantity of traffic handled both in terms of loading and unloading) among all major, intermediate and minor ports during the year 2012-13 (MoS, 2014; Tables 2-4). Naturally major ports handle more coastal traffic (in terms of quantity of goods) than minor ports and they were the natural choice of representative ports in maritime zones. If there is more than one major port in a particular maritime zone then the one that handled the highest tonnage of traffic was chosen as the representative port in that zone. In some cases, goods were transported internally within maritime zones (for e.g., in West Bengal, Andhra Pradesh and Tamil Nadu), thus, a second representative port was chosen, again on the basis of the quantity of coastal traffic handled by the port as well as its distance to the first representative port. That is, the port farthest to the first representative port was chosen since goods travelling short distances within a maritime zone are unlikely to be transported via shipping. Note however that inter-maritime zone transport distances are based on distances between the first representative ports chosen in each maritime zone. The representative ports selected in each maritime zone are listed below in Table 9.3.

Table 9.3: Representative Ports in the Coastal Shipping Maritime Zones

Maritime Zone	***Representative Port***	
	(1)	*(2)**
West Bengal	Haldia	Kolkata
Odisha	Paradip	-
Andhra Pradesh	Visakhapatnam	Krishnapatnam
Tamil Nadu	Chennai	V. O. Chidambaranar (Tuticorin)
Kerala	Cochin	-
Karnataka	New Mangalore	-
Maharashtra	Mumbai	-
Gujarat	Kandla	-
Goa	Mormugao	-
Puducherry	Puducherry	-
Andaman & Nicobar Islands	Port Blair	-
Lakshadweep	Kavaratti	-

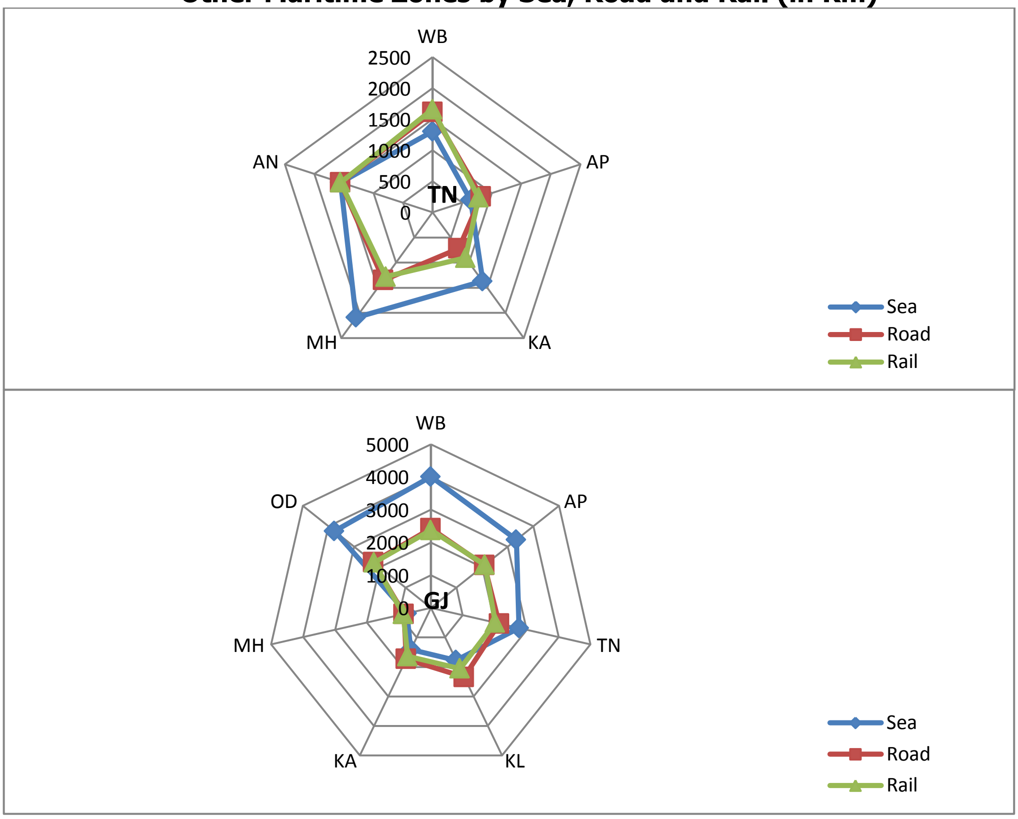
Note: * Only for internal (intra-maritime zone) transportation. Goods were not transported internally via coastal shipping within other maritime zones in 2012-13.

Sea distances between representative ports were calculated with the help of the Sea Rates port distance calculator[9]; road distances were calculated in Google Maps[10]; and rail distances were the distances between the main railway stations closest to the representative ports in each maritime zone and were obtained from the Indian Railways website[11]. Not surprisingly road and rail distances are shorter than sea distances when travelling across the country from the East- to the West-Coast (or vice-versa). However, when travelling along a particular coast, sea distances between ports tend to be shorter than road or rail distances, which are more or less similar between all pairs of representative ports. Note that since road and rail transport systems are not available from the mainland to the islands, sea distances to islands are used for road and rail transport as well. That is, it is assumed that if there was a road between the mainland and a particular island, the distance between the two would be the same as that of the sea route distance.

[9] http://www.searates.com/reference/portdistance/
[10] https://www.google.co.in/maps/
[11] http://indiarailinfo.com/

By way of an example, Figure 9.4 shows the distances from Chennai port in Tamil Nadu (top graph) and Kandla port in Gujarat (bottom graph) to representative ports in other maritime zones by the three modes of transportation. In both cases it is apparent that sea distances are longer than road or rail distances when travelling to zones on the opposite coast but they are shorter than road or rail distances when travelling to destinations along the same coast as the port of origin. Naturally sea, road and rail distances to Port Blair in the Andaman and Nicobar Islands from Chennai port are exactly the same since sea distance was assumed for the road and rail distances as well. The difference between road and rail distances is also negligible for almost all pairs of journeys in both graphs.

Figure 9.4: Distance from Tamil Nadu (top) and Gujarat (bottom) to Ports in Other Maritime Zones by Sea, Road and Rail (in Km)



9.3 Results and Discussion

The benefits of coastal shipping as estimated by equation (9.1) above are presented in Table 9.4. Since the costs saved by transporting goods via coastal shipping as opposed to transporting goods by the two alternative modes of transportation, namely road and rail, were both calculated, a range of cost savings values were obtained. The value range for the total benefits of coastal shipping is Rs. 16 – 62 billion (in 2012-13 prices). The value at the lower end of the range corresponds to the total costs saved in relation to rail transport and the value at the higher end of the range corresponds to the total costs saved vis-á-vis road transport. In other words, transporting goods via road is the most costly mode of transportation. Note that total costs saved are nothing but a sum of the economic and environmental costs saved. The environmental benefits of coastal shipping, including savings in terms of both air pollution abatement and GHG emissions reductions, amount to approximately Rs. 0.2 – 11 billion. In physical terms, GHG emissions reductions are estimated in the range of 1.2 – 22.1 lakh tonnes of carbon for the year 2012-13. Environmental costs saved by coastal shipping account for a modest 1.4 percent of total costs saved over rail transport, however they account for a significant 18 percent of total costs saved over road transport. There are GHG emissions reduction gains to be had by transporting all major commodities by coastal shipping as opposed to road and rail transport. Similarly, there are air pollution abatement savings to be had by transporting all major commodities by coastal shipping as opposed to road transport. However it seems to have been cheaper to transport iron ore and POL product by rail rather than by coastal shipping as indicated by the negative sign on the air pollution abatement cost saving estimates of those two commodities. In other words, the benefits foregone by transporting iron ore and POL product by coastal shipping instead of rail amounts to about Rs. 0.12 billion in 2012-13.

Table 9.4: Benefits of Coastal Shipping over Road and Rail Transportation (in 2012-13 Rupees Billion per Year)

Commodities	***Cost Savings over Road Transport***				***Cost Savings over Rail Transport***			
	Total	Economic	Environmental		Total	Economic	Environmental	
			Air Pollution Abatement	GHG Emissions			Air Pollution Abatement	GHG Emissions
Iron Ore	3.78	3.19	0.37	0.23	1.66	1.65	-0.01	0.01
POL Product	13.38	10.80	1.58	1.00	0.76	0.83	-0.11	0.04
POL Crude	4.68	3.98	0.44	0.26	1.34	1.33	0.00	0.01
Coal	26.07	21.45	2.94	1.69	8.10	7.92	0.09	0.09
Cement	1.50	1.23	0.18	0.10	0.42	0.40	0.00	0.01
Others	12.43	10.38	1.30	0.76	3.58	3.51	0.04	0.04
Total	**61.85**	51.02	6.80	4.03	**15.86**	15.63	0.02	0.21
(% Total)	*(100)*	*(82.5)*	*(11.0)*	*(6.5)*	*(100)*	*(98.6)*	*(0.1)*	*(1.3)*

It is important to note that coastal shipping does not provide 'end-to-end' connectivity, i.e. it cannot be solely relied upon to transport goods from the starting location to the final destination. Therefore, the coastal shipping costs in reality may include some additional costs that are incurred as a result of the movement of goods from the port to the final destination, presumably through links to road and rail networks. These additional 'last mile connectivity' costs incurred by the coastal shipping sector are not accounted for in this analysis and hence the cost savings presented in Table 9.4 may be seen as overestimates.

In addition to the economic and environmental benefits of coastal shipping, there are other social benefits of transporting goods by sea rather than by land. Transporting goods by sea as opposed to roads would lead to less congestion on roads by freight traffic, which would in turn lead to free movement of passenger traffic and subsequently a reduction in passenger travel times. Moreover, as noted in the introduction, road accidents are a common occurrence in India leading to significant losses in terms of human fatalities, injuries to people and damage to property. Thus, a modal shift from road to sea transport would lead to a reduction in the number of accidents occurring on roads and a consequent reduction in the economic loss to society.

The TTS-RITES study presented some estimates of unit accident costs for road and rail transport borrowing these values from AITD (2002), which estimated accident cost as the sum of real resource costs, such as vehicle damage, medical expenditure, police costs and the discounted value of the victim's future output. In addition, the AITD study also accounted for the pain, grief and suffering of those involved in road accidents by valuing these intangible costs by the willingness to pay approach. The unit accident costs based on the above approach and adjusted to 2012-13 prices are Rs. 0.061 per tonne-km for road transport and Rs. 0.001 per tonne-km for rail transport.

The total cost savings values in Table 9.4 are an underestimate of the true value of the benefits of coastal shipping due to the non-inclusion of social costs of transportation as discussed above. However the unit road and rail accident costs (as estimated by the AITD study) as a proportion of total resource costs may be used to scale the cost savings estimates upwards to at least partially account for the social benefits derived from transporting goods via sea as opposed to land. This leads to an estimate of Rs. 16 – 64 billion (2012-13 prices). Since rail accident costs are negligible, the benefit derived from a modal shift from sea to rail (i.e. a change in the lower-bound estimate) is insignificant. The inclusion of road accident costs leads to an increase in the benefits of coastal shipping vis-á-vis road transport to the tune of Rs. 2 billion. Note that accident costs for coastal shipping are not readily available so they have been assumed as zero here although this may not be the case in reality. Having said that, the number of road accidents far outweigh the number of shipping accidents in India in any given year, however in some cases the latter may cause greater and often more sudden damage or distress. It is important to note that all the monetary values derived above pertain to the quantity of goods transported via coastal shipping in the year 2012-13. In other words, if the amount of goods transported via sea as opposed to land changes, the monetary values would also change accordingly.

As noted in the introduction, only 7 percent of total domestic freight is transported by sea in India. KPMG (2014) identifies reasons as to why the share of coastal shipping in the overall domestic cargo movement is significantly lower than that of road and rail, which are as follows:

a. The provision of concessional freight fares by the railways on the transportation of large volumes of goods over long distances gives tough competition to coastal shipping;

b. The absence of concessional and long-duration finance for the acquisition of coastal vessels creates significant debt servicing burden on ship owners. The typical interest rate charged to ship owners is between 12-14 percent annually for an average period of seven years. This makes coastal freight uncompetitive vis-á-vis road and rail freight as ship owners are forced to pass on the effects of high financing costs to the end users;

c. High operating costs in coastal shipping as a result of high duties/taxes on bunker fuel and the high manning scale of coastal vessels may render coastal shipping uncompetitive vis-á-vis road and rail transportation; and

d. Inadequate facilities at ports for coastal vessels including the absence of dedicated berths for coastal shipping, leading to long waiting times at major ports, and the absence of quality handling facilities at minor ports, poses challenges to coastal vessel operators and may even lead to an increase in the costs of coastal shipping. Moreover, connectivity between the hinterland and minor ports is not as strong as it is for major ports.

If some or all of the bottlenecks in the coastal shipping sector are eliminated, the share of coastal shipping in the overall domestic cargo movement would rise from its current level of 7 percent. The share of coastal shipping in domestic freight transportation in India increased from 3 percent in 1986-87 to 7 percent in 2007-08 (TTS-RITES). Assuming that the rise in the share of coastal shipping in the future, due to the absence of bottlenecks in the coastal shipping sector, is similar to its growth rate in the past twenty years or so, a doubling of the share of coastal shipping (i.e. 14 percent) could be expected by the year 2030. In this case, the benefits of coastal shipping would also double to roughly Rs. 32 – 128 billion in 2012-13 prices, and GHG emissions reductions would increase to about 2.3 – 44.2 lakh tonnes of carbon per annum.

Table 9.5: Value of Coastal Shipping in 2012-13 Rs. Billion

Category of Benefits	***Cost savings over road transport***	***Cost savings over rail transport***
Baseline Value (Economic + Environmental Costs)	61.85	15.86
Inclusion of Social (Accident) Costs	63.80	15.88
Increase in the Share of Coastal Shipping	127.59	31.76

Table 9.5 presents the range of values for the benefits of coastal shipping as estimated in this study, a) under the baseline scenario (i.e. considering economic and environmental costs only); b) with the inclusion of accident costs in addition to the baseline costs; and c) with the removal of bottlenecks in the coastal shipping sector that would lead to an increase in the share of coastal shipping in the overall cargo movement. It is important to note that the first two categories of benefits are currently realisable (estimated for the year 2012-13), whereas the third category of benefits is hypothetical since an increase in the share of coastal shipping would occur only if the bottlenecks in the coastal shipping sector are dealt with effectively by the government.

Chapter 10

VALUE OF COASTAL PROTECTION BY MANGROVES

Mangrove ecosystems provide protection to people, livestock, property and other infrastructure in the eventuality of a storm. This service that mangroves provide has been well documented in the literature along with a host of other services that mangroves also provide (Barbier et al., 2011). The empirical studies on the valuation of storm protection service by mangroves, albeit few in number, indicate that this value may range from USD 32 per hectare per year to USD 8,017 per hectare per year (1996 prices; Bann, 1997 and Barbier, 2007 respectively). Differences in methodologies used, along with differences in mangrove quality and location could explain the wide range in the values estimated. Moreover, Das and Vincent (2009) note that empirical studies of this service have been criticised on the grounds that they use small samples and inadequately control for confounding factors such as the distance between a village and the coast.

From the Indian sub-continent, one study stands out as having systematically estimated the storm protection value of mangroves. This is the study by Das (2007a, 2007b) that has valued, using regression analysis, the number of human lives saved, number of livestock saved and damages to buildings avoided by mangroves in Kendrapada District in the event of the super cyclone that hit Orissa in October 1999. She estimated that a hectare of mangrove forestland stopped damages worth Rs. 18 Lakhs (USD 43,352) in the district during the super cyclone. She multiplied this value with the probability of occurrence of very severe storms in Orissa over the last three decades to arrive at the annual value of a hectare of land with intact mangrove forests, which is Rs. 3.6 Lakhs (USD 8,670) (all values in 1999 prices). This per hectare per year value more or less coincides with the value at the higher end of the range for this service as described above. It is important to note that Das and Vincent (2009) find that mangrove width and not the mangrove vegetation itself is significantly responsible for reducing damages. They also note that mangroves in Kendrapada provided significant protection only within ten kilometres of the coast.

The next section describes the methodology used for estimating storm protection services provided by mangroves in India. Data sources are subsequently discussed followed by a discussion of the results.

10.1 Methodology

Benefit transfer, which is the method of transferring values estimated in one study, location and/or context to another, is used to estimate the value of storm protection service of mangroves in India. In particular the annual per hectare mangrove value from Das's study for Kendrapada District is firstly scaled-up to the coastal State/UT level and then the subsequent aggregation across coastal States/UTs gives the all-India value. The scaling-up to the State/UT level was undertaken as follows:

A scaling factor was used to scale the Kendrapada storm protection value to the State/UT level based on three variables namely, maximum wind speed (or alternatively probable maximum wind speed), probable maximum surge height and per capita Net State Domestic Product. Differences in the former two variables across States would capture the differences in physical characteristics of cyclone activity across States and differences in the latter would capture differences in the level of income (a proxy for the stock of goods and built infrastructure) across States. More formally, the Scaling Factor (SF) for State *i* may be written as –

$$SF_i = \frac{WS_i}{WS_b} \times \frac{SH_i}{SH_b} \times \frac{pcNSDP_i}{pcNSDP_b} \qquad (10.1)$$

Where, *i* refers to the coastal State/UT in question, *b* refers to the reference district (or State), *WS* refers to the maximum wind speed (or alternatively probable maximum wind speed in m/s), *SH* refers to the probable maximum surge height (in m) and *pcNSDP* refers to the per capita Net State Domestic Product (in Rs./person).

The differences in the quality of mangroves both within and across States would also lead to differences in the storm protection value of mangroves within/across States and such adjustment ought to be made. The Forest Survey of India's data on the total mangrove area in each State/UT is disaggregated by the extent of mangrove cover, which is measured in terms of the canopy density obtained from remote sensing satellite data. They categorise mangrove cover into 'very dense' (canopy density of more than 70 percent), 'moderately dense' (canopy density between 40-70 percent) and 'open' (canopy density between 10-40 percent) (FSI, State of Forest Reports 2003 and onwards). The 17,900 ha of mangroves in Kendrapada district that Das considers in her study were classified as 'dense' mangroves (canopy density of more than 40%) according to FSI's 2001 assessment (Das and Vincent, 2009; FSI, 2001). In FSI reports in 2001 and before only two categories of mangrove cover existed, namely 'dense' and 'open'. Tracing the categorisation of area under mangroves in Kendrapada District over subsequent assessments reveals that the 17,900 ha of mangroves as per the 2001 assessment belonged to the 'moderately dense' category (i.e. canopy density between 40-70 percent). This is so since zero hectares of mangroves were reported in the 'very dense' category for Kendrapada District in the 2003 assessment (FSI, 2003) when the 'dense' category was further disaggregated to the 'very dense' and the 'moderately dense' categories between the 2001 and 2003 assessments. Moreover it is not until the 2009 assessment (FSI, 2009) when we see a non-zero record of area under 'very dense' mangrove cover for Kendrapada District (8,100 hectares) and the report notes that plantations and protection measures in Odisha (and in other States) led to an overall increase in mangrove cover compared to the previous assessment in 2005.

The storm protection values of 'very dense' and 'open' mangrove forests are thus estimated using the storm protection value for the 'moderately dense' forests as estimated in Das's study. A linear relationship is assumed between the benefits of coastal protection provided by mangroves and canopy density owing to the lack of literature that shows otherwise. In other words, it is assumed that an increase in canopy density leads to a proportional increase in the benefits of coastal protection provided by mangroves. The average values of canopy density for each of the mangrove categories (i.e. 85 percent for 'very dense'; 55 percent for 'moderately dense'; 25 percent for 'open') are used to scale the storm protection value of 'moderately dense' mangroves up to the storm protection value of 'very dense' mangroves and down to the storm protection value of 'open' mangroves (for example, value of 'very dense' mangroves = value of 'moderately dense' mangroves * (85/55)).

As mentioned in the introduction, the Das study converts the one-time super cyclonic storm protection value estimated for Kendrapada District to an annual value by multiplying this one-time value with the probability of occurrence of very severe storms in Odisha over the last three decades, which is 20 percent. Using the same annual value for all States implies that the probability of a 30-year very severe storm occurring in any given year in all other coastal States is also 20 percent. This will not be the case as we already know that cyclone activity is more frequent and intense over the East-Coast of India, when compared to the West-Coast. Accounting for the differences in the probabilities of occurrence across States is therefore imperative. In order to do this, the annual probability of occurrence of severe storms in each State is estimated using data on the number of severe cyclonic storms occurring in the past thirty years. This is then multiplied with the one-time storm protection value as estimated in Das's study to estimate the annual storm protection value for each State.

The all-India coastal protection value of mangroves is estimated as follows:

$$V_{ij} = V^* \times p_i \times \frac{CD_j}{CD_{md}} \times SF_i \times A_{ij} \quad (10.2)$$

$$\sum_{i,j} V_{ij} = V_{AI} \quad (10.3)$$

Where, V^* is the one-time value of storm protection service as estimated in Das's study (in Rs./ha), p_i is the probability of a 30-year severe cyclonic storm occurring in any given year, i is the State/UT in question, CD is the mean canopy density (percentage), j categorises mangrove cover- very dense, moderately dense and open, CD_{md} is mean canopy density of the moderately dense mangrove cover category, i.e. 55 percent, SF_i is the State-wise scaling factor and A_{ij} is the mangrove area (in ha) of State i under mangrove cover category j. Summing values across States and mangrove cover categories (the V_{ij}s) gives the all-India value (V_{AI} in Rs./yr).

The reference district (i.e. the base b) in equation (10.1) refers to Kendrapada District since V^*corresponds to the storm protection value estimated for mangroves in this district in Das's study. Thus, the values on the denominator of (10.1) all correspond to values for Kendrapada District. However, owing to the large differences in particularly the *pcNSDP* between Kendrapada District and the coastal States, leading to an upward bias in the *SF* for all i, we also used the values of Odisha as the base values for comparability. This gives us two values for V_{AI}. Further, two variables for *WS*, namely the maximum wind speed and the probable maximum wind speed, were used to check for consistency across physical cyclone characteristics thus expanding the range of values estimated for V_{AI} to four. The minimum, maximum and average V_{AI} values of this range are reported in the results section below. A GDP deflator was used to convert all values to 2012-13 Rupees.

10.2 Data Sources

The data on State-wise physical characteristics on cyclone activity come from the Vulnerability Atlas (BMTPC, 2006). Regional/district averages were used to represent State-level values. The probable maximum wind speed for the West-Coast States was not estimated by the Atlas, except for Gujarat, therefore this value was used for the rest of the West-Coast States and Daman and Diu. Similarly the data for the probable maximum wind speed and probable maximum surge height for Andaman and Nicobar Islands is missing thus East-Coast State averages were used instead.

The historical data on the number of severe cyclonic storms occurring in the past thirty years (from 1983-2013) in each coastal State comes from the Cyclone eAtlas (IMD, Version 2.0 web based application). This data corresponds to the number of cyclonic disturbances that had the highest intensity during their crossing from sea to land (as opposed to the number of cyclonic disturbances that had the highest intensity during their entire life-cycle). The former type of cyclone intensity is more relevant for this analysis since the coastal region, where mangroves are usually found, occurs at the intersection of the sea and land. The eAtlas reports data for Goa and Maharashtra (Konkan) together. Since no severe cyclonic storms have occurred in Goa, Maharashtra, Karnataka and Kerala over the past thirty years, the past 100-year storm frequency data was used to estimate the annual probability of occurrence. Moreover, a 1-in-100 year storm frequency was assumed for Karnataka and Kerala since no severe cyclonic storms have occurred in these two States over the past 100 years (from 1913-2013). Since this data is not available for the UTs of Andaman and Nicobar Islands and Puducherry, and Daman and Diu, the respective East- and West-Coast average 30-year frequencies were used instead for these UTs.

Data on the per capita Net State Domestic Product (at constant 2004-05 prices) are from the Central Statistical Organisation (available from State economic surveys or the RBI/ IndiaStat websites). The pcNSDP of Goa was used for Daman and Diu since this information is missing for the latter UT. Data on the per capita Net District Domestic Product for Kendrapada District comes from the Odisha State Economic Survey 2013-14 (Government of Odisha, 2014). The most recent data point was for the year 2010-11, hence all pcNSDP values also correspond to 2010-11 and were converted to 2012-13 values using a GDP deflator (annual percentage, base year is 2004-05), data for which was obtained from the World Bank's World Development Indicators Database (available online).

Data on mangrove area disaggregated by States/UTs and the three categories of mangrove cover (very dense, moderately dense and open) is from the most recent India State of Forest Report (FSI, 2013).

Table 10.1: Data on Variables Used in the Analysis

State/ UT	***Mangrove Area (ha)***				***Probability of storm occurrence (%/yr)***	***Max. wind speed (m/s)***	***Probable max. wind speed (m/s)***	***Probable max. surge height (m)***	***pcNSDP 2010-11 prices (Rs.)***
	Very dense	***Moderately dense***	***Open***	***Total***					
Andhra Pradesh	0	12,600	22,600	35,200	30	50.0	78.0	5.0	37,708
Goa	0	2,000	200	2,200	3	39.0	64.0	4.5	1,04,769
Gujarat	0	17,500	92,800	1,10,300	7	47.0	64.0	4.1	53,813
Karnataka	0	300	0	300	1	39.0	64.0	4.5	40,332
Kerala	0	300	300	600	1	39.0	64.0	4.0	49,391
Maharashtra	0	6,900	11,700	18,600	3	41.5	64.0	4.5	59,037
Odisha	8,200	8,800	4,300	21,300	20	50.0	64.0	6.8	23,968
Tamil Nadu	0	1,600	2,300	3,900	27	45.3	64.0	5.9	53,507
West Bengal	99,300	69,900	40,500	2,09,700	13	50.0	78.0	12.5	32,299
Andaman & Nicobar Is.	27,600	25,800	7,000	60,400	23	44.0	71.0	7.5	54,765
Daman & Diu	0	14	149	163	3	47.0	64.0	4.3	1,04,769
Puducherry	0	0	100	100	23	46.5	68.7	3.8	79,333
Kendrapada District	8,200	7,900	2,200	18,300	3	50.0	64.0	8.5	17,285

The data on the variables used in the analysis is presented above in Table 10.1. Among the States, West Bengal has the highest total mangrove area and Karnataka, the smallest. Going by the annual probability of occurrence of severe storms, East-Coast States/UTs are more prone to cyclones than their West-Coast counterparts; hence on average they also have higher wind speeds and surge heights than the West-Coast States. Barring Goa and the UTs that have relatively smaller populations compared to the other Coastal States, Maharashtra had the highest per capita NSDP in 2010-11 and Odisha, the smallest, which is considerably smaller than the national average of Rs. 36,202 per person.

10.3 Results and Discussion

The estimated range of storm protection values for mangroves in India are presented in Table 10.2. For the mainland the annual values range from Rs. 412 – 546 billion, for Andaman and Nicobar (the only group of islands with mangrove cover), the annual values range from Rs. 149 – 208 billion. Thus, the all-India annual values range from Rs. 560 – 754 billion, with an average value of approximately 650 billion per year. The storm protection value of Andaman and Nicobar Islands alone seems to contribute almost 30 percent to the total annual all-India storm protection value. This is a significant benefit provided by the mangroves located on the island and strengthens the case for their conservation.

Table 10.2: Value Range for Storm Protection Service of Mangroves in India (in 2012-13 Rs. Billion per Year)

	Minimum	*Maximum*	*Average*
India - Mainland	412	546	477
India - Islands (AN)	149	208	177
India Total	**560**	**754**	**654**

There are currently no other studies that have estimated this value for India at the macro-level, however a ballpark estimate of this value, borrowing the per hectare coastal protection mangrove value from an IUCN study conducted in a province in Thailand and multiplying it by the total mangrove area in India and a factor of '2' to account for other benefits of mangroves that have most likely been left out gives a value of roughly Rs. 710 billion per year, which is quite close to the average value estimated in this study. Note, however, that the year to which the estimate corresponds to is unclear in the IUCN study.

It is important to note that the values estimated in this study only include the storm protection service of mangroves in terms of lives saved, livestock saved and damages to buildings averted. Presumably there are other types of damages that are prevented by mangroves during storms such as damages to agricultural land, public infrastructure etc. As such, the above storm protection values are an under-estimate of the true storm protection values of mangroves in India.

Having said that, we noted in the methods section that using the values of Kendrapada District as the base case may lead to an upward bias in the scaling factors and thus the values estimated for all States. Hence we can expect some cancellation of the upward and downward bias in estimates but it is unclear what the net effect on the final value is likely to be.

The results may be more robust by conducting this analysis using district-level data rather than State-level information. However, information on a number of variables at the district-level is not readily available. This could be a possible way forward for future analyses of this kind.

Chapter 11

VALUE OF CARBON SEQUESTRATION

The capture and storage of carbon that would otherwise be emitted or remain in the atmosphere, or the prevention of carbon emissions produced by human activities from reaching the atmosphere can be defined as carbon sequestration. Marine and coastal ecosystems provide an important function of capturing and storing carbon, which is currently referred to as "blue carbon" to distinguish it from terrestrial sinks of carbon[12]. In addition to abating climate change risks, the sequestration of carbon provides other benefits such as increased soil water holding capacity, better soil structure, improved soil quality, nutrient cycling and reduced soil erosion. The literature on the contribution of coastal and marine ecosystems to mitigating climate change through the sequestration and storage of carbon indicates that these ecosystems are on par with, if not surpass, their terrestrial counterparts (Yee, 2010).

Apart from being a vital source of livelihood to many coastal communities, marine and coastal ecosystems, specifically mangroves, tidal marshes and seagrasses, are systems that are recognized for their role in partially mitigating global climate change through the storage and sequestration of harmful GHGs. Carbon that is "biologically fixed" by marine vegetation and microorganisms, and sequestered by burial in sediments, is secured for millennia if left undisturbed. Despite their global land cover (~0.5% of the sea bed) they sequester and store just as much as their terrestrial counterparts.

11.1 Coastal Ecosystems and Carbon Sequestration

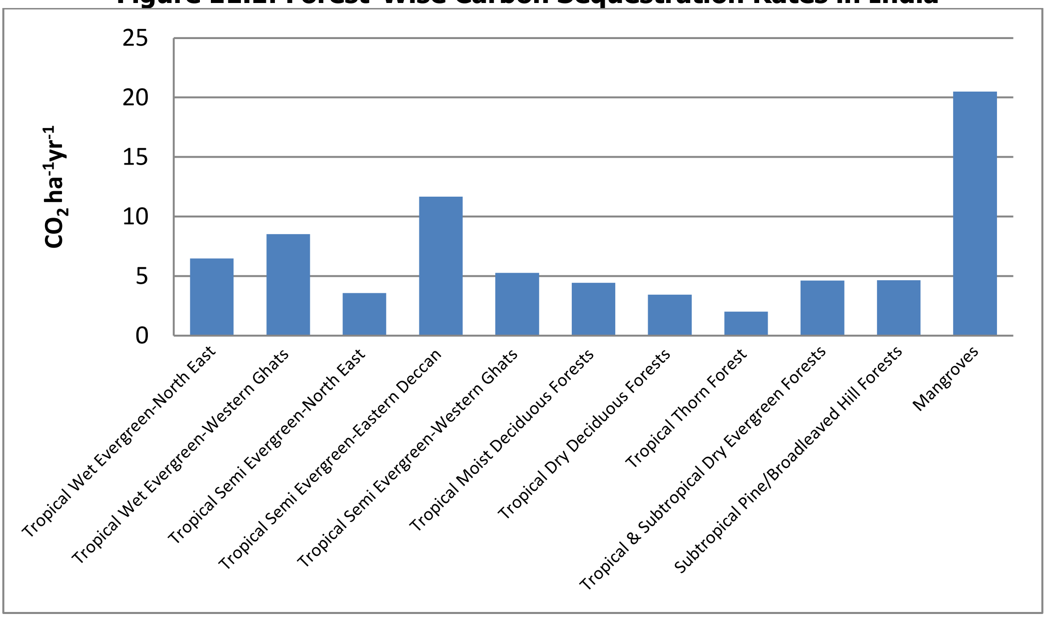
11.1.1 Mangroves

Mangrove forests, currently under threat of land clearing, aquaculture expansion, industrial and infrastructural development, are renowned for providing an array of ecosystem services, including fisheries, fibre, sediment/nutrient regulation, and hazard protection[13]. In addition to such services, mangrove plants are an important natural resource that sequesters carbon thereby reducing the concentration of greenhouse gas emissions in the atmosphere that contribute to global warming. This section discusses the potential monetary value of mangrove biomass in mitigating the impacts of GHG induced climate change.

[12] See 'Blue Carbon – The Role of Healthy Oceans in Binding Carbon' - http://www.grida.no/publications/rr/blue-carbon/
[13] See Mangrove Forests: Threats- http://wwf.panda.org/about_our_earth/blue_planet/coasts/mangroves/mangrove_threats/

Although mainstream efforts to mitigate the impacts of climate change have largely focused on tropical and temperate forests, recent studies have highlighted the importance of coastal and marine ecosystems, particularly mangrove plants, as carbon sinks (Laffoley and Grimsditch, 2009). Mangroves are considered one of the most carbon-rich forests in the Indo-Pacific region. High levels of below-ground biomass (intricate and extensive root systems) and considerable storage capacity of organic carbon in mangrove sediment soils are the main reasons for their high carbon sequestration rates. Figure 11.1 clearly illustrates the differences in the average carbon sequestration rates between mangrove forests and the other types of tropical and sub-tropical forests in India. The CO_2-e sequestration rates were calculated based on aggregated values of very dense forests (VDF), moderately dense forests (MDF), open forests (OF) and scrub forests of a particular type. For instance, mangrove forests sequester 6 times greater carbon per year than north-eastern tropical semi-evergreen forests and tropical dry deciduous forests and 10 times more than tropical thorn deciduous forests. These numbers should potentially provide sufficient incentive to encourage positive conservation and rehabilitation programmes for mangrove forests in the country[14].

Figure 11.1: Forest-Wise Carbon Sequestration Rates in India



Source: Verma et al. (2014).

[14] See for example the 'West Bengal State Action Plan on Climate Change', Government of West Bengal, 2012 - http://www.moef.nic.in/sites/default/files/sapcc/West-Bengal.pdf.

11.1.2 Seagrasses

Among coastal and marine ecosystems, seagrass meadows are one of nature's most effective ecosystems for sequestering (capturing and storing) carbon. Therefore, if the same are sustainably managed, they can contribute enormously to reducing the adverse impacts of climate change. Globally, seagrass meadows occupy less than 0.2 percent of the ocean floor but the proportion of carbon buried annually exceeds 10 percent. The sediments of seagrass meadows are known to have extremely high saturation levels and their rates of carbon sequestration are over 30 times than that of tropical rainforests (Mcleod et al., 2011). Apart from sequestering and storing carbon in the ocean floor, seagrass meadows are essential in providing regulatory services such as improved water quality, sediment stabilisation and nutrient accumulation as well as improving marine biodiversity and habitat.

On the other hand, if seagrass meadows are left unprotected resulting in their degradation, they could counter the efforts against climate change and leak stored carbon back into the atmosphere thus shifting seagrasses from carbon sinks to carbon emitters. This will potentially result in significant economic, social and ecological impacts that may be irreversible.

11.2 Methodology

The direct market pricing approach is used to value carbon sequestration of mangroves and seagrass meadows in India. The basis for estimating the value of carbon sequestration of coastal and marine ecosystems is to consider the sequestration potential of the respective ecosystems, the extent of coverage of the coastal ecosystem, and the market rate or the social cost of carbon. The following empirical function is used to determine the economic value of blue carbon sequestered:

$$VS_i = SQ_i * A_i * C \tag{11.1}$$

where, the value of carbon sequestered (VS) by a particular ecosystem (i) is measured by the product of its rate of carbon sequestration (SQ), measured in tonnes CO_2-e/ha/year, the area (in ha), and the social cost of carbon (C). The range in the final value will depend on the rates of sequestration and the values of the social cost of carbon that are chosen.

11.3 Data Sources

11.3.1 Mangroves

In this report, the state-wise annual rates of carbon sequestration are estimated from total biomass stocks in mangrove forests in different coastal States of India, the data for which comes from Sahu et al. (2015) and is reproduced in Table 11.1 below.

Table 11.1: Biomass Carbon Stock (t/ha) in Mangrove Forests of Different States in India

Location	***Dominant Species***	***Above Ground Biomass (t/ha)***	***Below Ground Biomass (t/ha) T/R= 2.5***	***Total Biomass (t/ha)***	***C-Stocks (tC/ha)***	***Reference***
West Bengal	*S. apetala, E. agallocha and A. alba*	54.41	21.76	76.17	38.05	Mitra et al. (2011)
Andaman Islands	*Rhizophora, Bruguiera and Ceriops forests*	169.00	67.60	236.60	118.30	Mall et al. (1991)
Gujarat	*Avicennia marina*	-	-	49.14	24.57	Pandey & Pandey (2013)
Tamil Nadu	*R. mucronata and A. marina*	88.8	36.82	125.62	62.81	Kathiresan et al. (2013)
Karnataka	*R. mucronata, A. Officinalis and S. alba*	72.00	28.80	100.80	50.40	Suresh et al. (2013)

Note: Above Ground Biomass to Below Ground Biomass (T/R) ratio is between 2 to 3 (Komiyama et al., 2008). Here we have taken the value 2.5. Please see source paper for the full references quoted in the table and accompanying notes.

Source: Sahu et al. (2015).

The mean annual increment in mangrove biomass was estimated from total biomass stock using Von Mantel's formula, which states that the sustained annual yield is equal to twice the growing stock volume of the forest divided by the rotation age of the forest. For the rotation age of mangrove forests, the weighted average rotation period for littoral and swamp forests (averaging across very dense, moderately dense and open littoral and swamp forests), which is 68.67 years is used (Verma et al., 2014). Mean annual biomass increment is converted to an annual rate of carbon sequestration assuming 50 percent of biomass as carbon and 1 tC is equivalent to 3.67 tCO_2 following

IPCC (2003). The estimated State-wise mean annual biomass increment and annual carbon sequestration rates are presented in Table 11.2. Note that for the other coastal States and Union Territories (UTs) for which total biomass figures are not available, the mean annual biomass increment and annual carbon sequestration rate are simply the mean values of all States/UTs for which such data is available.

Table 11.2: Estimated Mean Annual Biomass Increment (t/ha/yr) and Annual Carbon Sequestration Rate (tCO_2e/ha/yr) in Mangrove Forests of Different States in India

Location	*Mean Annual Biomass Increment (t/ha/yr)*	*Annual Carbon Sequestration Rate (tCO_2e/ha/yr)*
West Bengal	2.22	4.07
Andaman Islands	6.89	12.65
Gujarat	1.43	2.63
Tamil Nadu	3.66	6.71
Karnataka	2.94	5.39
Other Coastal States/ UTs	3.43	6.29

Note: Other coastal states/UTs include Andhra Pradesh, Goa, Kerala, Maharashtra, Odisha, Daman & Diu and Puducherry.

11.3.2 Seagrasses

The rates of carbon sequestration for seagrass meadows presented below provide a mean and range of estimates across the different regions of the world. Also, sequestration rates depend on seagrass species that vary within and across regions, sediment characteristics and depth range of the seagrass habitats. The mean value presented below combines estimates from a variety of species and other characteristics mentioned above (Murray et al., 2011).

Table 11.3: Global Averages and Standard Deviations of Carbon Sequestration Rates in Seagrasses

Habitat	*Annual carbon sequestration rate (t CO_2e $ha^{-1}yr^{-1}$)*	*Living biomass (t CO_2e ha^{-1})*	*Soil organic carbon (t CO_2e ha^{-1})*
Seagrasses	4.4 ± 0.95	0.4 –18.3	66 –1,467

11.4 Value of Carbon – The Social Cost of Carbon

The Social Cost of Carbon (SCC) is defined as the estimated monetised value of damages caused by a unit additional tonne of carbon dioxide emissions or its equivalent released into the atmosphere. In other words, SCC denotes the value of avoided damages as a result of a unit reduction of carbon dioxide or its equivalent emissions. Most economists and climate scientists often consider the SCC as an underestimated value of the damages caused as a result of climate change impacts.

The social cost of carbon is meant to be a value that signifies the magnitude of ecological and economic damages caused by the effects of climate change such as rising sea levels, rising atmospheric temperatures and increased incidents of natural hazards including floods, droughts and storms (Greenspan and Callan, 2011). Some of the key variables, determined by climate change science and economic theory, which constitute the value of SCC include net agricultural productivity, infrastructural damage and loss of human life[15].

The estimation of SCC is achieved using complex economic modelling procedures (commonly known as integrated assessment models) requiring substantial climate and financial data (Kelly and Kolstad, 1998). These models, such as MERGE, IMAGE, FUND and DICE, attempt to simulate real-world scenarios that observe costs and benefits imposed on society through the inter-linkages between ecological and economic processes. However owing to limitations with the modelling framework, data availability and accuracy, the likelihood of underestimating the true value of SCC is significantly large. Apart from certain ecological and economic impacts, monetising wider social impacts such as civil instability, mass migration and resource related conflicts are seldom considered in the estimation of SCC. Nonetheless, the SCC is a useful measure to assess the benefits of greenhouse gas reductions.

Generally, the SCC may inform policy makers, on the one hand, of the effectiveness of their climate change policies or regulations in terms of the mitigated damage costs through reductions in carbon emissions, or on the other hand, of the estimated monetary value of damages of a pro-industrial policy that may cause carbon emissions to exceed a sustainable level (Jerath et al., 2012).

Authors such as William Nordhaus, Chris Hope, Nicholas Stern and Richard Tol have significantly contributed to the large body of SCC literature. Ding et al. (2010) assessed a range of SCC estimates that are derived from the European funded CASES (Cost Assessment for Sustainable Energy Systems) project. The values ranged between $119/tC in 2000 to $213/tC in 2030. Chiabai et al. (2009) also used the CASES model to derive estimates of SCC for the years 2007 and 2050 which were $9/tC and $32.5/tC

[15] See http://www.epa.gov/

respectively. Nordhaus (2007) used the Dynamic Integrated model of Climate and the Economy (DICE) to estimate the value of SCC to be about (in 2005 prices) $29/MtC if atmospheric concentrations of CO_2 in 2100 are twice that of pre-industrial times, $31 if average temperatures grew by 2.5^{o}C and $27 if there are no emission limitations. A meta-analysis of 311 published estimates carried out by Tol (2011) affirms the levels of uncertainties in estimates. The mean estimate of all studies was $177/tC with a modal estimate of only $49/tC. The mean and modal estimates for SCC in peer reviewed studies are $80/tC and $26/tC respectively which are significantly lower than non-peer reviewed studies. Differences in SCC values are attributed to the different pure rates of time preference or discount rates, estimates of CO_2 emissions, rate of global warming, population and economic projections and the overall models used (Tol, 2008).

A report by The Indian Institute of Forests (Bhopal) was recently submitted and approved by the Ministry of Environment and Forests (Government of India) wherein ecosystem services of Indian forests such as timber, bamboo, fodder, fuel wood, non-wood forest products, bio-prospecting, carbon sequestration, carbon storage, soil conservation, water recharge, pollination, and water purification were appropriately estimated (Verma et al., 2014). For the purposes of monetising carbon sequestration and carbon capture values of forests, Nordhaus' (2011) paper on estimating the social cost of carbon was used. Nordhaus, in his paper, used an updated version of the RICE-2011 model to estimate the social cost of carbon for multiple countries. Table 11.4 presents the range of social costs of carbon and carbon dioxide for India specifically.

Table 11.4: Social Cost of Carbon for India in 2005 US$

Model Year	***Base Run Social Cost***			***Low Discount Run Social Cost***		
	2015	***2025***	***2035***	***2015***	***2025***	***2035***
1 Tonne Carbon	7.98	16.91	26.03	20.11	37.17	53.13
1 Tonne CO_2	2.17	4.60	7.09	5.47	10.12	14.47

Note: All estimates in 2005 US$.
Source: Nordhaus (2011).

Table 11.5: Social Cost of Carbon for India in 2013 US$

Model Year	***Base Run Social Cost***			***Low Discount Run Social Cost***		
	2015	***2025***	***2035***	***2015***	***2025***	***2035***
1 Tonne Carbon	9.26	19.62	30.19	23.33	43.12	61.63
1 Tonne CO_2	2.52	5.34	8.22	6.35	11.74	16.79

Note: All estimates have been converted to 2013 US$ using http://stats.areppim.com/

Table 11.6: Social Cost of Carbon for India in 2013 Indian Rupees

Model Year	***Base Run Social Cost***			***Low Discount Run Social Cost***		
	2015	***2025***	***2035***	***2015***	***2025***	***2035***
1 Tonne Carbon	541.16	1146.61	1764.34	1363.43	2519.98	3601.72
1 Tonne CO_2	147.27	312.08	480.39	371.10	686.10	981.23

Note: All estimates have been converted to Indian Rupees using the average 2013 US Dollar exchange rate of Rs. 58.44 (obtained from *http://www.oanda.com/currency/average*).

The range of values that has been chosen as the average social cost of carbon (CO_2) is the average of the low discount run social costs (Rs. 680 per tonne CO_2) and the average of the base run social costs (Rs. 314 per tonne CO_2) for the years 2015, 2025 and 2035.

11.5 Results and Discussion

The State-wise estimates of the value of carbon sequestration by mangroves are presented in Table 11.7. West Bengal has the highest mean value (Rs. 0.42 billion per year), followed by Andaman Islands (Rs. 0.38 billion per year).

Table 11.7: State-Wise Value of Carbon Sequestration by Mangroves (in 2013 Rs. Billion per Year)

Location	***Mangrove Area (ha)***	***Value of carbon sequestered (Rs./ha/yr)***			***Value (Rs. billion/yr)***		
		Low	***High***	***Mean***	***Low***	***High***	***Mean***
West Bengal	209700	1278	2768	2023	0.268	0.581	0.424
Andaman Islands	60400	3971	8599	6285	0.240	0.519	0.380
Gujarat	110300	825	1786	1305	0.091	0.197	0.144
Tamil Nadu	3900	2108	4565	3337	0.008	0.018	0.013
Karnataka	300	1692	3663	2678	0.001	0.001	0.001
Other Coastal States/UTs	78163	1975	4276	3126	0.154	0.334	0.244
India – Total	**462763**				**0.76**	**1.65**	**1.21**

Note: Data on mangrove area comes from FSI (2013). 'Low' refers to value based on the mean base run social cost (Rs. 314/tCO_2), 'High' refers to value based on the mean low discount run social cost (Rs. 680/tCO_2) and 'Mean' refers to the average of those two values.

The estimated range of carbon sequestration values for mangroves and seagrasses in India are presented in Table 11.8.

Table 11.8: Value Range for Carbon Sequestration Service of Mangroves and Seagrasses in India (in 2013 Rupees)

Habitat	***Annual carbon sequestration rate (tCO2e/ha/yr)***	***Area (in Hectares)***	***Average Social Cost of Carbon (Rs./t CO_2)***	***Economic Value of Carbon Sequestration (in Rs. '000s)***
Seagrasses	3.55 – 5.35	11,140	314 - 680	12,417 – 40,527
Mangroves	2.63 – 12.65	4,62,763	314 - 680	7,61,929 – 16,50,037

Note: Seagrass area includes 25.9 sq. km. in the Lakshadweep Islands (Nobi et al., 2012) and 85.5 sq. km. in the Gulf of Mannar, Tamil Nadu (Venkataraman et al., 2012). Value range of annual carbon sequestration rate of mangroves is based on the lowest and highest value among all states as in Table 11.2.

The carbon sequestration service of seagrasses is valued anywhere between Rs. 12 and Rs. 40 million. The carbon sequestration service of mangroves in India is currently valued between Rs. 0.76 and Rs. 1.65 billion depending on the range of carbon sequestration rates and the average social cost of carbon considered. Verma et al. (2014) estimated the annual per hectare carbon sequestration values of littoral and swamp forests in India as Rs. 8,736 for very dense forests, Rs. 3,729 for moderately dense forests and Rs. 1,207 for open forests. Applying these values to mangrove area (from FSI, 2013) within these canopy density classifications gives the total carbon sequestration value for mangrove forests in India as Rs. 1.94 billion per annum. This value is in the ballpark of the carbon sequestration value estimated for mangroves in this study (i.e. mean of Rs. 1.21 billion) albeit slightly higher, which is expected since the Verma et al. per hectare value was estimated for all littoral and swamp forests in India, whereas the value estimated in this study is for mangrove forests alone.

Chapter 12

VALUE OF COASTAL RECREATION

The economic importance of coastal zones lies in the fact that they provide livelihood support to fishers, and provide benefits of commerce, navigation and recreation. Coastal and Marine fishing produced 3.32 million tonnes and inland fishing contributed 5.72 million tonnes of fish catch together contributing Rupees (₹) 780.53 billion to the GDP (at current prices) during 2012-13 (GoI, 2015).

Coastal and marine ecosystems provide numerous benefits some which are use values and some are non-use values received by society either directly or indirectly for its benefits. This section focuses on the estimation of the consumer’s surplus from recreation alone. This chapter, as a part of this effort, provides estimates of net benefits of recreational services from coastal and marine ecosystems[16].

12.1 Methodology and Data

In an earlier attempt to value recreational values at the national level, Mukhopadhyay and da Costa (2015) had used the price-quantity product measure to arrive at an estimate of WTP which was Rs. 531.7 billion. If one were to borrow the value per hectare of recreational benefits from coastal ecosystems as used by Costanza et al. (1997), (which is $ 82/ha/year at 1994 prices) and multiply this with the area under coastal zone for each state (adjusted for 2012-13 prices) we arrive at a comparable value of Rs. 441.7 billion (see Table 12.1). In contrast to these estimates, this paper uses an econometric model to estimate the consumer’s surplus which is a methodological improvement to Costanza et al. (1997) and Mukhopadhyay and da Costa (2015). We also find that a revision of estimates (of Mukhopadhyay and da Costa, 2015) yields Rs. 453 billion as actual expenditures. This is remarkably close to the benefit transfer value discussed earlier, though the state-wise estimates differ.

12.1.1 Model of Zonal Travel Cost Method

The Zonal Travel Cost model assumes that N_i is the estimated number of visitors from zone ‘i’ and P_i is its total population. Then visitation rate for zone ‘i’ is defined as

$$V_i = (N_i / P_i) \quad (12.1)$$

[16] This chapter is a shortened version of a revised report submitted to NCSCM. See Mukhopadhyay et. al. (2016) for the full report.

The average travel cost from each zone is calculated depending on data available. Typically, if a survey was being carried out then it would be collected from the sample of visitors being interviewed from that zone. The travel cost is calculated 'per visitor' inclusive of all actual expenses from the visitor's originating point, entry-fee (if any) as well as his/her opportunity cost of time. If T_i is the average travel cost from zone 'i', then visitation from zone 'i' (V_i) is supposed to be functionally related as

$$V_i = f(T_i, Z_i) \quad (12.2)$$

where, Z_i is a vector of variables characterizing each zone that could affect V_i.
The relationship between V, T and Z is known as the Trip-Generating Function (TGF). Demand function for each zone can be obtained by putting the corresponding value of Z_i in the estimated TGF. The aggregate demand can be obtained as the sum of zonal demands.

The value of the recreational services offered by the site is the Consumer Surplus (CS) of the visitor, estimated as the area under the demand curve and above the price-line representing visitors' actual travel cost.

12.1.2 Data

This study relies on secondary data and this is put together from various sources—like the Tourism departments, Reserve bank of India, World Bank, Census etc. Given the limitations of data availability, numerous assumptions have also been made to fill in the data gaps while ensuring the reasonableness of the assumptions.

A. **Estimation of travel expense:** This value was obtained by multiplying the distance from the state of origin to the most visited recreation site of the host state by the cost per unit (kilometer) travelled. The per kilometer rate of travel was assumed to be Rs. 4/km.

B. **Expense on Accommodation and food, etc.:** Data is available from different sources on the number of days/nights overnight visitors spend in the host state and how much on average a visitor spends there. We multiplied this figure with the per capita income of the origin state to adjust for differences in expenditure patterns.

C. **Opportunity cost:** We have used the per capita income for 2012-13 for each originating state and multiplied it by the number of visitors to the host state.

Since there is a wide range of incomes earned within each state, the fractioning of incomes is likely to have been achieved by taking the average of income of the state.

The sum of three things: travel expenditure (from origin to destination and back), the opportunity cost (income foregone during duration of visit) and on-site local expenditure (on hotel and food, etc.) constitutes the travel cost of a visitor. All the prices and money values are adjusted to be valued at current prices of 2012-13. Wherever visitors' data from any originating state was missing we substituted it with values from their respective nearest neighbour (considering distance from destination state). We find that this actual travel expenditure amounts to Rs. 453 billion (see Table 12.1).

12.2 Empirical Estimation

Secondary data on per-capita average income is available and therefore used as a regressor.

The estimation of the TGF is done as a panel data model with random effects. In doing so, the thirty four originating zones were considered as cross-section observation points and the nine destination states were considered as "time" points. In this special 'panel' set up, the regressors (characteristics of originating states like percentage of urban population and percentage of poor etc.), do not show any variability for different destination states. However, the visitor chooses his/her destination randomly and so the TGF estimation is done using a random effect model.

The specific econometric model used for estimation is set up below:

$$Visitation\_Rate_{ij} = \beta_0 + \beta_1 TravelCost_{ij} + \beta_2 Poverty_{ij} + \beta_3 Urban_{ij} + \psi_{ij} + \varepsilon_i \qquad (12.3)$$

where,
"ψ" and "ε" represent the error term as discussed earlier,
i= Origin State of visitor,
j= Destination state of visitor
Travel Cost= Cost of travel including expense on travel, accommodation and opportunity cost
Poverty= Poverty rate (Proportion of people living under poverty line)
Urban=Urbanisation rate (Proportion of people living in urban areas)

In Equation (12.3) above, "β_1", "β_2" and "β_3" represent the impact of Travel Cost, Poverty and Urbanisation on the number of visitors, respectively. Thus, the partial effect of travel cost on visitation rate can be separated out from other factors that influence visitation.

12.3 Results and Discussion

The estimates of CS for each state are presented below (Table 12.1). Our estimates suggest that the extent of ecosystem services (CS) on account of recreation is about Rs. 3803 billion in 2012-13 prices. These are net benefits over and above what is recorded in the National Income accounts. The consumer's surplus generated is 4.5 percent of India's national net domestic product. Since we do not have any other study in India against which to benchmark our estimates we are unable to say whether our estimates are high or low at this point.[17] Interestingly, Kerala is able to generate the maximum CS followed closely by Tamil Nadu and Gujarat (see Table 12.1).

Table 12.1: Estimates of Recreational Value (Travel Cost) of Nine Coastal States in India

Sr. No.	***Name of State***	***Estimated CS (Billion Rs.) originating from all India and the Rest of the World in 2012-13***	***Estimated CS (Billion US$) originating from all India and the Rest of the World in 2012-13 (Rs. 62.7=$1)***	***Average Travel Cost per person in Rs in 2012-13 prices***	***NSDP at Current prices in 2012-13 in Rs. billion***	***Consumer's Surplus as percentage of NSDP (%)***	***Benefit Transfer Measure (Recreational Values) in 2012-13 in Rs. billion*** *(Costanza et al. 1997)*	***Total Travel Expenditure in 2012-13 in Rs. billion*** *(Travel + Accommodation + Opportunity Cost)*
1	Andhra Pradesh	485.84	7.75	15020	6718	7.2	50.8	64
2	Goa	224.61	3.58	22174	341	65.8	10.7	63
3	Gujarat	507.97	8.10	14657	6027	8.4	106.8	52
4	Karnataka	250.67	4.00	19784	4650	5.4	45.9	14
5	Kerala	561.11	8.95	33838	3174	17.7	14.6	70
6	Maharashtra	449.07	7.16	13751	12391	3.6	32.2	60
7	Odisha	333.14	5.31	17116	1769	18.8	36.7	39
8	Tamil Nadu	542.25	8.68	13712	6005	9.0	81.2	53
9	West Bengal	448.77	7.16	12923	4871	9.2	62.3	38
	Total	**3803.42**	**60.69**				**441.4**	**452.92**

Note: Exchange rate used is Rs 62.7: $1 (www.xe.com). Rounded to the nearest one decimal place.

If we compare the CS measures with respect to the coastal states' NSDP, the ratio of CS/NSDP in the nine destination states is highest for Goa (which is an outlier)

[17] In 2012-13, the contribution from "Hotels and Restaurants" in India to GDP was Rs. 1360.8 billion when India's GDP was estimated at Rs. 93888.76 billion.

and is followed by Odisha and Kerala. The reason for Goa to have such a large ratio could be that (a) it has a large tourist visitation in comparison to its own state's population, and (b) it also derives a large proportion of its income from tourism.

Note that in order to compare the coastal recreation value with the rest of the coastal ecosystem service values estimated in this study, the coastal recreation value comprising of total travel expenditure only (the price times quantity value, i.e. Rs. 453 billion) is used rather than the consumer surplus value since the latter was not estimated for other services.

Chapter 13

CONSOLIDATED VALUES AND DISCUSSION

The current macro-economic valuation exercise estimates the benefits derived from a wide range of coastal and marine ecosystem services including provisioning services such as, marine fisheries, seaweeds, coastal minerals, coastal salt, seawater desalination, seawater used for industrial cooling and coastal shipping; regulating services such as, coastal protection and carbon sequestration; and, recreational services such as, coastal tourism. The estimates of coastal and marine ecosystem services in India for the year 2012-13 are presented in Table 13.1.

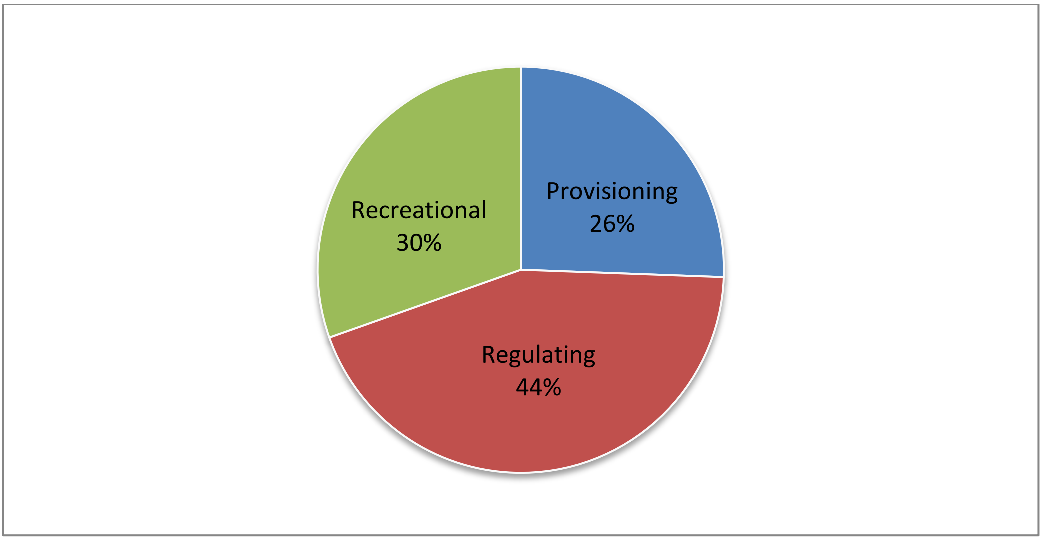
Table 13.1: Values of Coastal and Marine Ecosystem Services in India for the year 2012-13 in Rs. Billion

S. No.	*Service Valued*	*Method of Estimation*	*Value Range Min.*	*Value Range Max.*	*Average Value*
I.	**PROVISIONING SERVICES**				
1.	Marine Fisheries	Direct Market Pricing	-	-	294.48
2.	Seaweeds	Direct Market Pricing	-	-	0.09
3.	Coastal Minerals	Direct Market Pricing	-	-	12.47
4.	Coastal Salt	Direct Market Pricing	-	-	12.40
5.	Seawater Desalination	Direct Market Pricing	18.01	22.21	20.11
6.	Seawater – Industrial Cooling	Direct Market Pricing	2.58	4.76	3.67
7.	Coastal Shipping	Avoided Cost	15.88	63.80	39.84
	Total Provisioning		**-**	**-**	**383.06**
II.	**REGULATING SERVICES**				
8.	Coastal Protection (Mangroves)	Benefit Transfer	560.38	754.04	653.98
9.	Carbon Sequestration (Mangroves)	Direct Market Pricing	0.76	1.65	1.21
10.	Carbon Sequestration (Seagrasses)	Direct Market Pricing	0.01	0.04	0.03
	Total Regulating		**561.16**	**755.73**	**655.21**
III.	**RECREATIONAL SERVICES**				
11.	Coastal Recreation	Travel Cost	-	-	452.92
	Total Recreational		**-**	**-**	**452.92**
	GRAND TOTAL				**1,491.19**

The total value of the provisioning services estimated amounts to Rs. 383 billion. The total value of the regulating services estimated is roughly 1.7 times that of the provisioning service value at Rs. 655 billion with a value range of Rs. 561 – 756 billion. The total coastal recreational value is estimated at Rs. 453 billion. The total value of coastal and marine ecosystem services in India is approximately Rs. 1.5 trillion, of which provisioning services account for 26 percent, regulating services account for 44 percent and coastal recreation accounts for 30 percent of the total value (see Figure 13.1). The estimated mean total coastal and marine ecosystem service value for India (Rs. 1.5 trillion) is approximately 3.2 percent of Net National Product (NNP)[18]. The coastal ecosystem service value is similar to that estimated by World Bank (2013), i.e. 1.4 trillion in 2009. However, the World Bank estimate includes ecosystem services from several biomes including coastal ecosystems. Among the various ecosystems and the services valued in the World Bank study, wetlands, including coastal wetlands, account for the highest percentage (48 percent) followed by coral reefs (22 percent). As also noted in the introductory chapter, Mani et al. (2012) estimated the total annual cost of environmental degradation in India at 3.75 trillion rupees, equivalent to 5.7 percent of gross domestic product in 2009. It may be noted that although the atmosphere provides provisioning ecosystem services in the form of clean air and water, the ecosystem service valuation exercises (including the present study and the World Bank study) do not typically account for such services. This partly explains the divergence between cost of environmental degradation and value of ecosystem services estimated for India in the present study as well as in the World Bank study.

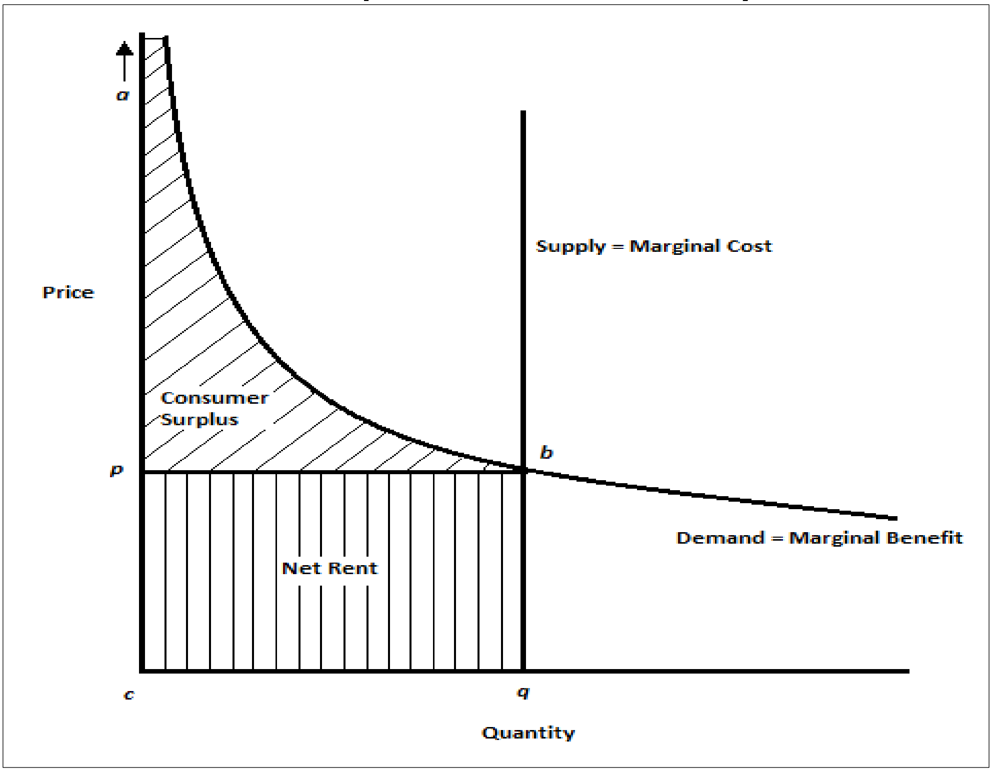
[18] NNP at factor cost (in constant 2004-05 prices) in 2012-13 is Rs. 47,288 billion (RBI statistics).

Figure 13.1: Percentage Share of Types of Services in Total Coastal Ecosystem Service Value for India in 2012-13



The total coastal ecosystem service values estimated in this study are underestimates since they do not include the consumer surplus value. Costanza et al. (1997) note that the ecosystem service value is represented by its total economic value, which is nothing but the sum of the consumer surplus and the producer surplus (or net rent) excluding the cost of production. Consumer surplus is the welfare the consumer receives over and above the price paid, and the producer surplus is the welfare the producer receives over and above the cost incurred. The sum of the consumer and producer surplus is depicted by the shaded areas in Figure 13.2 that shows the supply and demand curves for some essential ecosystem services. Most of the values estimated in this study are price times quantity estimates, which would be represented by the area *pbqc*. For a normal good, i.e. a man made and substitutable good, the price times quantity estimate includes the cost of production. Costs have not been subtracted from the values estimated in this study and hence are greater than the producer surplus value. For an essential ecosystem service that is not easily substitutable (as in Figure 13.2), there are no costs involved, thus the price times quantity estimate represents the producer surplus value. Costanza et al. (1997) note that total economic value can be greater or less than the price times quantity estimates, however they also note that price times quantity estimates may be used as a proxy for the economic value of the service, assuming that the demand curve for the ecosystem service looks like that in Figure 13.2 (wherein the demand approaches infinity as the quantity available approaches zero or some minimum necessary level of services). This implies that the price times quantity value, i.e. the area *pbqc* is a conservative underestimate of the area comprising of both the consumer and the producer surplus. Therefore, given that most services valued in this study are price times quantity estimates, they represent an underestimate of the total economic value of the ecosystem service. In the case of one ecosystem service, namely coastal recreation, where both price times quantity valuation and consumer surplus valuation was undertaken, the price times quantity valuation is more than eight times lower than the consumer surplus value. And yet at the same time, since in the direct market pricing method followed, the inputs costs were not subtracted from the final values, the estimates in this study could be upwardly biased. Overall, the first-cut values of coastal ecosystem services in India that are estimated in this study could be upwardly revised in due course with improvements in the valuation methodologies and inclusion of more ecosystem services.

Figure 13.2: Supply and Demand Curves, showing the definitions of Net Rent and Consumer Surplus for some Essential Ecosystem Services



Source: Adapted from Costanza et al. (1997).

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