A framework of indicators of potential coastal vulnerability to development

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Abstract

This paper presents a framework of indicators of coastal vulnerability to development-related activities in India. The main objective of this exercise is to enable policy makers and others involved in coastal management develop a sense of the vulnerability of coastal regions in India and to examine the links between anthropogenic activities and the health of coastal ecosystems. This framework helps us to identify:

- *Key development pressures with the potential to affect coastal ecosystems,*
- *Where development driving forces are most strong;*
- *Where coastal ecosystems are most affected*
- *Coastal districts that have heavy development pressures as well as stressed ecosystems.*

The results list coastal districts in India in order of priority for intensive study aimed at improving coastal planning and suggesting management interventions. The indicators suggested could be used to design coastal monitoring systems, which can help develop more sophisticated socio-economic and environmental indicators for the coast.

Key words: Coastal vulnerability, indicators, development activities, ecosystems

Introduction

Coastal planning and management are constrained largely by a lack of information, data and analysis about the interaction between development activities and the coastal environment. Development activities are agents of change. The extent of impact of these activities at the ecosystem level will depend on the kind of pressure imposed and the extant health of the ecosystem.[1] Knowledge relating to the health of such systems and the kind of development stressor active will enable more careful planning of development activities. This paper reports on a framework of indicators of potential vulnerability developed at the socio-economic and ecosystem level for coastal India. Such an assessment can help improve future coastal management through targeted interventions aimed at stressors and stressed systems. The concern with coastal vulnerability is really a concern for the negative outcomes that may result from the combination of development pressures and stressed ecosystems. Stressed ecosystems will in turn, impinge on the socio-economic and health status of people residing or dependent on the coast

India does not have a specific coastal focus for its development policies. There is an attempt to provide a coastal focus through the use of coastal zoning in order to spatially separate incompatible uses and protect fragile ecosystems. It has on the one hand, policies and plans for sectoral development, and on the other, environmental policies and legislation to protect the environment from such development. Some of these are incompatible. So coastal development occurs with no or little management. There is today an attempt at introducing a notion of integrated coastal management[1], but the meaning of integration is still unclear. There is an urgent need for integrated coastal management in the Indian context with the new development push that globalization forces have created. After 1991, a set of processes was set in motion by which production and consumption activities gradually shifted from the local or national scale to the global. As India globalizes, the impacts of development are increasingly felt in the coastal states through increased multilateral investment, new industry, increased rural-urban migration, and other societal forces. This is already evident in increased levels of investment in the country, and especially in the coastal states of India[2], and more policy

[1] In 1998, the Department of Ocean Development with the assistance of the World Bank took up an infrastructure development and capacity building programme to facilitate adoption of the concept of Integrated Coastal and Marine Area Management (ICMAM) by coastal areas. The programme focuses on development of expertise in ICMAM oriented activities and dissemination of knowledge gained to the coastal areas through organized training programmes.

decisions to gear up the economy to open up and out. The coast has come to assume a special significance, for its logistic advantages, more developed infrastructure, potential for accommodating global tourism, and also supporting export industries such as aquaculture. In this paper, we identify and examine the drivers of change on local coastal ecosystems as a first step towards contributing to more integrated thinking on coastal management issues.

A number of different frameworks have been proposed to measure links between development and the environment. The function these frameworks perform determines where they are placed within the literature on the subject: whether they for purposes of accounting, reporting, and/or to track sustainability.[3] *Accounting frameworks* such as natural and environmental resource accounting frameworks require that national income accounts be adjusted for the cost of using up natural resources and/ or causing environmental degradation. They explicitly quantify and value economic activity and the use of resources in such activities, either through physical or monetary accounts. A sizeable literature exists on the subject (Ahmad, Serafy, and Lutz 1989). More recently, a number of countries have moved in the direction of green accounting and more developments have occurred in theory and practice (Peskin 1996; Chopra and Kadekodi 1997; Uno and Bartlemus 1998).

Reporting frameworks are those that report on environmental, economic and socio-economic conditions. They include economic indicators at the country level by the World Bank in their World Development Reports, social and economic indicators in the UNDP's Human Development Reports, and many different structures and formats on environmental reporting. International organizations have taken the lead in environmental reporting over the last decade (UNEP 1994; OECD 1993; FAO 1997; World Bank 1996, 1997; Hammond 1995). The Condition-Stress-Response framework, first proposed by Statistics Canada, and subsequently modified and adapted by numerous organizations and countries around the world, is particularly adapted to environmental reporting. This was further developed used and popularized by the OECD in 1993 and is known as the Pressure-State-Response (PSR) framework. This framework links human activities, which cause pressures on the environment with changes in the environmental state or conditions. Society then responds to these changes which feed back to mitigate the pressures. The US EPA (1995) has extended this framework. Pressures have been defined more broadly through the inclusion of factors, human and non-human. Second, pressures have been divided into three sub-categories: underlying, indirect, and direct pressures. Underlying pressures include social and demographic forces, technological change, and policies that stimulate economic activities. Indirect pressures include human activities (mostly but not exclusively economic activities) intended to benefit human welfare, as well as some natural processes and forces, such as nutrient cycles, volcanic eruptions, earthquakes, and meteorological events and cycles. Direct pressures include actual biophysical stresses on the environment, such as pollutant releases, resource extraction, and exotic species introductions. Effects, has been added to the basic PSR-type framework, defined as indicators of attributed relationships between two or more pressure, state and/or response variables. This category would contain whatever relationships are well enough understood to make such attributions, derived from modelling and analyses of the connections between the primary variable categories. Corvalan, Briggs, and Kjellstrom (1996) extend this further to develop the Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework for environmental health (Corvalan et. al. 1996). The Commission on Sustainable Development also uses the framework of Driving Force-State-Response to organize its 130 indicators of sustainable development (CSD 1996).

Frameworks to *assess sustainable development* seek to assess the long-term viability of systems, activities or sectors. They include (FAO 1996):

Ecosystem approaches which are based on assessing the performance of a sector according to ecological, economic, and social dimensions and use four criteria for sustainability: productivity, resilience, stability, and equity.

Total factor productivity where systems are deemed to be sustainable when total factor productivity (the ratio of the value of all outputs divided by all inputs, economic and environmental, normalized to remove changes in price) show a non-declining trend. Noronha (2000) shows how impacts from mining can be monitored using environmental, economic, and socio-political indicators.

More directly relevant to this paper, is the World Resources Institute’s index of potential threats to coastal ecosystems due to development-related activities. (Bryant et al. 1995). This index is based on five globally available indicators of human pressure: population density, cities, major ports, road networks, and pipelines. Combining threat results with the locations of a subset of the world's marine protected areas (georeferenced sites located within 100 kilometres of continental and major island coastlines) indicates that over 60 percent of these sites are potentially at high risk from nearby development activities. The Intergovernmental Oceanographic Commission is also currently engaged in the task of understanding the role of indicators for integrated coastal management (IOC/GE-ICAM II/3s, 2001).

Many of the frameworks require an enormous amount of data to be really useful operationally. They work well at the micro level where detailed studies have been done to generate the kind of causal connections required. This may not be possible, however, for development planning at a more general level such as the coastal region of a country. In this paper, we present a more simple approach that is based on the Driver-Pressure-State conceptual frame, but allows us to work with the limitations of data to arrive at a fairly robust idea of where development drivers are strong; where there is potential for the pressures created by such drivers to stress ecosystems; where stressed ecosystems already exist; and therefore by using a simple tool such as a Venn diagram, it is possible to list those coastal areas that have both pressures and stressed systems and which therefore are likely candidates of vulnerability to negative outcomes if left unattended. Once these areas are short-listed, it is possible to have more detailed investigations to assess whether there is indeed a causal connection between identified pressures and ecosystems, or if there are other mechanisms and intermediary systems and processes that mediate to enhance or reduce vulnerability.

Method

The process of developing the indicators followed the steps used by CALFED and is summarized in Figure 1. In addition, a detailed survey of the literature was carried out which provided an account of the influence of development drivers in coastal areas of India. Key characteristics of the drivers and each of these ecosystems were identified through consultation with experts and a literature search. Indicators were developed based on these characteristics. District-specific data for each pressure indicator for each driver were collected. To link ecological and socio-economic data, there is need for a spatial dimension. In this paper, coastal districts were used as the spatial unit of analysis, as the secondary data availability for both ecological and socio-economic data was better at this level. The main sources of information for this were the Centre for Monitoring the Indian Economy (CMIE) Profile of Districts, census books, databases on industry, reports on aquaculture, and government statistics on tourism infrastructure. Data on ecosystems were collected from a number of scientific organizations, state and central government department officials, officials and databases of the Central Pollution Control board and groundwater organizations of several coastal states. Ecosystem specialists of the National Institute of Oceanography and the Goa University assessed the health of the ecosystems.

The indicator databases were used to rank the coastal districts by drivers and stressed ecosystems.This involved two parallel exercises:

1 Ranking the coastal districts according to those which had the most intense operation of the drivers as measured by the pressure indicators. For each driver, an index was constructed by giving equal weights to component indicators. A ranking of districts was obtained, by driver, for all coastal districts.

2 Ranking the coastal ecosystems in these districts according to their level of stress through expert opinion, available secondary data from local bodies and national level databases. Each of these districts was then ranked according to the relative stress levels of the three component coastal ecosystems to arrive at a single index of stress for each district.

The following steps were followed to rank coastal districts with respect to different pressure indicators (using the Borda Rule)[4]:

1 Ranking of all districts by assigning the driver-specific indicators with the highest value the lowest rank.

2 Summing of ranks of all the indicators with respect to each district.

3 Assigning of ranks which correspond to sum of ranks (obtained from Step 2) of different districts by assigning the highest value, the lowest rank.

Thus the district with the highest rank for each of the drivers was the district where this driver was the most important.

Results

An expert workshop held in 1999, identified the following as the main drivers of change in coastal India: Urbanization, Industrial activity, Intensive aquaculture/agriculture, Tourism and Port activity.[5] Urbanization is a continuing process associated with a gamut of factors that underpin the process of economic growth and social change (Bose 1974). It is very much an aspect of economic growth, and more precisely, of investment patterns. An observation found commonly in the literature is that urbanization is both a determinant as well as a consequence of economic development. However, there are certain other policy interventions that can push the urbanization process, such as the spatial mix of development programmes, ad hoc processes such as location policies (the result of these is often urban islands); the political process by which boundaries of existing urban areas are changed arbitrarily to achieve political ends (the National Commission on Urbanisation 1988). In other words, policy, whether economic or political, can drive urbanization. Urban areas in India are characterised by large and populations, and over 75% of the people not working in agriculture. The main pressures for the ecosystems from urbanization arise from the growth of population whether due to migration or natural growth and the consequent increase in demand for water, land, sewerage and other infrastructure. Coastal areas in India are particularly vulnerable to pressures from urbanization, as 25% of its one billion people live along the coast and the migration to coastal areas occurs all the time.

The importance of the industrial sector in the Indian economy has risen over the years. The New Economic Policy (NEP) introduced in 1991 with its package of globalization, liberalization, and privatization changed the entire scenario of the Indian industrial sector. A sharp rise in foreign investment was also witnessed, 55% of which has gone to coastal states (www.westbengal.com). A number of investment proposals are expected to come up on the coast. According to the scenarios of industrial development for India around 305 industrial projects in seven potentially polluting industries are announced, proposed or being implemented in the coastal districts of India (CMIE). Industrial activity is an important driver as it has potential to stress ecosystems with its by-products and its discharges. The impacts can emerge both from resource use and from the environmental loads generated. Locating industry on the coast, especially if these are potentially polluting industries, can, in the absence of effective management systems result in discharge of untreated effluents into nearby creeks, increase the presence of heavy metals in the nearshore waters and increase levels of eutrophication. It can also disturb coastal vegetation and create pressures on the quantity and quality of groundwater.

Intensive agriculture refers to a form of agriculture that is accompanied by a heavy use of inputs in order to increase yield. When India achieved independence, agriculture was not very well developed: the yields per hectare were very low. In 1964, the Indian Government decided to systematically apply science and technology to agriculture. High yielding varieties of crops, which were highly responsive to fertilizers and irrigation, were introduced. This change to an intensive form of agriculture came to be known as the Green Revolution. Hence, agricultural development in independent India occurred in two phases: until the mid-sixties, increase in production was on account of expansion of area under crop production. During and after the mid-sixties, emphasis has been laid on increasing the productivity of land, through increased inputs. Coastal states in India are among the highest users of fertilizers, pesticides, and irrigation.

Aquaculture has become a major economic activity in coastal India. Traditional farming with production levels of around 200-300 kg/ha/year evolved into extensive farming at 750-1500 kg/ha/year, semi-intensive farming at 2.5-5.0 t/ha/year (two crops) and intensive farming with production levels of 5-10 t/ha/year (two crops). The total area under production doubled from about 50,000 (traditional system) to 1000,000 ha during the decade (Rao 1999). Aquaculture in India is mainly linked to shrimp production. The intensive shrimp farms in India are located primarily in the coastal states of Andhra Pradesh, Tamil Nadu, Gujarat, and Maharashtra.

India's external trade is almost entirely dependent on ocean transport through its ports. During the year 1997/98, all the major, intermediate and minor ports together handled a total cargo of 286.3 million tonnes. The major ports alone handled 88% of the total cargo (Paul 1999). Thus seaports play an important role in the development of India's foreign trade and also national economy. India has 12 major ports and 181 minor/intermediate ports. Since the initiation of trade liberalization measures in 1992, port traffic (cargo) has grown at seven to ten percent per annum on an average. This has resulted in port congestion and considerable degradation of coastal waters around the port areas.

Tourism implies large-scale movement of people into a destination–a people who have consumption needs, both basic and those created by the tourist industry. This consumption, both in terms of quantity and in terms of the type of resources that it utilizes, creates a number of impacts and brings about changes in the social structure of local communities, the norms and standards of the host communities, and in the environmental resources that it utilizes (TERI 2000). Coastal tourism is a very important part of tourism in India, with 50% of all tourists to India visiting the coastal states. Kovalam, Goa, and Mahabalipuram, have become major international coastal tourist destinations, Konark, Puri in Orissa, and Kanyakumari in Tamil Nadu also attract considerable tourist attention (Noronha 1995).

In this paper, we have focussed on three coastal ecosystems as the objective of this exercise is to demonstrate the use of this framework and we were limited by data and time. More ecosystems can be added to enrich the framework. The ecosystems considered here are mangroves and dune vegetation, coastal aquifers and nearshore coastal water. These are also typically the ecosystems that are stressed by anthropogenic activity in Indian coastal areas[6] (Voices for the Ocean 1996). Mangroves are generally found in the littoral zones of tropical and subtropical sheltered coastlines. Quite apart from their role as coastal stabilizers and buffer zones, these ecosystems are very highly productive, which enables them to support large artisanal and commercial fisheries. Very recent studies have estimated a mangrove cover of approximately 3,15,000 ha in the country of which almost 80% occurs long the northeastern (Orissa and West Bengal) coast and in the Andaman and Nicobar group of islands. Approximately over 80% (2,67,000 ha) of the total Indian mangrove cover, exists in the deltaic regions, of which 78% occurs in the Ganges (Sunderbans) delta alone (Untawale and Jagtap 1991). The Gulf of Kuchchh and Gulf of Khambat and Kerala coasts, have most degraded mangroves.

Sand dune vegetation has been classified into the pioneer zone, midshore zone and the backshore zone (Desai 1995). The pioneer zone is closest to the sea and the backshore zone is the farthest. The three zones together form a vegetation slope, which acts as a block to the movement of wind and sand. (Desai 1995). Plants on dune systems flourish with the organic matter brought by high waves during storms or heavy winds.

The berm swells due to the aeolian import of sand. Dune vegetation traps sands and thereby increases the amount of sand in the dunes. Sand dunes play a vital role in protecting the coast from erosion and flooding. One of the important factors in dune stability is the cover it provides. The number of dune vegetation species on India's west coast is almost double that on the east coast. The maximum number of species is reported from Tamil Nadu (113), followed by Kerala (107), Maharashtra (84), Andhra Pradesh (76) and Saurashtra (60).[7] In Goa there are 59 species (Desai 1995). Reviews of the state of the groundwater quality in India suggest that this quality is deteriorating and the quantity of ground water stored in coastal aquifers is fast diminishing (Chachadi and Raikar 1999). The majority of the aquifers in the coastal areas are unconfined and consist of highly permeable sands and gravels which allow easy movement of contaminants from surface sources. Anthropogenic activities are seen to be the causes for this deterioration.

The literature survey enabled the identification of the main characteristics of the drivers. These are given in the chart below.

Chart 1 Characteristics of drivers

Driver	Characteristic
Urbanization	Population density, workforce in non agricultural sectors
Tourism	Tourism infrastructure, tourist arrivals,
Intensive agriculture/ aquaculture	Extent of cultivated land, extent of irrigated land, fertilizer consumption, area under aquaculture
Industry	Number of potential polluting industrial units as per CPCB criteria
Port activity	Cargo handled

Based on these characteristics, it was possible to identify the pressure indicators and their significance to the environment:

- Persons/square km (population density) captures threats from coastal development, sewage, land cover clearance, ground water depletion, and overexploitation of resources.
- Density of tourist rooms (tourist infrastructure) captures the threat to land use and land cover, ground water depletion, water and beach pollution from recreational activities

- Area under intensive aquaculture captures threats to mangrove clearance, land use change (e.g., agriculture), saline intrusion into coastal aquifers, eutrophication, threats to wild stock
- Fertilizer use/ha, cultivated area, irrigated area captures potential threats of eutrophication, groundwater depletion, soil degradation, and land cover change.
- Number of potentially polluting industrial units located captures threats from industrial pollution, land cover change, and ground water depletion
- Total cargo handled at ports measures potential threats from oil spills and impacts on marine life; from species introduction through release of ballast water and need for port extension and consequent impact on marine life.

The key characteristics for each of the ecosystems of our study are given in the chart below.

Chart 2 Characteristics of ecosystems

Ecosystem	Characteristic/attribute
Coastal water	Water quality
Groundwater	Water quality and quantity
Mangrove vegetation	Area covered, trends in composition and abundance

The state indicators are based on the characteristics of the ecosystems or surrogates that provide information on the condition of the ecosystems. The following were used for this study:

- Coastal water: (physical, chemical, biological parameters)
- Coastal aquifers: (physical, chemical, biological parameters)
- Mangroves/dune vegetation: (basal area covered, number of species, canopy cover)

To assess the state of ecosystems (groundwater, mangroves, coastal waters) in the coastal districts, the following indicators were used to grade coastal ecosystem health:

- Coastal water: levels of DO, BOD, pH, colour and odour, floating matter, turbidity, suspended solids, oil and grease, heavy metals (Hg, Pb, Cd), dissolved iron, manganese, faecal coliform and following the use classification suggested by the CPCB (SW1 to SW5).
- Ground water: levels of pH value, coliform count, TDS (ppm), nitrate (ppm), specific conductivity (micro seimen/cm), hardness (ppm), percentage of sodium, boron (ppm), depth to WT (m), total groundwater draft (%), rainfall recharge (%) and aquifer type.
- Mangrove vegetation: Area covered by forest, number of species, luxuriance of the forest

Indicators of the health of coastal ecosystems within each district were placed in grades from 1-5. The grades/categories used to indicate the quality of each ecosystem are: Good - 1, moderately affected - 2, affected – 3, highly affected – 4, and severely affected - 5. Using the indicators described above, these grades were assigned to each ecosystem within each district based on the experts' (scientists working with the each of the relevant ecosystem) opinion. These five levels are taken as scores of each state indicator (from 1 - 5). The scores were summed for all three ecosystems and the district, with the highest score for state indicators, was assigned the highest rank indicating that the ecosystems here were the most affected.

Figure 2 presented below summarizes the hypothesized links between driver and ecosystem. Coastal districts most threatened or vulnerable to development activities were those ranked high for both drivers and for stressed ecosystems. The Venn diagram (Figure 3) below illustrates this.

Discussion

In this sub section, the results of using the pressure indicators to rank the 66 coastal districts are presented and discussed. The data upon which this assessment is based is provided in Annexures 1-5.

Urbanization

The indicators used to rank districts with respect to urbanization were:

1 Population density

2 Percentage of labour force in the non-agricultural sector.

The following is a list of the first 15 districts where this driver is important.

Table 2 Districts ranked by urbanization as a driver

Rank	District
1	Mumbai
2	Chennai
3	Mahe
4	24 Paragnas North
5	Ernakulam

6	Pondicherry
7	Kozhikode
8	Alleppey
9	Daman
10	Ahmedabad
11	Trivandrum
12	Trichur
13	Quilon
14	Yanam
15	Thane

Industrial activity

The indicator used to rank districts with respect to industrial activity was:

1 Total number of units of the seven potentially polluting industries identified in the literature survey.[8]

The following is a list of the first 15 districts where this driver is important.

Table 3 Districts ranked by industrial activity

Rank	Industrialization
1	Mumbai
2	Thane
3	Ahmedabad
4	Raigad
5	Chennai
6	Bharuch
7	Vadodara
8	Surat
9	Kheda
10	Valsad
11	Visakhapatnam
12	Pondicherry
13	Ratnagiri
14	24 Paragnas South
15	Daman

Intense agriculture/aquaculture

The factors used to rank districts with respect to agriculture/aquaculture were:

1 Percentage of cultivated land

2 Percentage of irrigated land

3 Fertilizer consumption/ha

Since adequate data on aquaculture were not available, first ranking was done using agricultural indicators. Among these districts, those with the highest level of aquacultural activities were short-listed based on expert opinion.

The following are the first 15 districts where this driver is important.

Table 4 Districts ranked by intensive agriculture/aquaculture

Rank	District
1	Kheda
2	Tanjore
3	West Godavari
4	24 Paragnas North
5	Krishna
6	Ernakulam
7	Kottayam
8	Chengai Anna
9	Alleppey
10	Srikakulam
11	Vadodara
12	East Godavari
13	Surat
14	Pudukkottai
15	Mednipur

For this driver, Mednipur, Ernakulam and East Godavari emerge as the districts most representative of intense agriculture activities. Among these, East Godavari also has the highest level of aquacultural activities.

Port activities

The indicator used to rank districts with respect to port activities:

1 Total cargo handled at each of the ports.

The following is a list of the first 15 districts where this driver is important.

Table 5 Districts ranked by port activity

Rank	Coastal district
1	Mumbai
2	Chennai
3	Kachch
4	Visakhapatnam
5	24 Paragnas North
6	SouthGoa
7	Dakshin Kannad
8	Ernakulam
9	Cuttack
10	Jamnagar
11	East Godavari
12	Raigad
13	Ratnagiri
14	North Goa
15	Sindhudurg

Tourism

The indicator used to rank districts with respect to tourism:

1 Number of hotel rooms per square kilometre.

The following is a list of the first 15 districts where this driver is important.

Table 6 District ranked by tourist activity

Rank	Coastal district
1	Chennai
2	Mumbai
3	North Goa
4	South Goa
5	Ernakulam
6	Trivandrum
7	Kozhikode
8	Kanyakumari
9	Ahmedabad
10	Kottayam
11	Vadodara
12	Pondicherry
13	Visakhapatnam
14	Puri-

	Bhubaneshwar
15	Trichur

Districts included in the affected ecosystem category are those for which we had complete data sets for all three ecosystems. To be included in the affected data set (grade > 1) we need a minimum score of 4. Thus, the districts with the lowest ranks and scores more than or equal to 4 were those included in the category ‘degraded’. Annexure II has the detailed data that support these results. Complete data sets (i.e., for all three ecosystems) were available for only 22 districts from our study region. From this set, those which are in the ‘under affected’ (score more than or equal to 4) category, are given below. The ranking for each of the ecosystems is given in Annexure 6.

Table 7 Coastal districts in India where ecosystems are degraded

Rank	State indicators
1	Mumbai (14)
2	Chennai (12)
2[9]	Dakshin Kannad (12)
2	Visakhapatnam (12)
5	Ernakulam (11)
5	Thane (11)
7	Trivandrum (10)
7	Quilon (10)
9	Kanyakumari (9)
9	East Godavari (9)
9	Jamnagar (9)
12	Cannore (8)
12	Nagapatnam (8)
14	Surat (8)
14	Mednipur (8)
14	Tanjore (8)
17	24 Parganas South (7)
18	North Goa (6)
18	South Goa (6)
20	Raigad (5)
20	Uttar Kannad (5)
20	Ratnagiri (5)

Scores are given in brackets.

Because of absence of data upon which state indicators could be based, only 22 districts are said to have affected ecosystems.

If these districts are examined for (1) pressures from the various drivers, and (2) ecosystem stress, we get:

- Urbanization driver: Of the 15 districts potentially threatened by urbanization pressures, only six can be said to have affected ecosystems. These are Mumbai, Chennai, Ernaculam, Trivandrum, Quilon, and Thane.
- Industrial activity: Of the 15 districts potentially threatened by heavy industrial activity, only four districts can be termed affected: Mumbai, Chennai, Thane, and Visakapatnam.
- Intensive aquaculture/agriculture driver: Mednipur, Ernakulam and East Godavari emerge as districts most representative of intense agricultural activities. Among these, East Godavari has the highest aquacultural activities. These also have affected ecosystems
- Port activity: Of the 15 districts potentia lly threatened by port activity, only seven districts can be said to have affected ecosystems. Mumbai, Chennai, Vishakhapatanam, Dakshin Kannad, Ernakulam, Jamnagar, and East Godavari.
- Tourism activity: The districts of Mumbai, Chennai, North Goa, South Goa, Ernakulam, Trivendrum and Visakhapatnam emerge as potentially vulnerable districts.

Thus, combining the driver-specific ranking with condition-specific ranking, gives us a short list of coastal districts that have stressed ecosystems and heavy pressures from development drivers. This is presented below.

Table 7

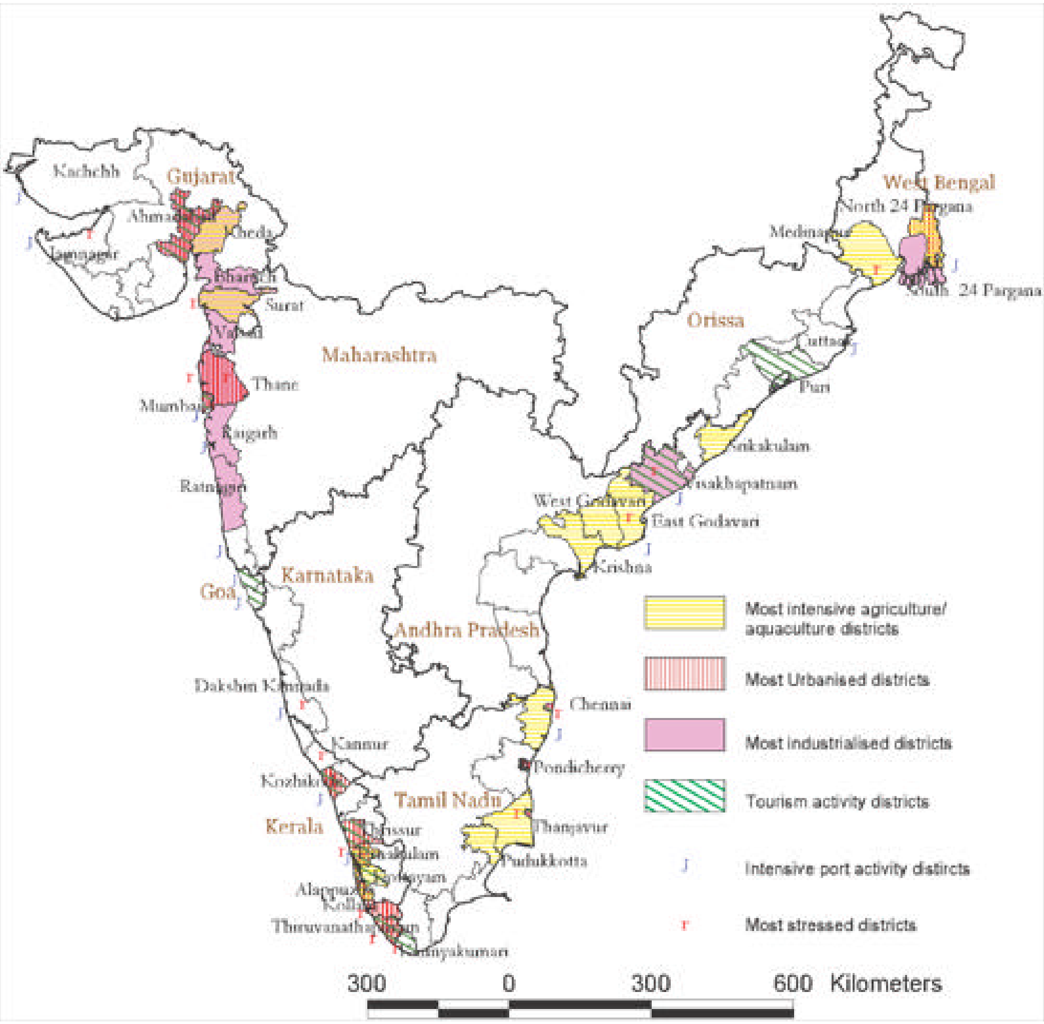
Coastal districts short-listed by heavy pressures from drivers and with affected ecosystems

Districts/ Driver listed by ranks	Urbanization	Industrialization	Aquaculture/ Agriculture	Port Activities	Tourism	Stressed ecosystem

1	Mumbai	Mumbai	Kheda	Mumbai	Chennai	Mumbai
2	Chennai	Thane	Tanjore	Chennai	Mumbai	Chennai
3	Mahe	Ahmedabad	West Godavari	Kachch	North Goa	Dakshin Kannada
4	24 Paragnas North	Raigad	24 Paragnas North	Visakhap atnam	South Goa	Visakhap atnam
5	Ernakula m	Chennai	Krishna	24 Paragnas North	Ernakula m	Ernakula m

The coastal districts whose ecosystems are vulnerable to development drivers are given in Map 1.

Map 1 Coastal districts defined by drivers and stressed ecosystems



Conclusions

This paper has reported on a framework of indicators of potential vulnerability developed for the coastal regions of India. Arriving at vulnerable coastal districts by ranking those with heavy development pressures and stressed ecosystems, using pressure and state indicators enables us to suggest that any further development in a `business as usual' scenario will put these districts at risk and result in negative outcomes for the people and activities located there. So there is need to put in place a coastal monitoring and managing system, which takes into account the ecosystems in each district that are particularly stressed by a particular driver. The ecosystem level indicators can also help regulatory regimes to be more sensitive to location specificities and vulnerability and also to stress from multiple uses.

The framework has a number of limitations but also a number of strengths. The strength of the framework lies in the fact that the indicators have the following features:

- They are relevant to the user and easy to understand
- They are measurable as it is possible to estimate the value of the indicator using numerical or non-numerical data.
- They are analytically sound and use standardized measurements wherever possible to permit comparison.
- They are sensitive because the framework can be used to see trends over time.

The limitations in the method used here:

1 Data availability constrained the use of a more rigorous statistical method of analysis to establish the connection between pressure and state indicators

2 Coastal districts are used as units of analysis to enable collection of data for indicators; while this worked well for socio-economic and policy-related information, it was not the most suitable unit for ecological information

3 Intrinsic vulnerability of coastal areas was not factored in. Some of the pressure indicators may be more threatening in some areas than in others.

4 Since only the most important drivers were considered, some pressures were left out of the analysis. One of importance is fishing.

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Annex 1: Ranking of coastal districts with respect to urbanization

Coastal districts	Population density	R1	Non-agricultural workforce %	R2	Sum (R1, R2)	Borda rank
Mumbai	16460	2	99.16	1	3	1
Chennai	22076	1	98.95	2	3	2
Mahe	3716	3	82.8	3	6	3
24 Paragnas North	1778.67	5	64.18	11	16	4
Ernakulam	1170	8	66.84	8	16	5
Pondicherry	2076	4	62.68	12	16	6
Kozhikode	1117	9	65.32	10	19	7
Alleppey	1415	6	59.41	15	21	8
Daman	862	16	70.49	5	21	9
Ahmedabad	551.49	23	73.14	4	27	10
Trivandrum	1344	7	52.52	20	27	11
Trichur	902.81	14	60.81	14	28	12
Quilon	966	11	53.11	19	30	13
Yanam	676	19	62.12	13	32	14
Thane	549	24	66.81	9	33	15
Cannore	759	18	57.53	16	34	16
Diu	987	10	47.76	25	35	17
Karaikal	910	13	48.64	23	36	18
Kottayam	829	17	49.8	22	39	19
Mallapuram	872	15	45.5	26	41	20
Chengai Anna	592	20	48.55	24	44	21
NorthGoa	382	38	68.01	6	44	22
Kanyakumari	950	12	40.98	33	45	23
Kasargod	537	26	50.2	21	47	24
Surat	443	32	54.91	18	50	25
SouthGoa	256	48	67.28	7	55	26
24 Paragnas South	573.8	22	40.31	34	56	27
Dakshin Kannad	319.19	43	57.05	17	60	28
Cuttack	495	27	33.56	39	66	29
Mednipur	591	21	30.65	45	66	30
Nellaikattapomman-Tirunlveli	367	39	43.94	28	67	31
Vadodara	396	37	43.48	30	67	32
Valsad	414.51	35	37.7	35	70	33

Chidambarnar	315	44	44.47	27	71	34
Krishna	423.84	33	33.28	41	74	35
Kheda	478.3	28	29.44	47	75	36
Tanjore	547	25	27.38	50	75	37
East Godavari	420.21	34	31.97	43	77	38
West Godavari	454.35	29	27.81	48	77	39
Puri-Bhubaneshwar	352	41	35.03	37	78	40
Bhavanagar	205	52	43.86	29	81	41
Visakhapatnam	294.34	45	37.29	36	81	42
Raigad	255	49	34.22	38	87	43
Baleshwar	444	31	21.67	58	89	44
Guntur	360.55	40	26.17	51	91	45
Jamnagar	110	60	41.85	31	91	46
South Arcot Vallar.	447	30	18.54	61	91	47
Kachch	27.66	61	41.5	32	93	48
Junagadh	225	51	31.32	44	95	49
Srikakulam	397.66	36	21.61	59	95	50
Vizianagaram	322.82	42	24.97	53	95	51
Amreli	185	54	32.53	42	96	52
Ramanathapuram	270	46	25.78	52	98	53
UttarKannad	118.58	59	33.3	40	99	54
Pudukkottai	258	47	24.22	54	101	55
Bharuch	171.07	56	30.12	46	102	56
Nellore	182.95	55	27.78	49	104	57
Ganjam	252	50	22.56	57	107	58
Ratnagiri	188	53	23.26	55	108	59
Sindhudurg	159.81	57	22.79	56	113	60
Prakasam	156.54	58	20.25	60	118	61

Annex 2 Ranking of coastal districts with respect to industrialization

Coastal districts	Total industrial units	Rank
Bombay	141	1
Thane	137	2
Ahmedabad	108	3
Raigad	85	4
Chennai	83	5

Bharuch	60	6
Vadodara	55	7
Surat	53	8
Kheda	44	9
Valsad	41	10
Visakhapatnam	29	11
Pondicherry	21	12
Ratnagiri	20	13
24 Paragnas South	17	14
Damman	17	14
Bhavanagar	14	16
Chengai Anna	14	16
Vizianagaram	14	16
Ernakulam	13	19
SouthGoa	13	19
Guntur	13	19
Jamnagar	12	22
Srikakulam	12	22
North Goa	11	24
Nagalnaquaidnaenamilletnanagapatnam	10	25
Dakshin Kannad	9	26
Nellore	8	27
Krishna	8	27
Kachch	7	29
Trichur	7	29
24 Paragnas North	7	29
Nellaikattapomman-Tirunlveli	6	32
Tanjore	5	33
Prakasam	5	33
West Godavari	5	33
Karaikal	5	33
East Godavari	4	37
Puri-Bhubaneshwar	4	37
Mednipur	4	37
UttarKannad	3	40
Kanyakumari	3	40

South Arcot Vallar.	3	40
Junagadh	2	43
Kozhikode	2	43
Alleppey	2	43
Cuttack	2	43
Cannore	1	47
Kottayam	1	47
Pudukkottai	1	47
Baleshwar	1	47
Yanam	1	47

Annex 3 Ranking of coastal districts with respect to agriculture/aquaculture

Coastal Districts	% cultivated land	R1	% Irrigated land	R2	Fertilizer kg/ha	R3	Sum R1, R2,R3	Borda Rank
Kheda	76.24	3	33.74	6	126	11	20	1
Tanjore	62.55	16	54.82	2	155	7	25	2
West Godavari	53.32	28	43.50	4	271	1	33	3
24 Paragnas North	67.84	12	33.08	7	103	15	34	4
Krishna	56.17	24	40.77	5	202	5	34	4
Ernakulam	75.82	4	19.59	17	94	19	40	6
Kottayam	83.16	2	2.84	42	153	8	52	7
Chengai Anna	39.56	35	31.00	9	145	10	54	8
Alleppey	75.78	5	17.43	22	71	28	55	9
Srikakulam	54.33	26	32.09	8	89	21	55	10
Vadodara	69.42	10	16.27	23	88	22	55	11
East Godavari	35.59	41	22.68	11	170	6	58	12
Surat	51.8	30	15.05	24	205	4	58	12
Pudukkottai	42.62	34	21.96	12	118	13	59	14
Karaikal	72.23	7	68.58	1	0	52	60	15
Mednipur	64.33	14	17.66	21	81	26	61	16
Bhavanagar	63.29	15	21.34	13	57	36	64	17
Baleshwar	70.02	8	20.87	15	44	42	65	18
Ahmedabad	69.19	11	14.33	27	69	30	68	19
Valsad	57.36	21	9.74	32	98	16	69	20
Kozhikode	69.63	9	2.20	44	96	17	70	21
Trichur	52.07	29	19.35	18	87	23	70	21
Nellore	24.49	49	18.53	20	226	2	71	23

Amreli	72.62	6	14.67	26	50	40	72	24
South Arcot Vallar.	60.21	18	3.46	40	104	14	72	24
Kanyakumari	39.14	37	13.83	28	152	9	74	26
Pondicherry	57.8	20	49.99	3	0	51	74	26
Vizianagaram	49.45	31	19.21	19	81	25	75	28
Guntur	43.79	33	2.44	43	207	3	79	29
Junagadh	56.95	22	12.92	29	67	32	83	30
Mahe	85.61	1	9.16	33	0	53	87	31
Prakasam	33.61	43	8.93	34	120	12	89	32
Nellaikattapomman-Tirunlveli	35.5	42	12.01	30	90	20	92	33
Bharuch	54.08	27	5.07	38	70	29	94	34
Ramanathapuram	48.85	32	14.87	25	57	37	94	34
Mallapuram	55.41	25	7.41	36	62	34	95	36
Ganjam	39.34	36	20.24	16	32	44	96	37
Trivandrum	65.42	13	1.90	47	55	38	98	38
Jamnagar	58.62	19	5.12	37	29	45	101	39
Dakshin Kannad	26.04	47	10.32	31	85	24	102	40
Yanam	35.81	40	23.46	10	0	54	104	41
Cuttack	62.53	17	3.58	39	22	49	105	42
Puri-Bhubaneshwar	25.05	48	21.13	14	26	46	108	43
Quilon	56.7	23	1.65	48	44	41	112	44
Raigad	26.73	46	1.44	49	95	18	113	45
24 Paragnas South	36.28	39	1.41	50	76	27	116	46
Visakhapatnam	22.88	50	7.59	35	69	31	116	46
Cannore	38.44	38	2.06	45	60	35	118	48
Uttar Kannad	10.68	53	1.93	46	65	33	132	49
Thane	28.66	45	0.52	52	53	39	136	50
Sindhudurg	21.05	51	2.88	41	0	50	142	51
Ratnagiri	28.83	44	0.39	53	22	48	145	52
Kachch	15.61	52	1.17	51	22	47	150	53

Annex 4 Ranking of coastal districts with respect to port activity

Coastal districts	Total cargo handled (in million tonnes)	Rank
Mumbai	30921	1

Chennai	24549.9	2
kachch	22534	3
Visakhapatnam	19455.5	4
24 Paragnas North	14953	5
SouthGoa	14928.3	6
Dakshin Kannad	8106	7
Ernakulam	7287.2	8
Cuttack	7034	9
Jamnagar	5018	10
East Godavari	1807	11
Raigad	1666	12
Ratnagiri	241	13
North Goa	212	14
Sindhudurg	183	15
Junagadh (Porbandar&Veraval)	182	16
Bhavanagar	180	17
South Arcot Vallar.	62	18
UttarKannad (Karwar&Tadri)	60	19
Kozhikode	34	20
Pondicherry	22	21
Baruch (Dahej)	20	22
Chengalpattu MGR	18	23
Alleppey	6	24

Annex 5 Ranking of coastal districts with respect to tourism

Coastal districts	Number of rooms per sq km	Rank
Chennai	23.6782	1
Mumbai	11.4594	2
North Goa	3.5950	3
SouthGoa	1.4125	4
Ernakulam	0.5588	5
Trivandrum	0.3016	6
Kozhikode	0.2253	7
Kanyakumari	0.0926	8
Ahmedabad	0.0917	9
Kottayam	0.0899	10

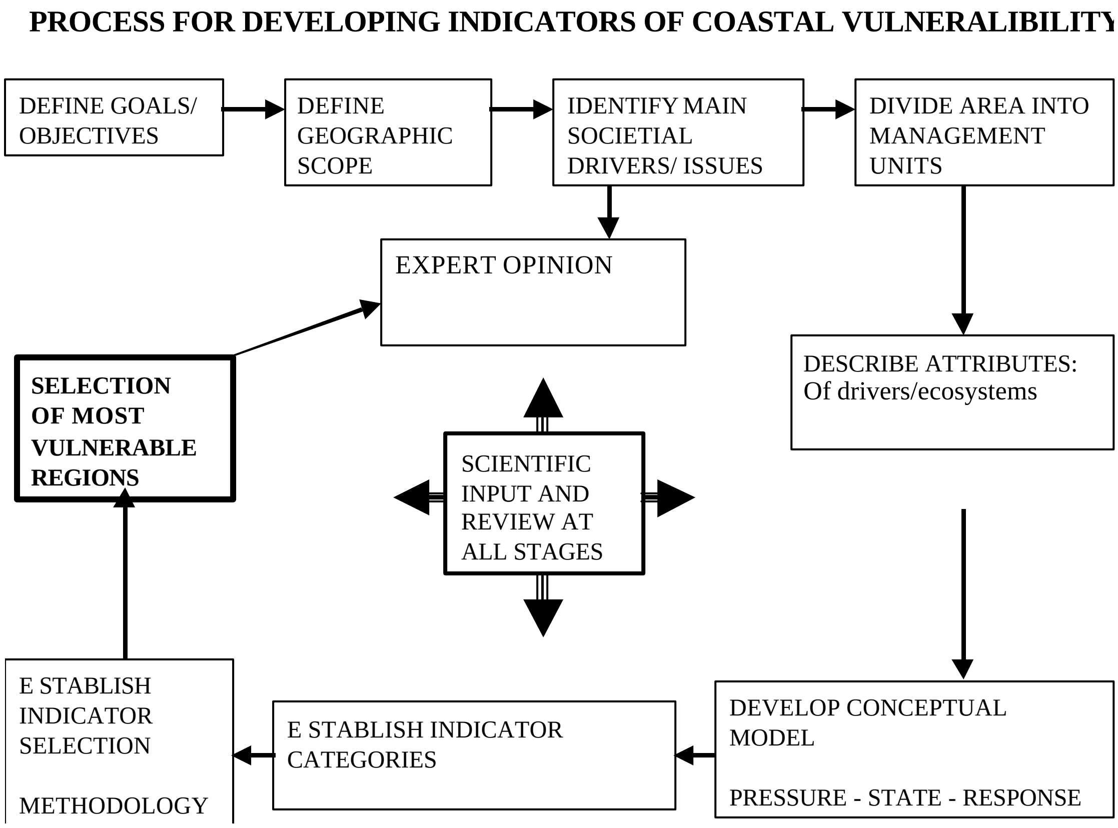
Vadodara	0.0715	11
Pondicherry	0.0683	12
Visakhapatnam	0.0680	13
Puri-Bhubaneshwar	0.0602	14
Trichur	0.0590	15
Surat	0.0468	16
Dakshin Kannad	0.0458	17
Quilon	0.0401	18
Raigad	0.0400	19
Alleppey	0.0339	20
Ganjam	0.0299	21
Thane	0.0255	22
Cannore	0.0247	23
Guntur	0.0167	24
Nellaikattapomman-Tirunlveli	0.0158	25
Tanjore	0.0145	26
Bhavanagar	0.0135	27
Bharuch	0.0126	28
Nellore	0.0122	29
East Godavari	0.0108	30
South Arcot Vallar.	0.0086	31
Valsad	0.0069	32
Cuttack	0.0057	33
Srikakulam	0.0055	34
Chengai Anna	0.0048	35
Ratnagiri	0.0045	36
Kachch	0.0003	37

Annex 6 Ranking of coastal districts with respect to state indicators

Coastal districts	Groundwater quality	Mangrove vegetation	Coastal water quality	Sum of scores	Rank
Bombay	4	5	5	14	1
Chennai	5	5	2	12	2
Dakshin Kannad	3	4	5	12	2

Visakhapatnam	4	5	3	12	2
Ernakulam	3	5	3	11	5
Thane	3	3	5	11	5
Trivandrum	4	5	1	10	7
Quilon	3	5	2	10	7
Kanyakumari	3	4	2	9	9
East Godavari	4	2	3	9	9
Jamnagar	4	4	1	9	9
Cannore	3	4	1	8	12
Surat	2	5	1	8	12
Mednipur	4	3	1	8	12
Tanjore	3	4	1	8	12
Nagalnaquaidnaenamilletna Nagapatnam	3	4	1	8	12
24 Paragnas South	3	3	1	7	17
NorthGoa	3	2	1	6	18
SouthGoa	2	3	1	6	18
Raigad	2	2	1	5	20
UttarKannad	1	3	1	5	20
Ratnagiri	2	2	1	5	20

Figure 1 Adapted and modified from: CALFED Bay - DELTA ERP indicator



framework (poster abstract presented at the 1999 International Conference on ecosystem health, Sacramento, California, August 1999).

Figure 2 The Driver-Pressure-State indicator framework

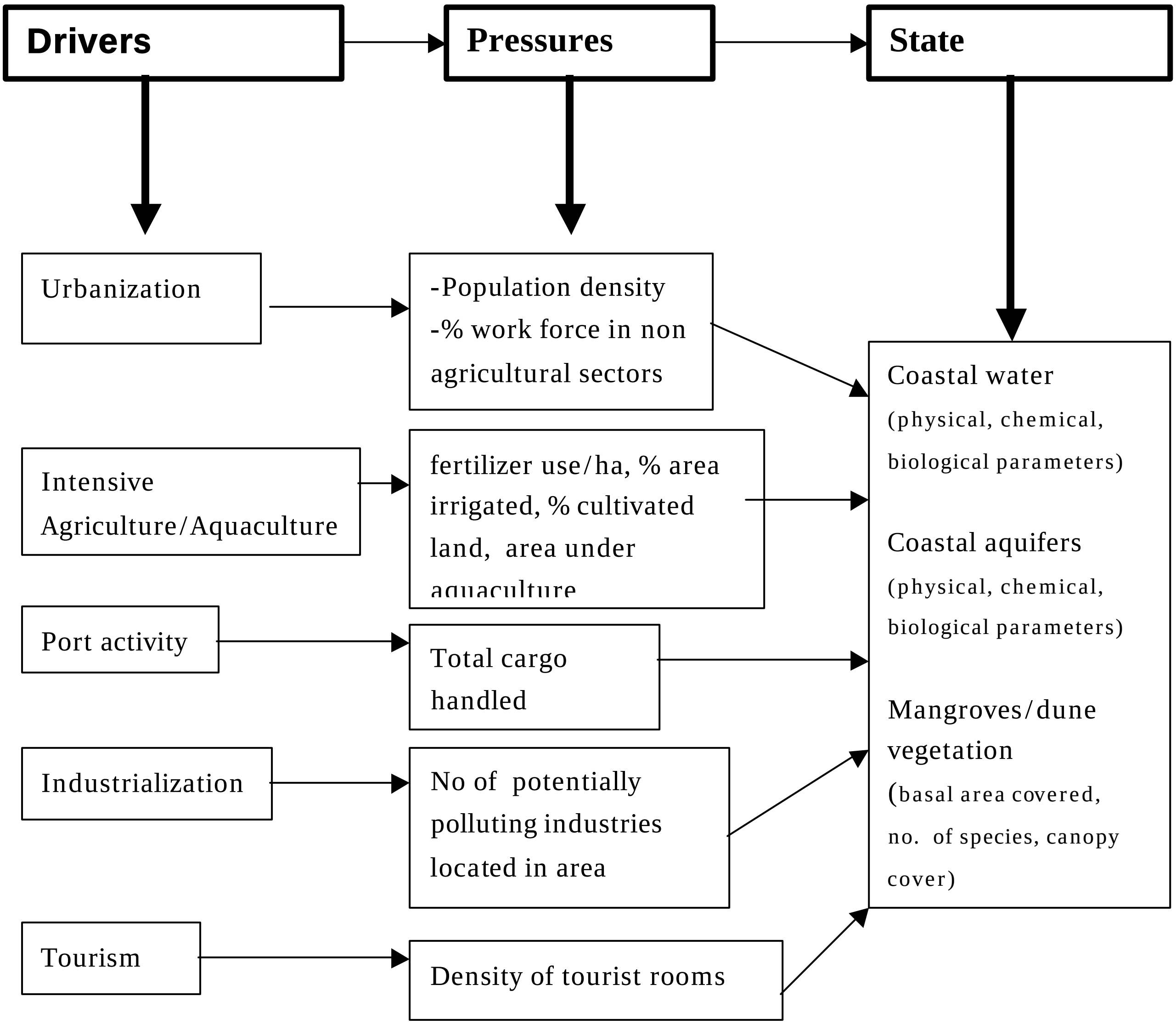
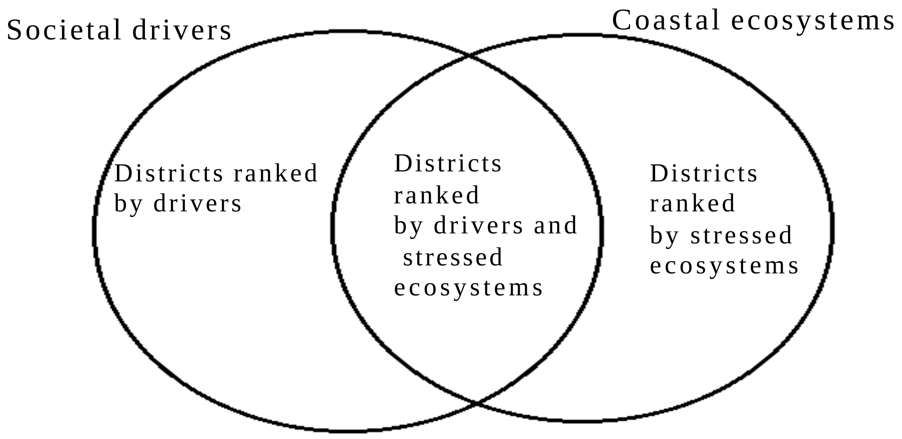


Figure 3. Potentially vulnerable Coastal districts



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1 An ecosystem is considered to be well-functioning and healthy if it is active, it maintains its organization, connectivity and autonomy over time and is resilient to stress. (Constanza, 1992, p 241) Karr et al. (1986) state that a biological system can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self repair when perturbed is preserved, and minimal external support for management is needed.(Quoted in Rapport, p 7). We would like to state here that our concern is with ecosystem health in terms of services and goods that contribute to human health and well-being.

2 See the Centre for Monitoring the Indian Economy (CMIE), **19th Quarterly Survey of Project Investments** , November 15, 1999 . According to this survey 6 coastal states have corned 58% of the total investment planned in the country of Rs. 1253. 67 billion

[3] This section is based on the survey included in Noronha, 2002.
[4] Borda rule:This rule provides a method of rank-order scoring, the procedure being to award each alternative(here,district) a point equal to its rank in each criterion of ranking(here criteria say population density,workers in non-agricultural sectors, etc), adding each district's scores to obtain its aggregate score, then ranking districts on the basis of their aggregate scores. (see :Partha Dasgupta.(1993),*Wellbeing and Destitution*.(Oxford University press Inc, Newyork)

[5] These were arrived at a workshop held with policy people and coastal scientists held in Goa, India on 22 February 1999. the details are available at http://teriin.org/teri-wr/coastin

[6] The other sensitive ecosystems are coral reefs which are not included here as these are not generally common on the Indian mainland coast to which this exercise is restricted..
[7] A.G. Untawale, `Management of Coastal Zone Vegetation: I - Dune Vegetation along the Indian Coast' pp 7.8.1 - 7.8.4, in **Regional Course on Tropical Hydrology and Coastal Zone Management** [February 12-26, 1992], Dona Paula, Goa.

[8] The seven groups are 1.Textiles 2.Chemicals/petrochemicals/oil (including dyes and dye intermediates, oil refinery, petrochemicals, drugs and pharmaceuticals and sulphuric acid) 3.Mineral processing (includes zinc smelting, copper smelting and aluminium smelting) 4. Sugar /distilleries (sugar, fermentation and distilleries) 5.Fertilisers and pesticides 6.Cement and 7.Power. These are the 18 groups of industries reclassified into 7 groups identified by the Central pollution Control Board of India as having major potential for pollution.
[99] Repeated ranks: When total score of two/more districts are equal, same ranks were assigned to them by using initial rank. For example, state indicator scores of second, third and fourth districts are same and both were assigned third rank and started next district with fifth rank.