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Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

Impact Analysis of Critical Land Uses on Urban Coastal Zones Using the Coastal Zone Health Index

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Abstract

From the planning perspective, most anthropogenic impacts in the urban context have their humble origin in the way we allocate land uses, and this is especially true in the case of coastal cities. This paper links land use planning and Integrated Coastal Zone Management (ICZM) that necessitates ICZM to be done is mostly a result of lack of appropriate planning practices. The basic hypothesis is that majority of coastal problems can be avoided if we plan for land use on coastal zones carefully and after an impact analysis. Here the independent variables are some of the critical land uses and the dependent variable is general coastal zone health expressed as coastal zone health index or CHI as defined from a planning perspective.

1. INTRODUCTION

Although urban planning and integrated coastal zone management have made significant strides in recent years, their interdisciplinary interaction has been minimal. An article to this effect highlights that although both management of urban areas and coastal zones have been objects of extensive research over the past two decades, there is no deep research done linking both. This is an important but neglected area as the need for ICZM arises often due to inappropriate land use planning practices. World over, coastal cities grow at an exponential rate and at a higher rate than their non-coastal counterparts with their constantly swelling population, activities and consequent pollution (Table 1). At present, more than 50 percent of world's population lives within 200 km from the coast and this trend is on the increase in North America, Southeast Asia, India and South America. It is also predicted that by 2025 world's population will be 8.5 billion and of this 75 percent will be living on coasts. However, for such cities, while allocating land uses, (which is the most pivotal part of the total task of urban planning); planners hardly care for the innate development sensitivity of coastal zones. This paper is intended to address this long term missing collaboration between land use planning and its coastal implications with the help of a metric to quantify coastal zone health.

ICZM evolved as a powerful mechanism for allocation of natural resources and control of unplanned development on coastal zones where unitary management and multiple stakeholder presence are of prominent importance. ICZM has its origin as a continuous and dynamic process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection and development of

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Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

Table.1 : Worldwide Distribution of Coastal and Non-Coastal Cities

	No. of Cities			Number of Cities		
	1 Million to 10 Million Cities			10 Million+ Cities		
	Coastal	Non Coastal	% of Coastal Cities	Coastal	Non Coastal	% of Coastal Cities
World	108	159	40	6	2	75
Asia	59	88	40	5	1	83
Africa	13	14	48	0	0	---
America	19	22	46	1	1	50
Europe	12	35	26	0	0	---
Oceania	5	0	100	0	0	---
Asia %	55%	55%	---	83%	50%	---

coastal ecosystems and resources. It is imperative that if land use planning is done with an eye on the impacts it would unleash ICZM as a process becomes easier and more productive in implementation. The primary impediment in impact analysis of land uses on coastal zones is the lack of a suitable metric to capture the health aspects of coastal zones from a 'planning for sustainability' angle. Coastal Zone Health Index (CHI) is coined as a composite indicator that would try to capture the health status of any coastal zone from a total system sustainability angle. Composite CHI is computed out of a suite of core component CHIs which are suitably weighed respectively based on expert opinion. The paper covers the conceptual basis for CHI, component environments considered and its broad context of application from a land use planning perspective.

2. OBJECTIVES AND PREMISES OF CHI

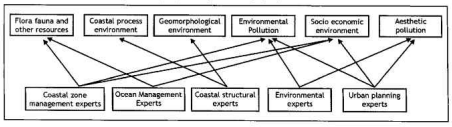
Coastal zone health is contributed by a set of generic characteristics which can be traced back to a set of critical parameter values corresponding to the core characteristic components. Although they are mutually influencing to varying extent, to make the model less complex, they are treated independent for modeling CHI. Six basic characteristic components of any coastal zone as shown in Fig. 1, are considered for postulating the metric.

A set of core values which would make a coastal zone healthy from the planning angle is identified first. As per this, a healthy coastal zone should be able to

- to provide clean or unpolluted water conducive for recreation and other human activities;
- to support fisheries and other socio-economic activities including resource exploitation in a sustainable manner;
- to assure diverse biota;
- it should be resilient to human activities' onslaught; and

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

Fig. 1 : Characteristic Components (CC) vs. Expert Category Input



- lack of pathogens and toxicants in the coastal environment;

The CHIs have been conceptualized and developed to measure coastal zone health. They are meant for use in a variety of direct and indirect coastal zone management contexts. They serve as:

- state indicators for baseline condition mapping;
- metrics to compare and monitor baseline and future coastal system status;
- tools to measure efficacy and results of policies and actions;
- process indicators reflecting management of coastal resources; and
- indicators of efficiency of institutional arrangements for ICZM.

The basic premises for formulating CHIs and the questionnaire survey of experts (QSE) which elicited the core know how to develop them are listed below:

- for coastal zones generically and typically for India, there are six characteristic components (CCs) (Fig. 1);
- there are nine Critical Dimensions (CDs) collectively pertaining to the six CCs;
- a CHI is specified for each CD. Each CHI comprises a set of influencing attributes relevant to the respective CDs;
- individual CHIs can be aggregated into a Composite CHI; and
- it is assumed that the CCs are independent and a linear weighted sum can be used to determine the CHIs for each CD;

Characteristic Components or CCs are so chosen that they together capture typical characteristics of a coastal zone which has a set of core values that make it healthy from a planning point of view. The weightages corresponding to the CCs, CDs and attributes reflect their contextual importance as derived from the QSE. These are developed using the Analytic Hierarchy Process (AHP), a popular multi-criteria decision methodology. Specific CHI models are developed for each CD (nine CHIs corresponding to the nine CDs). A composite CHI is computed using the nine component CHIs which are suitably weighted. Finally, each CHI is validated for a set of coastal city contexts.

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

The premises, the CCs, their CDs, and attributes are initially obtained from literature and expert consultation, and refined before being validated through a QSE. Questionnaire is constructed with the objective of validating the basic premises and also to quantify the relationship between attributes at different levels of typical Indian coastal zones without being location specific. Expert opinion on the CDs and their respective attributes to be captured under each component and their relative weightages are assessed through the questionnaire survey.

Our survey has covered 67 experts across 3 different coastal regions of India namely, Konkan, Kerala and Chennai and 5 expert categories. Experts are drawn from academic institutions, research institutions, NGOs, consultant organizations, development authorities, and other central and state government establishments of repute in India. As Fig. 1, shows the expert categories with their respective fields of expertise, for determining the relative weightages of the CCs, their CDs and the respective attributes, the Analytic Hierarchy Process (AHP) methodology is adopted using the Expert Choice software. In all the three cases, the weightages are subjected to an analysis of variance (ANOVA) to establish their consistency across the five expert categories and found to be consistent. The weightages are then used to integrate the CHI models corresponding to the critical dimensions identified and the CHI categories are listed and explained in the next section.

3. INDICATOR CATEGORIES AND THE COMPOSITE CHI

Corresponding to the CCs and their CDs, nine CHIs are used to indicate the coastal zone health status as detailed below.

3.1 Flora and Fauna Indicator - The CHI-FF

This indicator reflects the vigor, biodiversity and exuberance of coastal flora and fauna. Any useful notion of an ecosystem should involve both the structure (the species and population involved) and function (the flow of energy and materials) of the ecosystem. It is based on the premise that the coast's original, virgin profile with its biodiversity, extent and sensitivity is the ideal and best base model and deviations due to human interventions and activities alter, and in the worst case deteriorate it. Thus, human encroachment at the cost of loss of bio-resources is considered undesirable. A higher value indicates exuberance, pristineness and conserved biodiversity of flora and fauna and less of unsustainable land uses and activities in operation.

3.2 Other Resource Indicator - The CHI-OR

In addition to the living resources, there are a variety of coastal resources on which an urban conglomeration depends heavily at various stages of its development. Such resources include sand, salt, chemicals, freshwater, coastal minerals, etc. A higher value of this indicator corresponds to an optimal level of extraction of resources. There needs to be a well laid out plan for safe and sustainable extraction and equitable distribution of these resources for common good. To this

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

level, resource extraction is treated positive and is a subjective decision. Beyond a sustainable level, extraction of such resources would obviously be detrimental.

3.3 Geomorphologic Indicator - The CHI-GEO

This indicates the geomorphologic and geologic vulnerability aspects of the coast that are significant for planning in terms of the length of time some of these aspects take to manifest changes. Mostly morphological evolutions are a direct consequence of changes in sediment transport both in space and time, and happen over geological time. This may not have much significance for planning and hence lies beyond the purview of this indicator. However, the short term consequences of morphological changes and the extent of their influence over the vulnerability of coastal zones are reflected by this indicator. A higher value indicates minimal vulnerability and presence of gentle beach slope.

3.4 Coastal Process Indicator - The CHI-CP

This indicator captures the sensitivity of the coastal zone to various coastal processes such as waves, currents, tides, cyclones, etc., and allied calamities. All secondary impacts of coastal processes such as erosion, accretion and saline intrusion are also captured by this indicator. Although complex, to the extent possible, this indicator should capture the mutual impacts of human activities and coastal processes on each other. A higher value indicates a potentially safe coastal zone with minimal interference of coastal physical processes on the landscape and human activities.

3.5 Socio-Economic Indicator - The CHI-SE

This indicator reflects the support of coast to its economy and the extent of the society's dependence and belongingness to the coast. All direct and indirect bread winning activities dominantly dependent on the sea or coast are included sector-wise in this indicator. A higher value indicates a coast having high socio-economic influence where again sustainable practices are the guide map.

3.6 Coastal Aesthetic Pollution Indicator - The CHI-AeP

This indicator reflects the coast's health status through human sensory perceptions including visual, sonic and olfactory aspects of the coastal zone. A higher value indicates a coast that affects one's sensory perceptions less in a negative way. It is a subjective indicator. A higher value indicates the coast's potential to accommodate tourism and allied recreation related land uses.

3.7 Environmental (Air, Water, and Land) Pollution Indicators - The CHI-AP, WP, and LP

Under this category there are three different CHIs representing air, water and land pollution levels respectively. These indirectly indicate the capacity of the coastal zone to absorb or not to absorb more development. A higher value indicates a coast of pristine environmental quality where most pollutants are neither present or are within safe levels.

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

Although each CHI is computed as a value between 0 and 1, for convenience these are scaled and expressed as a value out of 10. There are relative and absolute parts for each CHI. These are separately computed and by assigning an appropriate weightage to each (in all the study contexts, equal weightage is given to the relative and absolute parts of the CHI) a final CHI is computed. The Composite CHI is expressed out of 100 by using a weighted sum of individual CD wise CHIs and then scaling them.

4. MODELING THE CHIS

The CHIs combine a group of heterogeneous attributes. This section explains how various attribute properties are considered for integrating them into the proposed model. This is followed by a detailed explanation of the CHI models.

4.1 Attribute Properties and Other Issues in Modeling

Each CHI is not simply a weighted sum of attributes. Each attribute's nature and its influence on its parent component CHI are considered for developing the model. Being composite indicators, CHI models include both generic and location specific inputs. The list of attributes and their weightages at various levels, as incorporated in the CHIs, is generic in nature and holds good for most coastal zones in India (unless they are declared to be especially sensitive based on selected criteria). These models also use location specific values obtained from a pool of local experts and data banks for quantifying coastal zone health to compute CHIs. In integrating the generic and location specific inputs as explained, the critical issues that have to be sorted out in regard to each attribute are discussed below.

Universal and Local Nature of Relevance: Some of the base attributes may not always be present and applicable in every coastal context, and their importance may vary from local to national and international level based on rarity, extinction status, environmental significance, etc. In order to factor in this aspect, as it is done in the Rapid Impact Assessment Matrix (RIAM), each component CHI model has a term called Importance factor (If) which may vary from 0 to 4.

Qualitative and Quantitative Nature: Most of the listed attributes lack proper units of measurement and many are not in the list of systematically maintained coastal data in India. So, qualitative judgments obtained from experts are used for such attributes. Realistic and balanced values of these attributes can be obtained through interactions with multi-disciplinary experts.

Positive or Negative Nature: Attributes may contribute to coastal zone health positively or negatively and this needs to be determined generically to the extent possible. As a part of the model logic, attributes are classified as positive or negative depending upon their innate characteristics that enhance or diminish coastal zone health. Total system sustainability serves as the reference principle to finalize this status. Measurement or assessment methods are suitably formulated and the signs are assigned to be positive or negative according to the attributes' influences.

Bound or Unbound Nature: It is important to know whether attributes are bound by limits or not either by law or otherwise. The model should include limits in such cases where the attributes are bound, e.g. there are government specified permissible limits for suspended particulate matter in a given environment. It is assumed that these limits are valid across the country. Depending upon the context, attributes can be changed from bound to unbound, if necessary. The model is robust and remains the same irrespective of the bound or unbound status of an attribute.

Relative versus Absolute Values of Attributes: As the proposed CHIs are used for assessing land use impacts on coastal zone health, they have to capture both the relative and absolute aspects of the attributes in an appropriate proportion, for example, in general equal weightage is given to the relative and absolute parts of the attributes. However, in the context of strong or weak sustainability, the absolute or relative part gets a higher weightage, as the case may be. The proposed model provides for these aspects to be factored in appropriately.

In addition, as all urban planning projects are time bound and have an associated plan period, the concept of CHI should incorporate values that depend upon the plan period being considered. The variations in the CHIs across plan periods should also be addressed by the model. It helps in comparing and monitoring attribute performance over different periods. Indirectly, it helps in assessing the efficiency of the institutional arrangements in place.

4.2 CHI Model Formulation

Fundamentally, the CHI values are expected to be coast specific as each coastal zone is different in its own way. The proposed model is made versatile by making the CHIs comprehensively capture the generic aspects of any coastal zone, and recognizing that any specific aspect may or may not be present in every coastal zone. Thus, the CHIs are designed with two specific parts, the relative and the absolute. In the relative part, the extent of what is achieved with reference to what is planned is measured for a particular attribute during the previous plan period. In the absolute part, the absolute values of attributes are considered. These are of significance in the rare case of inter coast comparisons. Also, the model accommodates absolute values to reduce any proneness to manipulation. By default, the model assigns equal weightages to the relative and absolute parts of the indicator. However, users may modify the weightages to reflect weak or strong sustainability outlooks of the ICZM authority in any specific planning location. For positive and negative attributes, the models are slightly different as a higher final CHI value will always mean better coastal health.

Relative Component: The flowchart for developing the model is shown in Fig. 2. The relative part (left half of Fig. 2) reflects the relative performance of the coastal attributes with respect to the planned values and over the previous plan period. When the CHI is computed for the first time for a coastal zone, there can be an assumed plan period and a planned value for each attribute based on the

expected level at the end of the plan period concerned. The relative part helps planners to assess the system performance over time and against set goals, and it is primarily to appraise the health status from within the coastal zone and system under consideration.

Absolute Component: The absolute part reflects the absolute status of the attributes considered (refer to the right half of Fig. 2), where the reference datum is of broader significance, say of national and regional relevance. The absolute part of the CHI model can help in inter-coastal comparisons and to benchmark a given coast with general standards of the CHI concerned as may be stipulated.

The Combined Model: The relative and absolute parts of the model are given equal weightages (0.5 each) and added to form the combined CD specific CHI model. The combined model for positive attributes is:

$$0.5\ (\Sigma w.If.REa) / (\Sigma w.If.REp) + 0.5\ (\Sigma w.If.AEa) / (\Sigma w.If) \quad (1)$$

The combined model for negative attributes is:

$$0.5\ (\Sigma w.If.(2-REa)) / (\Sigma w.If.(2-REp)) + 0.5\ (\Sigma w.If.(1-AEa)) / (\Sigma w.If) \quad (2)$$

The abstract model used for computing the Composite CHI is:

$$\Sigma wiCHIi \quad (3)$$

Where, for all i = 1 to 9, respectively representing FF, OR, GEO, CP, AP, WP, LP, AeP, and SE.

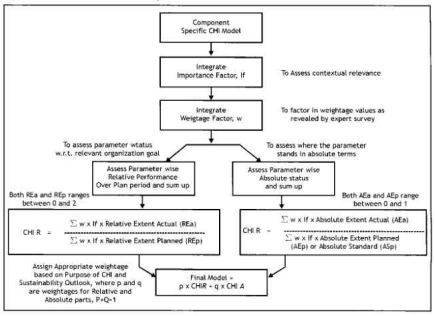
If is the importance factor

The wi are the AHP weightages/importance scores obtained from the experts for the respective CDs.
REa is the Relative Extent of the actual realization of the attribute considered, and
REp is the Relative Extent planned for the attribute considered.
AEa is the Absolute Extent of the actual realization of the attribute considered, and

Although the relative and absolute parts in the combined model are given equal weightage (0.5 each for p and q, where p and q represent the weightages for the relative and absolute parts respectively), these weightages can be different depending on whether a weak or strong sustainability outlook is adopted by the policy makers. For instance, when the relative part is given a higher weightage than the absolute part, say when p is 0.7 and q is 0.3; it means that the combined CHI is computed from a weak sustainability point of view since the relative part reflects actual values with reference to locally planned ones. Similarly, when the absolute part is given a higher weightage than the relative part, say when p is 0.3 and q is 0.7, the combined CHI is computed from a strong sustainability point of view since the absolute part reflects the actual values with reference to global

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

Fig. 2 : Flow Chart for Model Development



standards. The CHIs are comparable only when the weightages for the relative and absolute parts are equal, otherwise their interpretation is only location specific.

As quantitative data is neither available nor collectible with reference to many of those constituent parameters, a qualitative measurement instrument based on a five point likert scale may be used for measurement where with the input from about three experts familiar with the area, a suitable value to be fed to the model can be arrived upon. Effective interaction of a heterogeneous group of local experts or stakeholders, where they brainstorm in a systematic and structured way can yield reliable input data. The local coastal experts' interaction session arranged in this connection can readily come up with these values.

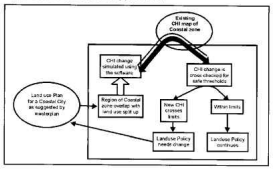
5. BROAD CONTEXT OF APPLICATION

CHI considers coast as composed of its 6 core characteristic components and coastal zone health is conceived as holistically reflected by the value of critical parameters pertaining to these specific characteristic components. These

Institute of Town Planners, India Journal 9 - 2, April - June 2012, 41 - 51

component environments are so chosen to comprehensively contain all coastal issues influenced directly or indirectly by land use planning. Primarily it is a metric to measure the health status for baseline condition mapping of the coast. It has to reflect state and process aspects of coastal systems and performance efficacy of coastal zone management system in place. Much of this is influenced by the land use planning system in place and the way it factors in measures to protect the development sensitivity of urban coastal zones. With the baseline condition mapped and coastal zone health condition assessed, land use alternatives make better sense as the proneness aspects of the background coastal zone is better documented and can be better taken care of. By establishing benchmarks and prescribing limiting thresholds for core component environment CHIs, land use planning process can be made impact analysis based, minimizing adverse impacts.

Fig. 3 : Broad context of Application



As shown in the Fig. 3, when a land use plan is proposed for an urban coastal zone stretch, one can assess the impact, the particular land use parcel has on the prevailing CHI and on comparing the crucially changed CHI values with acceptable minimum thresholds prescribed, and decision making or policy formulation is easier in land use plan or master plan finalization. An appropriate framework can bundle these modules into a user friendly graphical user interface (GUI) as shown in Fig. 3 with or without a geographical interface can help in structuring decision making in the area of sensitized coastal zone planning, which is the overall aim of this system.

6. CONCLUSIONS

CHIs as developed were reflecting the coastal zone health characteristics of the corresponding component environment to a considerable extent when validated. Wherever validated, availability of systematic data for CHI computation was a major problem in the Indian context and often the system has to depend on expert consultation for data validation. Hence, it is suggested that in the absence of well-maintained data on concerned parameters, a meeting of experts or stakeholders concerned need to be conducted in a systematic way to yield reliable input data. All the issues mentioned under critical aspects of modeling are tackled to the possible extent and treating this as a beginning, further refinements are possible on the model's logic and structure. An advantage of the component environment specific multiple CHI logic is that based on the city's preferences it can choose to be primarily ecology, economy or environment sensitive.

Land use categories versus CHI constituent parameters structure tends to be intricate, and hence needs focused deliberations involving appropriate experts. But it pays as ultimately compatibility of a land use category in terms of its influence on CHI is decided by a cross impact structure (CIS). Land use plan implementation system needs thorough revamping for this system to be effectively put in place for a coastal city. This happens only when grit, determination and synergy are shown by both administration and academia of the city concerned. However, in view of the grave danger that is imminent for most coastal cities and the order such a system would bring to those virgin coastal zones yet to be developed, and for the sustainable coastal systems it would put in place, it would be appropriate to attempt to implement the CHI based land use impact analysis system.

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