ASSOCIAÇÃO PORTUGUESA DOS RECURSOS HÍDRICOS

Journal of Integrated Coastal Zone Management (2023) 23(1): 7-26
© 2023 APRH
ISSN 1646-8872
DOI 10.5894/rgci-n489
url: https://www.aprh.pt/rgci/rgci-n489.html

QUANTIFYING THE INTERACTIONS OF LANDUSE ALLOCATION AND COASTAL ZONE SYSTEMS: A CONCEPTUAL FRAMEWORK

P. P. Anilkumar[@ 1], Koshy Varghese[2], L. S. Ganesh[3], K. S. Krishnaveni[4]

ABSTRACT: This paper presents a conceptual framework for quantifying the impact of landuse on coastal zone systems from a planning perspective. The framework is validated in a coastal zone stretch in Kerala, South India. Coastal critical landuses are identified through an expert questionnaire survey, and their relationship with the Coastal Zone Health Indicator (CHI) is established using the Analytic Hierarchy Process (AHP). The framework, which integrates the CHI models and the CHI Landuse Interaction Matrix (CLIM), is used to compute the changes in CHI values based on different landuse options. The proposed framework was validated using real-life landuse allocation cases in Kozhikode, Kerala, India, and the results showed that the framework could better assess and quantify landuse impacts. The framework is adaptable to different coastal contexts, and its capabilities can be enhanced by incorporating more specific algorithms. The methodology is a potential tool for decision-makers to promote better coastal sustainability by adopting appropriate governance policies and landuse planning decisions.

Keywords: Urban/Landuse Planning; Coastal Policy; Landuse Impact; Urban Coastal Management; Coastal Cities.

RESUMO: *Este artigo apresenta um marco conceitual para quantificar o impacto da utilização do solo nos sistemas de zona costeira a partir de uma perspectiva de planejamento. O marco é validado em uma região costeira em Kerala, na Índia do Sul. As utilizações críticas da costa são identificadas por meio de uma pesquisa com questionário para especialistas e sua relação com o Indicador de Saúde da Zona Costeira (CHI) é estabelecida usando o Processo de Hierarquia Analítica (AHP). O marco, que integra os modelos CHI e a Matriz de Interação de Utilização do Solo do CHI (CLIM), é usado para calcular as mudanças nos valores do CHI com base em diferentes opções de utilização do solo. O marco proposto foi validado usando casos reais de alocação de utilização do solo em Kozhikode, Kerala, na Índia, e os resultados mostraram que o marco pode melhor avaliar e quantificar os impactos da utilização do solo. O marco é adaptável a diferentes contextos costeiros e suas capacidades podem ser aprimoradas ao incorporar mais algoritmos específicos. A metodologia é uma ferramenta potencial para os tomadores de decisão promoverem uma melhor sustentabilidade costeira através da adoção de políticas adequadas de governança e decisões de planejamento de utilização do solo.*

Palavras-chave: *Planejamento Urbano/Uso da Terra; Política Costeira; Impacto do Uso da Terra; Gerenciamento Costeiro Urbano; Cidades Costeiras.*

@ Corresponding author: ppa@nitc.ac.in

1 National Institute of Technology Calicut, Kerala, India - Role: work conception, interpretation of data; design of the project, acquisition of data taxonomic identification; manuscript writing

2 Dept. of Civil Engineering, Indian Institute of Technology, Chennai, India-Role: Work guidance, Insights for data analysis, Interpretation of results. Email: koshy@iitm.ac.in

3 Dept. of Management Studies, Indian Institute of Technology, Chennai, India-Role: Work guidance, Statistical analysis, Interpretation of results. Email: lsg@iitm.ac.in

4 National Institute of Technology, Kozhikode, India-Role: Content organisation, Manuscript revision. Email: kveni07@gmail.com

Submission: 2 DEC 2021; Peer review: 22 DEC 2021; Revised: 7 SEP 2023; Accepted: 7 SEP 2023; Available on-line: 7 FEB 2024

1. INTRODUCTION

The coastal zone is a geographic area identified separately from terrestrial and oceanic domains. It may have an appropriate width of concern (with land and water together) based on relevant attributes of concern and/or the diverse forces at work. All coastal areas have exclusive features, which make them very sensitive to development plans. The sensitivity of coastal zones to development of any sort has been established long since (Clark,1998; Beach, 2002; Kay and Alder, 2005; MEA, 2005; Finkl, 2016; Dhiman, 2019; Jayanthi *et al*., 2022). The shoreline location of a coastal city is generally highly valued by investors and attracts them to develop there, causing it to grow and expand rapidly. (Kullenberg, 2001; Beach, 2002; Marshall, 2005; Barragán and de Andrés,2015; Zhang, 2019; Airoldi, 2021). The growth consequences typical of cities, when confronted with sensitive coastal systems, result in several conflicts and impacts and make development-related decision-making a very complex task (Chuai *et al*., 2016; Zhang *et al*., 2019; Eva *et al*., 2019; Xu *et al*., 2019; Bao *et al*., 2019). In essence, in most cases, the attention coastal urbanization righteously deserved was not granted. It is found that engineering construction and the generation of excessive domestic and industrial waste due to the development and growth of coastal cities have caused increased pressure on the environment and resources of coastal areas (Jiang *et al*., 2001; Diaz and Rosenberg, 2008; Shao, 2020; Zhao, 2022). These are the predominant problems of coastal urbanization in the developing and developed world.

Generally, different land areas are allocated for specific uses through the process of land use planning. It also includes policy-level interventions for economic, social engineering, and environmental benefits. Over time, the landuse plan and the accompanying proposals shape a city/region's (irrespective of its coastal status) development. These documents, which plan and schedule the future expansion of a city, are integral to the master plans; thus, they may be conceived as the earliest level of potential intervention for the sustainable development of coastal cities. The conceptual basis of this paper is rooted in this point. In coastal cities, landuse allocation, implementation, and management play a significant role in how coastal zones are used, developed, and often exploited. However, most Integrated Coastal Zone Management (ICZM) methodologies have not directly addressed this issue.(Olsen *et al*., 1997; Chua *et al*., 1997; Gilman, 2002; Burak, 2004; Barragán and de Andrés, 2015).

Kay and Walder (2005) established a link between coastal planning and management tools and argued that coastal planning should include the determination of the best use of their resources in the next 25-50 years, thereby ensuring a certain degree of certainty for future operations in that region. Though few independent instances of simulating landuse changes and impacts thereon were noted, such studies lacked the use of a suitable metric. Such studies have addressed the impacts of coastal development from such varied angles like climate change, biodiversity, etc., and yet lacked rigor for want of use of a metric (David, 2009; Mancosu *et al*., 2015; Hong, 2013; Qiandong *et al*., 2019; Rizal, 2020). Varied approaches adopted to evaluate ICZM implementation efficiency have not treated landuse aspects with deserving importance (Anthony, 2010; Eneko *et al*., 2010; Areizaga *et al*., 2012; Ballinger, 2017; Juanes, 2020). In addition, through a collection of well-formulated objectives, chapter 17 of Agenda 21 advocates that coastal states are committed to working towards the integrated management and sustainable development of coastal areas and marine environments in their jurisdiction. These observations highlight the need to formulate a conceptual framework to quantify interactions of landuse with various coastal zone systems from a planning perspective for appropriate decision-making.

The absence of a suitable metric to assess/quantify the implications of coastal landuse planning has made it nearly impossible for coastal city planners to consider the distinctive sensitivity of these zones towards development. This paper uses a composite metric, the Coastal zone Health Indicator (CHI), developed by the authors of this paper and founded on the principle of coastal system sustainability. CHI attempts to measure the aspect-wise and composite system health status of any coastal zone (Anilkumar *et al*., 2010). This paper discusses a conceptual framework and, thereby, an assessment system using CHI to quantify landuse impacts due to critical landuse allocation in urban coastal zones. Such a system can help in analyzing landuse allocations for their future impacts; thus, landuses can be planned to minimize the adverse effects. It can also help decision-makers compare alternative proposals, revise decisions, formulate policies, and thereby embark on a comprehensive strategy to attain sustainable coastal cities.

The paper is divided into six sections. The first section includes a general introduction, a literature review on coastal zone management systems, the metric CHI, and its purpose. The second section outlines the methodology, which includes identifying critical land uses, a framework for identifying land use impacts, predicting generic impacts of landuses, the basis for the CHI land use interaction matrix (CLIM), and expert-inputbased CD-specific CLIMs. The third section presents the results, which are further divided into three parts: weightings for the most critical land uses in the coastal zone, a consolidated CLIM table, and the application of the framework in the study area. The fourth section validates the proposed framework through real-life land use allocation cases in Kozhikode, Kerala, India. The fifth section provides a detailed discussion of the results. The final section summarizes the conclusions and limitations of the work.

Literature Review

The first part of this section attempts to overview similar systems characterized by a computer-based framework of specific methodology to help decision-making in sustainable urban planning, development, and ICZM. The second part of this section briefly details the conceptual framework objectives and scope of CHIs as a metric.

1.1 Systems of Coastal zone management significance

In order to aid in informed decision-making necessary for formulating policies to ensure efficient and optimal management of coastal resources, access to appropriate, dependable, actionable, and timely data and information in an acceptable format is of critical importance. Empirical knowledge of the mechanisms driving the Coastal zone system and its constituent sub-systems is an essential prerequisite for effective ICZM implementation (Capobianco, 1999; Trumbic, 2008; Elliot, 2020; Caviedes *et al*., 2022). The proposed framework attempts an integrated solution in this direction as it connects landuse planning initiatives and their impacts on coastal zone system status.

From investigating the impacts of coastal morphology and erosion on coastal communities (Krause and Glaser, 2003; Clark, 2016; Pikelj *et al*., 2018) to sustaining coastal systems' pristineness and eco-tourism potential (Foucat, 2002; Giuseppe *et al*., 2013; Nur *et al*., 2019), the notion of decision support models for ICZM has been examined and implemented by a multitude of research groups (Varghese *et al*., 2006; Frank *et al*., 2007; Maccarrone *et al*., 2014; Gumbira, 2019). These studies were, however, not sufficiently holistic or integrated for deriving the coastal profiles required for ICZM. Many of the decision support methodologies and systems in ICZM were developed in the Netherlands, and the prominent ones include the Coastal zone Simulation Model (COSMO), Risk Assessment in the Marine Environment (RAM) methodology, Rapid Assessment Module for Coastal zones (RAMCO), Coastal zone Simulation Model – Biodiversity (COSMO-BIO) and Policy wizard. These systems could analyze, prepare, and evaluate coastal zone management plans in a structured way. These interactive tools allow the decision-makers and planners to explore the effects of development projects and suggest various measures to protect the coast and environment (Taal, 2021; Delden and Vanhout, 2021).

Other similar broad-based systems of Urban/Environmental planning relevance include RIAM, ICity, DESYCO, etc. To aid the Environment Impact Analysis (EIA) process, Pastakia and Jensen (1998) proposed the Rapid Impact Assessment Matrix (RIAM). As an outcome, RIAM computes component-wise environmental score (ES) of impacts for baseline and alternative project options as a matrix. Mohammed and Kheireldin (2020) did a detailed environmental assessment to study the impacts of a drain in the surrounding ecosystem of the Nile delta using RIAM methodology and reported it as a valuable tool in offering environmental solutions. ICity (Stevens *et al*., 2007) is a software tool used in the predictive modeling of urban growth and was developed as an embedded model within a standard desktop geographic information system (GIS) with a user-friendly interface to control modeling operations for urban land-use change using cellular automata (CA). This may be applicable in predicting landuse changes and, thereby, systemic changes in the coastal zone. The Decision Support System for Coastal climate change impact assessment (DESYCO) is an easy-to-use GIS-based decision support system designed to manage and analyze the numerous impacts of climate change on coastal areas and associated ecosystems (e.g., wetlands, beaches, forests, urban and rural areas) at the local to regional scale within the framework of ICZM. The concept and scope of the metric Coastal zone Health Indicator (CHI), used for coastal zone profiling in the research, are presented next.

1.2 The metric CHI and its scope

To measure coastal systems' health from the perspective of landuse planning, a fleet of sectoral indicators along with an integrated composite indicator, the CHI, was postulated by Anilkumar *et al*. (2010). CHI is formulated and modeled to capture the status of the coastal zone at three levels, namely at characteristic components of the coastal zone, critical dimensions, and appropriate attribute levels. This metric can help monitor the urban planning (landuse) related activities and their ultimate impacts on the coastal zone through continuously tracking CHI changes. A brief description of the CHIs and their application is included in section 2 of the paper. It directly uses economic, environmental resource-related, and social inputs as a core attribute under six characteristic components (CCs) of a typical coastal zone. The CHI can help monitor, evaluate, and review coastal system health status against set goals and support decision-making. It can also provide important clues on the efficiency of the ICZM implementation system, specifically from an urban planning orientation.

The basic assumptions in formulating CHIs are listed below:

1. For coastal zones generically, there are 6 Characteristic Components (CCs) (as shown in column 2 of Table 1);
2. There are nine Critical Dimensions (CDs) collectively pertaining to the 6 CCs (as shown in column 3 of Table 1);
3. A CHI is specified for each CD. Each CD-specific CHI captures the status of a set of influencing attributes (as shown in column 4 of Table 1);
4. The individual CHIs can be aggregated into a Composite CHI as a gross level indicator;

CHIs are meant for use in various direct and indirect coastal zone management instances. In the process, they serve as:

1. State indicators for coastal zone's baseline condition mapping;
2. Metrics to compare and monitor baseline and future coastal system status;
3. Tools to measure efficacy and results of urban planning policies and actions operating on the coastal zone;
4. Process indicators reflecting management of coastal resources; and;
5. Indicators of efficiency of institutional arrangements for ICZM.

The CHI (Coastal zone Health Indicator) methodology proposed in this paper offers potential advantages as a comprehensive tool for coastal landuse management. The CHI models, as presented, can be refined to capture context specificities better, making them more effective in specific regions, such as urban coastal zones in India. However, some of the CHI attributes are subjective, and a consensus-based assessment by local experts is advised. The methodology used in the model formulation is extendable and can be adapted to include more relevant attributes. The CHI model addresses most of the objectives specified by Agenda 21 and is a step towards a comprehensive and sustainable coastal landuse management system for sensitive coastal zones. The baseline condition can be mapped, and the coastal zone health condition assessed, which makes it easier to understand and protect coastal zones. The CHI-Landuse Interaction Matrix can analyze the impacts of critical landuse proposals and help in rational decision-making. The proposed model can bring order to virgin coasts and help make sustainable coastal systems a reality, especially in light of the dangers coastal cities will continue to face in the coming decades.

2. METHODOLOGY

Decision-making on landuse allocations becomes complex in coastal cities, especially when impacts can matter to a much higher degree due to several sensitive coastal systems. This section deals with the methodology for evolving the stated framework. The first logical step to capture the sensitivity towards the development of various landuses in coastal zones is to identify the critical landuses to be located in coastal zones. The next step is to analyze and assess the impact dimensions of such critical landuses. This may lead to encouraging, accepting unconditionally or conditionally, regulating/controlling, restricting/limiting, or even banning certain landuses based on their expected impacts. Next, a theoretical framework to address the issue of landuse impact assessment on the CHI-based coastal zone profile status is presented. As part of the framework, quantification, and consolidation of the interaction of CHIs and landuses is done through the CHI landuse interaction matrix (CLIM). Next, the integration of CLIM with CHI models to devise the system to predict landuse impacts in the form of change in CHIs (both positive and negative) is proposed. Both to assess the critical landuses (based on their potential impacts on coastal zone systems) and assign weights to the impacts per se, the Analytical hierarchy process (AHP) was used. AHP (Saaty, 1980; Forman, 2001) is a dependable weight evaluation method and is presented as the most promising technique in various similar contexts in the literature (Eastman *et al*., 1998; Marinoni, 2004; Yoshimatsu, 2006; Youssef *et al*., 2010; Bathrellos *et al*., 2011). Figure 1 shows the flowchart of the methodology adopted.

The outcome of the methodology is an illustration of the Landuse Impact Assessment framework on the actual coastal zone of Kozhikode (Kerala, India) for a hypothetical set of land use allocations based on a master plan. This will provide insight into the potential impacts of different land uses on various coastal attributes and CHIs, allowing decision-makers to make informed choices about land use allocation in coastal zones.

Table 1. Characteristic Components (CCs), Critical Dimensions (CDs), and Attributes and their respective weightings for CHI computation (Anilkumar *et al.*, 2010).

No.	Characteristic Components (CCs)	Critical Dimensions/Aspects	Attributes
1	Flora and Fauna, and other resources (0.178)	Biodiversity and Resource abundance (0.5)	1. Mangrove wetlands (0.249) 2. Seagrass meadows (0.152) 3. Coral reef systems (0.249) 4. Lagoon and estuary systems (0.202) 5. Seafood resources (0.147)
		Other resources exploited within sustainable limits (0.5)	1. Non-living resources (sand, rock, etc.) (0.184) 2. Placers and other minerals (0.151) 3. Hydrocarbons (0.139) 4. Salt and Chemicals (0.158) 5. Freshwater (0.217) 6. Renewable energy resources (0.152)
2	Geomorphologic component (0.148)	Vulnerability to calamity/damage (1.0)	1. Geomorphologic vulnerability (0.620) 2. Beach slope (0.380)
3	Coastal process component (0.180)	Coastal process-related impacts/calamities on the Coast (1.0)	1. Coastal erosion (0.234) 2. Cyclones and storm surges (0.253) 3. Flooding (0.183) 4. Sea level rise (0.148) 5. Salinity intrusion (0.182)
4	Socio economic component (0.178)	Sectors of socio-economic activities and sector-wise volume of the transaction (1.0)	1. Industrial activities (0.081) 2. Tourism-related activities (0.132) 3. Fishing (0.262) 4. Residential activities (0.133) 5. Aqua/agriculture activities (0.194) 6. Basic trade/port/harbor (0.194)
5	Aesthetic component (0.083)	Visual, Noise, and Olfactory aspects (1.0)	1. Visual clutter, Litter, garbage, and filth (0.390) 2. Noise, Sounds of interfering nature (0.407) 3. Stench, obnoxious smells (0.203)
6	Environmental Pollution (0.234)	Air pollution (0.330)	1. Suspended Particulate matter (SPM) (0.226) 2. Oxides of Nitrogen(NOx) (0.252) 3. Oxides of Sulphur (SOx) (0.284) 4. Oxides of Carbon (COx) (0.238)
		Water pollution (0.330)	1. Pathogens (0.161) 2. Dissolved Oxygen (DO) (0.155) 3. Inorganic chemicals (0.127) 4. Organic chemicals (0.133) 5. Sediment contaminants (0.08) 6. Heavy metals and 1radioactive substances (0.353)
		Land Pollution (0.330)	1. Fish waste (0.099) 2. Sewage outfalls (0.248) 3. Pesticide used in coastal agriculture (0.145) 4. Litter/garbage (0.219) 5. Industrial waste (0.290)

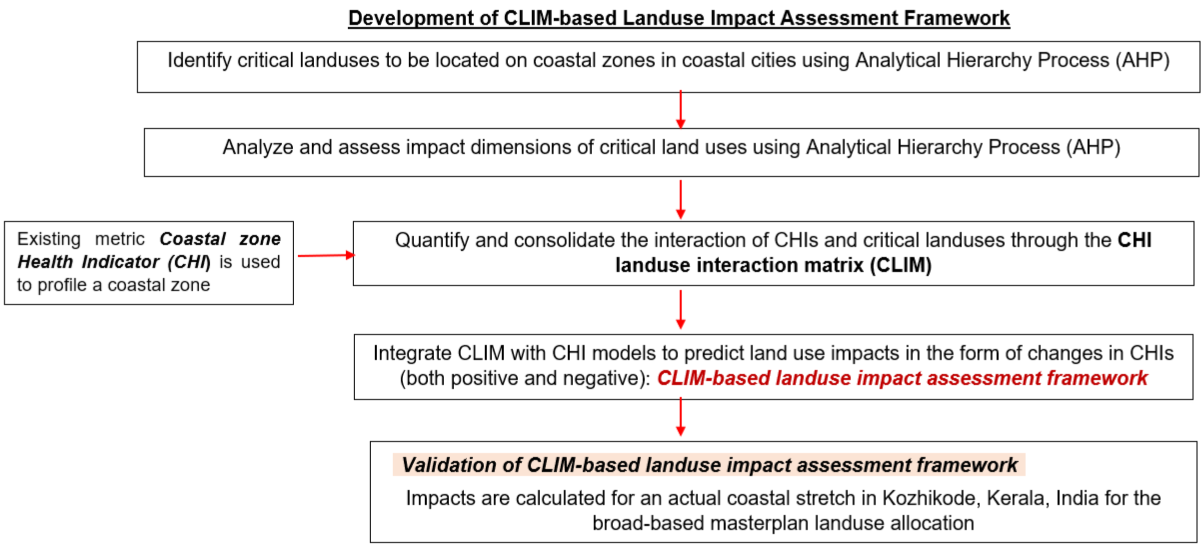


Figure 1. Flowchart of methodology.

2.1 Identification of Critical landuses

The critical landuses to be located in coastal zones have been identified using the AHP questions in a questionnaire survey of experts (QSE). The experts made pairwise comparisons of the six given landuse options. The criteria used by the experts to rate landuse criticality in coastal zones are given below.

1. Resource depletion/utilization caused by the landuse;
2. Waste production and disposal potential of the landuse concerned;
3. Movement of goods and people, the landuse would generate and;
4. Activity/infrastructure/amenities/support/services requirements of the landuse to function.

The first three criteria depend more on the inherent landuse based processes, whereas the last criterion focuses on building infrastructure for the landuse concerned. Based on the mean weighting for each landuse, its criticality has been assessed.

2.2 The framework to identify landuse impacts

The next step of the methodology consisted of evolving a theoretical framework for the assessment of impacts consequent to allocating critical landuses on the coastal zone. For this, landuse impacts were considered under two categories; Generic and Project specific impacts. Generic impacts are those which can be predicted even when landuse allocation/zoning is made. For most landuses, our ability to predict such impacts can be enhanced further by structuring and prescribing the planning parameters, such as type, scale, coverage, etc., of the landuse. In general, landuse allocations are realized/implemented in the form of specific projects and ancillary facilities of required details over a specific period (plan period). The project-specific impacts refer to the nature, quantum, and specifics of the generic impacts that follow the implementation of the complete landuse through projects. Broadly speaking, *Project-specific Impacts* = *Generic Impacts* $\pm\ \delta$. It depends on many parameters like developmental policies, the efficiency of the implementation process, funding patterns, etc., and are hence more difficult to predict, and the process may not be cost-effective.

2.3 Predicting the generic impacts of landuses

The term *generic impacts* imply the foreseeable limits of the impacts of landuses in the planning stage. For reasons cited in the previous section, the CHI-Landuse interaction matrix (CLIM) is developed solely based on the generic impacts of landuses. Important aspects considered for effective prediction of the generic impacts are:

1. Landuse Type: It refers to the basic types of landuse, such as industry, recreational, residential, institutional, etc., that are considered while planning;

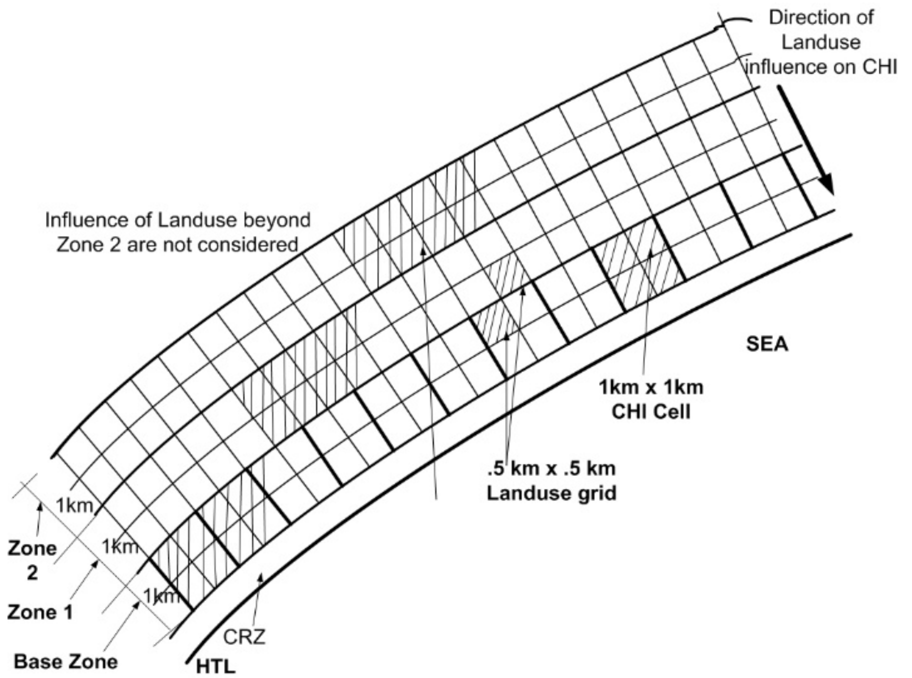


Figure 2. Premises for CHI Landuse interaction.

2. Geographical Area of Influence: It is the geographical extent of its influence zone;
3. Spheres of Influence: These are the various spheres of influence on which a landuse's impacts are of concern, such as natural environment, economy, society, etc., based on the context considered;
4. Baseline Documentation: Comprises the stock of the baseline status of the background before we analyze landuse impacts;
5. Development Control Instruments at disposal: It includes coverage, height, floor area ratio (FAR), etc.

2.4. Conceptual basis of CHI Landuse Interaction Matrix (CLIM)

As shown in Figure 2, all CHI categories are defined over 1 km^2 cells forming a base zone contiguous to the high tide line (HTL) or coastal regulatory zone (CRZ) limit. The next two consecutive zones (zones 1 and 2 of the same 1 km width, each consisting of cells of area 1 km^2) on the landward side away from the coastline (Figure 2). As part of the proposed framework, landuses are allocated in multiples of standard parcels 500 m x500 m for all zones. Although normal landuse parcels may be smaller in size in an urban context and bigger in the city peripheries, the size of 500mx500m may be treated as an average size chosen for the convenience of modeling. Even for validating the framework in the study area, 500m x 500m landuse sizes are considered.

The direct impacts on the CHIs are assumed to be only due to the landuses allocated in the base zone. The first and second-order indirect impacts are due to landuses allocated on zone 1 and 2, respectively, and it varies inversely proportional to distance. For simplicity, only impacts in a direction perpendicular to the coastline are considered.

CHI Landuse Interaction Matrix (CLIM) was formulated/modeled based on the following assumptions:

- CLIM is expected to reflect only the direct and generic impacts caused by critical landuse subcategories;
- CLIM is based on the assumption that landuses impact the CHIs only seaward subject to a maximum distance of influence;
- All cells are referred to using their geometric center;
- If multiple landuses are present in the same unit cell, only the most predominant landuse is considered.

2.5 CD-specific CLIMs based on Experts' inputs

The CHI Landuse interaction matrix (CLIM) shows (Table 2) the influences/impacts of various critical landuses (row-wise) on different CHI attributes (column-wise under specific CDs). These values are determined based on expert inputs obtained using an AHP methodology based on the aspects listed under section 2.3. The values in CLIM are for the direct generic impacts resulting from the landuse category concerned. Indirect impacts are computed based on the rule that the gravity of an impact is inversely proportional to the distance, subject to the maximum limiting distance of influence, which is landuse specific.

As stated earlier, CLIM was developed based on an AHP methodology. For this, a questionnaire survey requiring pairwise comparisons of landuse influences on CD-wise attributes as responses was administered. The questionnaire has been designed to understand the generic impacts of different landuses on various coastal attributes of concern. The survey covered sixty-seven experts over five expert categories from three different coastal regions in India (namely Konkan, Kerala, and Chennai). The experts were drawn from research institutions, academic institutions, development authorities, NGOs, consultant organizations, and other state and central government establishments of repute in India. To determine the relative weightings of the CCs, their CDs, and their respective attributes, the AHP methodology was also employed.

Six such questionnaires were developed corresponding to the six CCs. Each questionnaire had two parts. In the first part, the experts were required to make pairwise comparisons of CD-wise attributes with reference to each critical landuse so that the gravity of the influence could be rated attribute-wise. The second part consisted of two sections. In the first section, the experts were required to specify (on a 1 to 10 scale) the possible gross extent of impact intensity on each CD corresponding to the intensity variation of the particular landuse. In the second section, each expert was required to indicate (on a 0 to 3 scale having a least count of 0.25) the maximum drop/rise in the corresponding CHI for cross-checking the consistency of inputs.

3. RESULTS

Results obtained during the various phases of the methodology were put together to develop the CHI based landuse impact assessment framework. Details are discussed further in this section.

Table 2. CLIM table in detail for the critical components (CC) geomorphologic component and coastal process.

CZ CCs		Geomorphologic Component and Coastal Process (GC, CP)						
CC's CDs		Geomorphologic component		Coastal process component				
		CD Attributes		CD Attributes				
Land use Category		Geomorphologic vulnerability	Beach slope	Coastal erosion	Cyclones & storm surges	Flooding	Sea level rise	Salinity intrusion
Industrial	SS							
	MS							
	LS							
Residential	LD							
	MD		0.83					
	HD							
Recreational	SS							
	MS							
	LS							

A value reflecting the landuse type's generic impact on corresponding CHI attribute

3.1 Weightings for the most Critical Landuses on the Coastal zone

Based on the results of the AHP analysis, the critical landuses to be allocated on Indian coastal zones are identified as given below, in their order of criticality or importance in coastal zone landuse planning. Their weightings are shown in brackets:

1. Industrial (0.306);
2. Landfill/ waste dumping (0.278);
3. Recreational (0.123);
4. Residential (0.122).

However, from this list, the landuse of Landfill/Waste dumping is excluded in all further analyses, as there is sufficient evidence to suggest that activities associated with this landuse are damaging to the natural environment and its sustained productivity. At the next level, the three critical landuses were sub-classified as given below for effective allocation/zoning to minimize their adverse impacts on CHIs and for a more structured assessment of impacts:

- Industrial – based on intensity/scale, it is further classified into *small*, *medium*, and *large scale* (represented as *SS*, *MS*, and *LS*);
- Residential – based on permitted population density, it is further classified into *low, medium*, and *high population density* (represented as *LD*, *MD*, and *HD*) and;
- Recreational – based on the scale of operation, it is further sub-classified into *small*, *medium*, and *large scale* (represented as *SS*, *MS*, and *LS*).

The background assumptions/premises for CHI landuse interaction are presented next.

3.2 Consolidated CLIM table

The consolidated CLIM table (a part of this is shown in Table 3) helps to simulate CHI changes due to landuse changes. It consists of all the nine CD-specific matrices corresponding to all nine landuse subcategories (three critical landuses with their three subcategories). The CLIM page has also incorporated the limiting distance of influence factor in its last column. Values, as given in the table, are based on the survey outcome and may vary based on the coastal region and its context sensitivity.

When landuse changes are suggested, the CLIM data is accessed (from a full version of Table 3, where values corresponding to the interactions of all landuse categories with all the CD-wise attributes are documented) to compute CHI changes accordingly.

3.3 Application of the framework in the study area

The proposed framework that utilizes the CLIM table is illustrated with the help of an abstracted real-life landuse allocation case based on a masterplan in the Northern part of Kozhikode (Calicut) city, Kerala, India (Figure 3).

Table 3. CLIM Table showing landuse impacts on Geomorphologic Component and Coastal Process (CD's).

Geomorphologic Vulnerability and Coastal Process (GV CP)								
Land use Category	GV, CP Parameters							
	Geomorphologic Vulnerability	Beach Slope	Coastal Erosion	Cyclone Proneness	Flooding	Sea Level Rise	Saltwater Intrusion	Limiting distance
Ind.SS	0.83	0.93	0.97	0.98	0.98	0.98	0.94	3
Ind.MS	0.78	0.90	0.96	0.96	0.96	0.97	0.91	3
Ind.LS	0.70	0.87	0.93	0.95	0.94	0.95	0.87	4
Recr.SS	0.90	0.94	0.96	0.98	0.95	0.97	0.94	2
Recr.MS	0.84	0.90	0.93	0.96	0.92	0.95	0.89	2
Recr. LS	0.73	0.82	0.91	0.94	0.88	0.92	0.85	3
Resi. LD	0.84	0.88	0.97	0.97	0.95	0.97	0.92	1
Resi. MD	0.77	0.83	0.95	0.96	0.93	0.95	0.87	1
Resi. HD	0.67	0.76	0.92	0.94	0.90	0.93	0.81	2
NCL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1

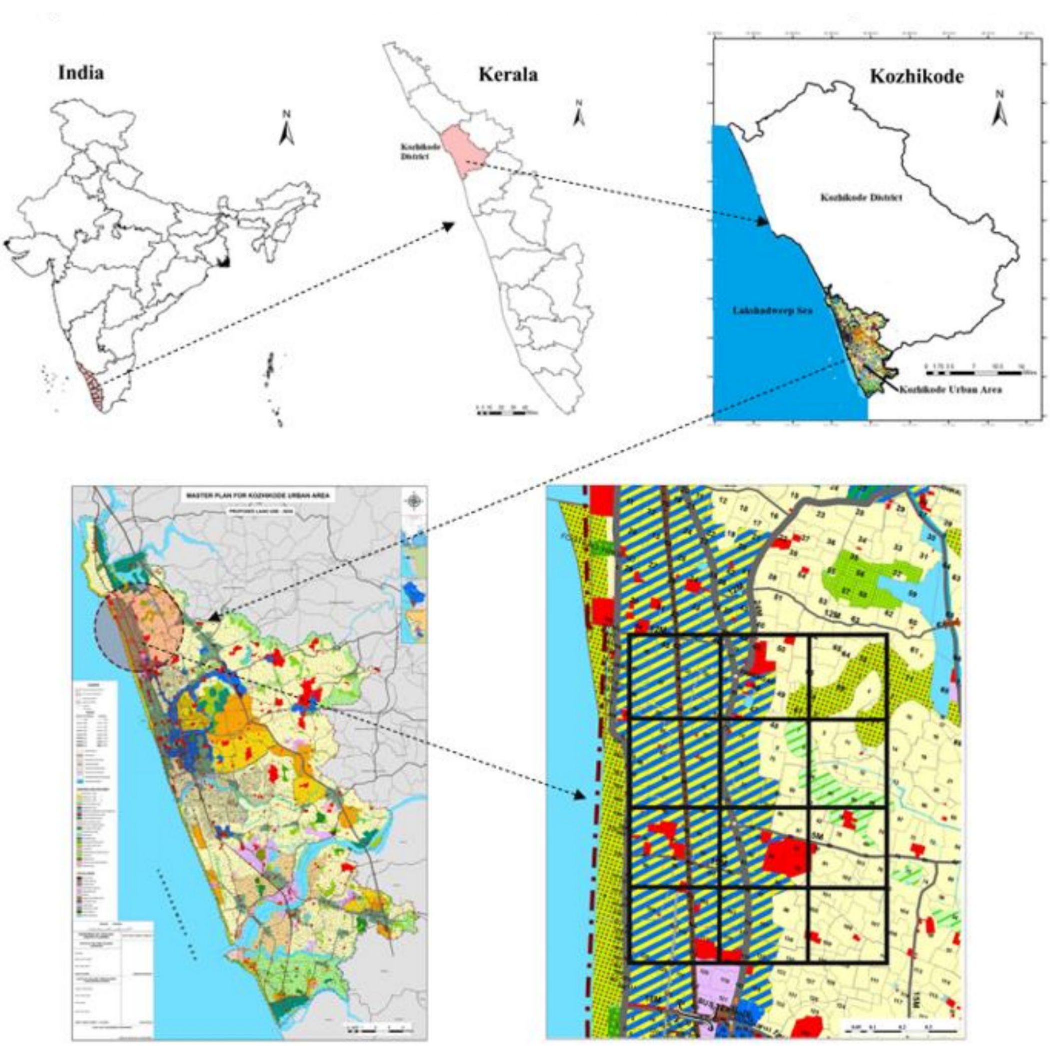
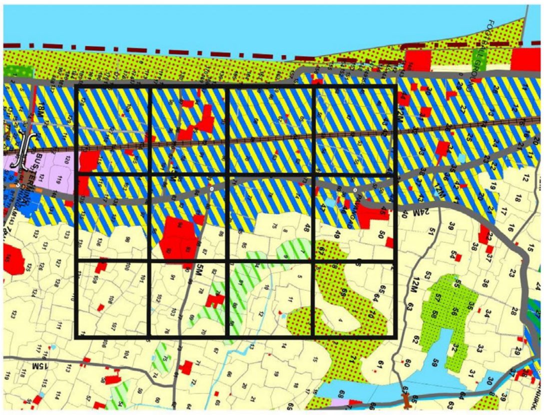


Figure 3. Map of the study area location.

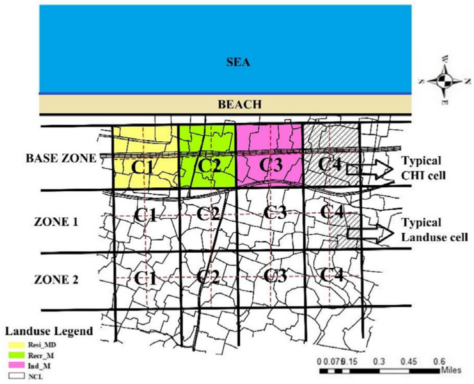
The coastal zone extends for about 2 km length along the coastline (bounded by HTL) and 1.5 km of width perpendicular to the coastline (this 2 km x 1.5 km stretch is divided into a base zone, zone 1, and zone 2 of 0.5 km width each along the coastline, called as the study area (Figure 4)).

As the existing landuse parcels in the validation area are smaller in size in the study area (compared to the typical CHI and landuse cells prescribed as 1 km x 1 km and 0.5 km x 0.5 km, respectively), in the abstracted real-life case CHI cell size considered is 0.5 km x 0.5 km and the landuse cell/ parcel size considered is 0.25 km x 0.25 km. This part of the coastal zone is located approximately 8km from the Central Business District (CBD) Mananchira, and the current master plan (2015-35) proposes landuses in this area that are not tested for coastal zone compatibility.

The model case of landuse allocation/change analyses four alternative cases of landuse allocation in the study area. The base zone, in this case, has four cells (of 0.5 km x 0.5 km size for which CHIs are defined) named C1 to C4 (Figure 4). Landward from the base zone, zones 1 and 2 respectively of 0.5 km width each are also considered part of the model case (Figure 4). Each CHI cell, as depicted, is approximated into four numbers



Orientation changed to 90 degrees



Layout of typical CHI cell and land use cells across different zones

Figure 4. Equivalent grid-based land use layout based on the masterplan.

of 0.25 km x 0.25 km landuse cells as proposed. Baseline CHIs computed as per the concept explained are used for this analysis and further to illustrate the use of CLIM for analyzing landuse impacts on CHI. At present, all cells have NCLs, and the baseline CHIs correspond to this status.

4. VALIDATION

The validation presented here using the proposed framework aims to quantify the landuse allocation impacts and assess its coastal zone compatibility. Currently, this area is dominated by non-critical landuses (NCL). The validation attempts to allocate typical parcels of critical landuses in three out of four cells in the chosen area's base zone, zone 1 and zone 2, and evaluate the CHI changes as detailed in Figures 5 and 6.

Cases 1A to 1D correspond to the introduction of different sets of critical landuses into this layout's various zones in sequence. In all these cases, landuses are allocated only to cells 1 to 3 of the base zone, zone 1 and 2. 4^{th} cell's NCL is retained in each zone for ease of comparison (say, with the baseline conditions). These landuse allocation options are discussed as cases 1 A to 1D below.

Case 1A: All three cells of the base zone only are allocated medium-density residential (RESI MD), medium-scale recreational (RECR M), and medium-scale industrial landuses (IND M), respectively (Figure 5 (case 1A)). As mentioned, no new landuse is allocated to the fourth cell, and NCL continues there. This case (1A) helps assess the impact on respective CHIs when critical landuses of medium density/medium scale are allocated only on the base zone.

Case 1B: All three cells of the base zone only are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 5 (case 1B)). As in Case 1A, NCL continues in the fourth cell. This case helps assess the impact on respective CHIs when critical landuses of high density/large scale are allocated on the base zone.

Case 1C: All three cells of the base zone and corresponding cells of zone1 are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 6 (case 1C)). As mentioned, the fourth cell has NCL continuing. This case helps assess the extent of the impact of allocating various critical landuses of high density/large scale on the base zone and zone 1 together as it can capture the compounded and indirect impacts to a certain extent.

Case 1D: All three cells of the base zone, zone 1 and zone 2 cells, are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 6 (case 1D)). As in the previous case, the fourth cell has NCL continuing. This case helps in assessing the extent of the impact of allocating various critical landuses of high density/large scale on the base zone, zone 1, and zone 2 simultaneously as it can capture the compounded and indirect impacts of the allocation.

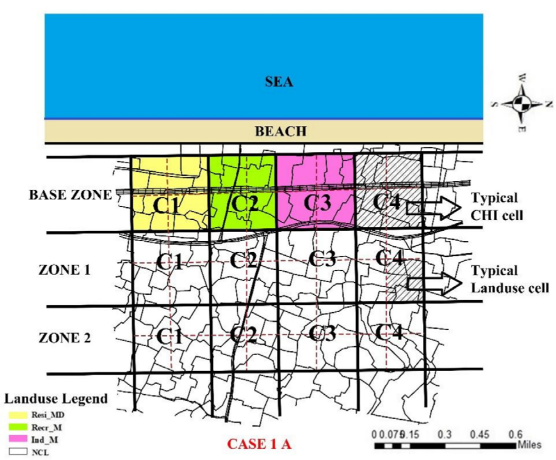


Figure 5. Case 1A and Case 1B Landuse grids.

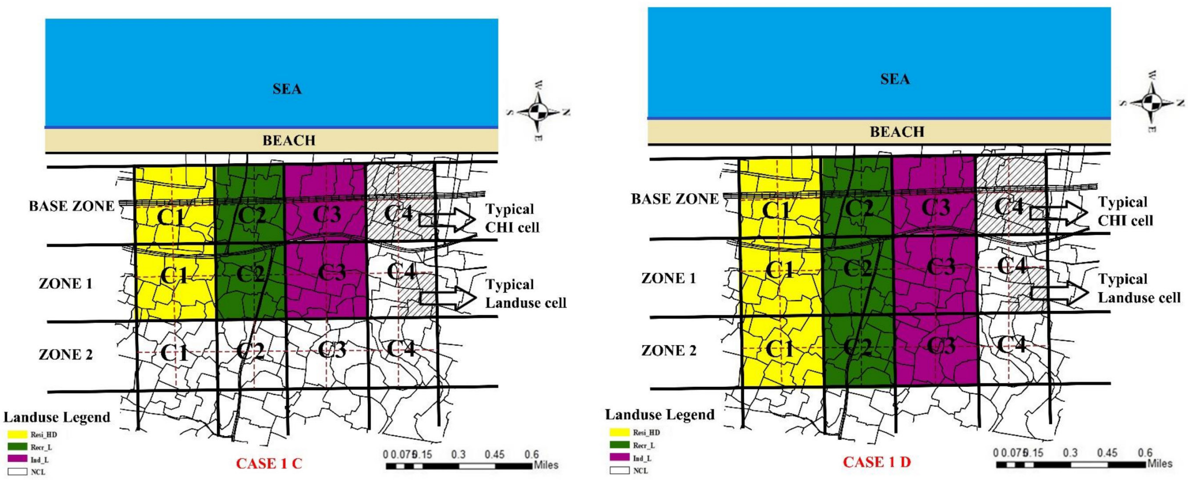


Figure 6. Case 1C and Case 1D Landuse grids.

5. DISCUSSION

From figure 7 to 10, which consolidates cases 1A and 1B, it is seen that with a critical landuse of even medium-density allotted to the base zone cell, CHIs decrease across the board (all 9 CHIs) but to varying extents.

It can be seen that from a generic perspective, recreational landuse impacts CHIs the lowest, residential influences the higher, and industrial the highest. When environmental (air, water, and land) pollution, CHIs are considered recreational landuse is more detrimental than residential and industrial has the highest influence. In the case of other resources' CHI, residential is the most detrimental as it prevents the process of resource extraction from taking place as a policy priority. (As per CHI assumption and as a matter of policy, resource extraction up to a sustainable level is encouraged as it can sustainably enhance the quality of life of the coastal population.) CHI of Geomorphologic vulnerability is influenced most by residential landuse, and this may be attributed to the substantial amount of land modification to the landmass consequent to residential development on coastal zones. It is interesting to note that aesthetic pollution CHI is least affected by residential landuse as planned residential development is capable of maintaining improved aesthetics. The impact on socio-economic CHI by all three medium-scale critical landuses is comparable. Regarding socioeconomic CHI, landuse allocation (especially industrial and recreational) may have both positive and negative impacts, and the observed values may reflect the net change. When composite CHI value consequent to medium-scale landuse allocation is compared, recreational and industrial landuse have caused the highest and almost comparable drop, and residential landuse brought a lesser drop.

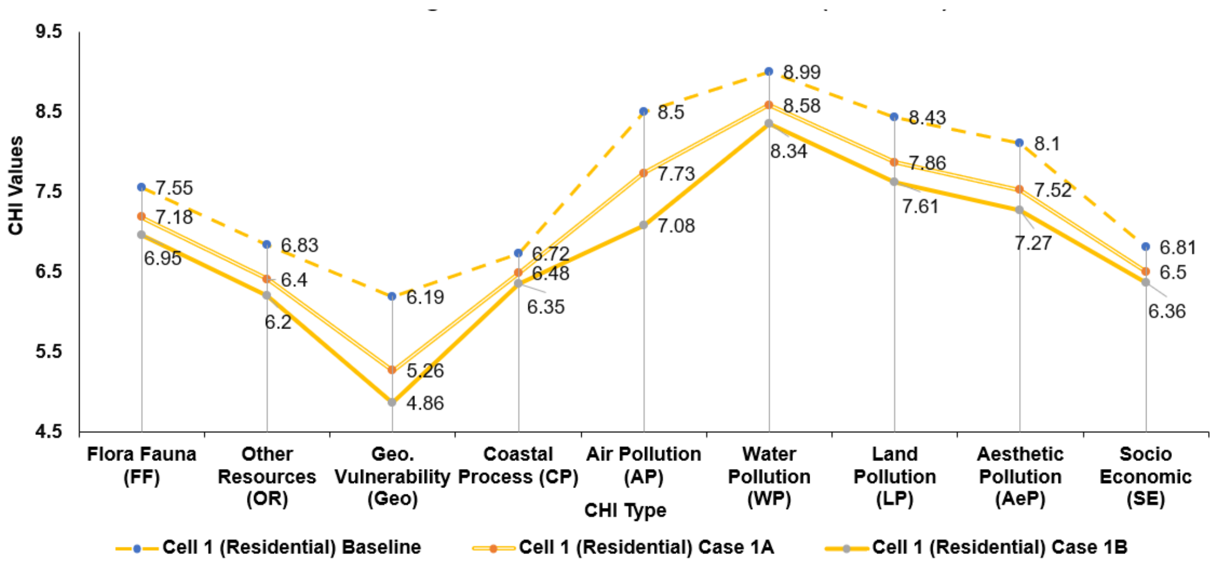


Figure 7. Baseline and changed CHI along cell 1 (C1) due to landuse allocation (Residential) on the base zone.

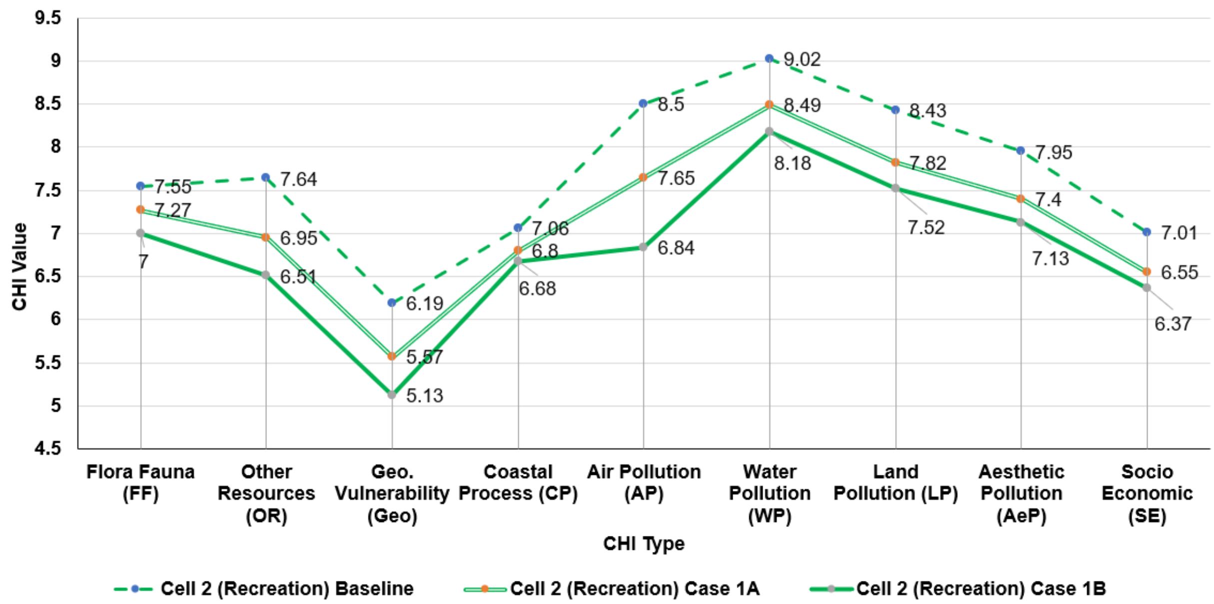


Figure 8. Baseline and changed CHI along cell 2 (C2) due to landuse allocation (Recreational) on the base zone.

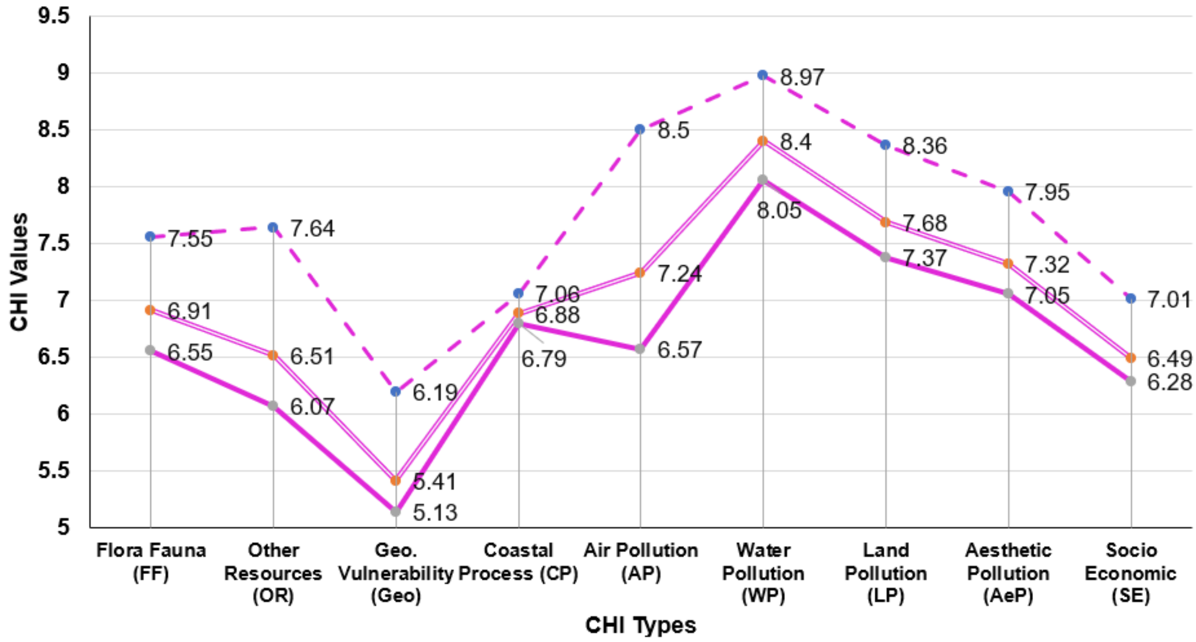


Figure 9. Baseline and changed CHI along cell 3 (C3) due to landuse allocation (Industrial) on base zone.

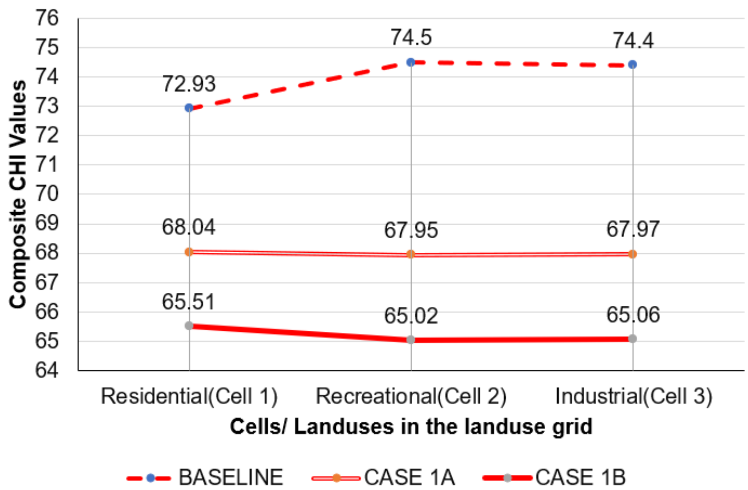


Figure 10. Variation of composite CHI across different cases.

When landuses of large/high intensity/density were allocated to the base zone, understandably, it was observed that the extent of CHI drop increased for all categories of CHIs compared to medium-scale landuses. Most features of individual CHI variations, as discussed above, remain the same in this case as well. It is observed that the CHI drop due to replacing medium-scale/intensity landuses with large-scale/intensity ones in the base zone results in the net CHI drop going up by 50 to 100%. It is observed that the extent of the negative influence of a particular landuse depends on the CHI category under consideration and the scale/intensity of the landuse proposed.

Figures 11 to 14 (that consolidate cases 1C and 1D) document the change in CHIs due to allocating landuses on zones 1 and 2 in addition to the base zone. In this instance also, it can be seen that recreational landuse impacts CHIs the lowest, residential influences higher, and industrial the highest. When environmental (air, water, and land) pollution CHIs are considered, industrial landuse is the most detrimental, followed by recreational landuse and then residential landuse. Although the CLIM worked out is capable of assessing CHI changes due to mixed categories of critical landuses in zones 1 and 2 (critical landuse that is different from the one assigned to the base zone cell), for simplicity, in this illustration, the same critical landuse that is assigned to the base zone is assigned to the corresponding cells of zone 1 and 2.

When cases of 1C and ID are considered, where critical landuses are allotted to zones 1 and 2 in addition to the base zone, the outcomes and trends are different for cases 1C and 1D. In the case of 1C highest drop in CHIs is caused by the landuse of industry, and the next highest drop by recreation and residential causes the least drop-in CHI. When you compare the case of 1D, where critical landuses are allotted to zone 1 and 2 in addition to the base zone, again, industries are bringing down the CHIs maximum, followed by residential, and then the least drop is by recreational. This is opposite to what we have seen in case 1C, which is specifically similar to the earlier cases discussed in 1A and 1B. It is observed that the CHI drop due to the additional allocation of large scale/intensity landuses to zone 1 and 2 cells (where base zone cells are already allocated the same landuse) is higher by 40 to 60% in this case.

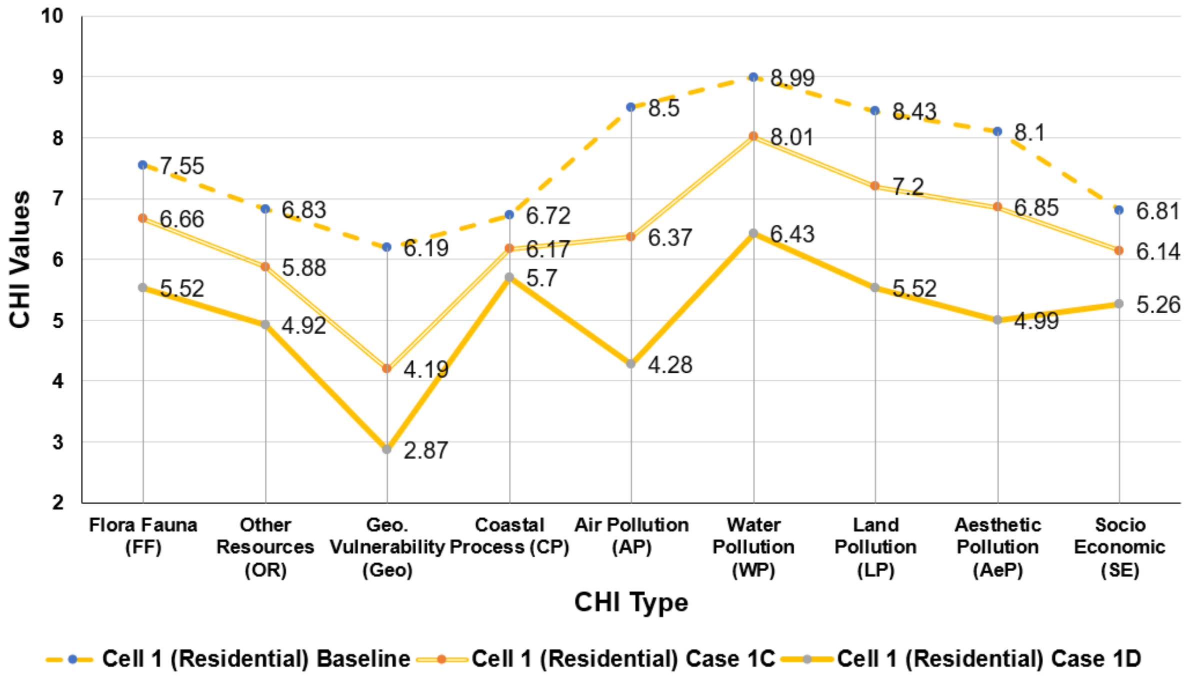


Figure 11. Baseline and changed CHI along cell 1 (C1) due to landuse allocation (Residential) in zone I and zone II.

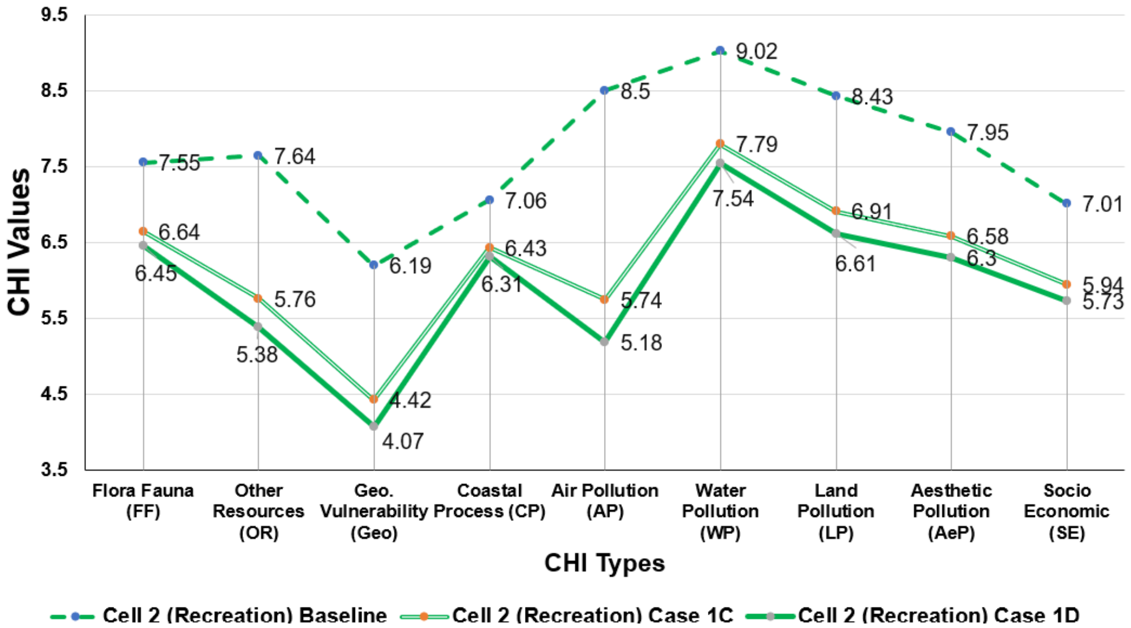


Figure 12. Baseline CHI and changed CHI along cell 2 (C2) due to landuse allocation (Recreational) in zone I and zone II.

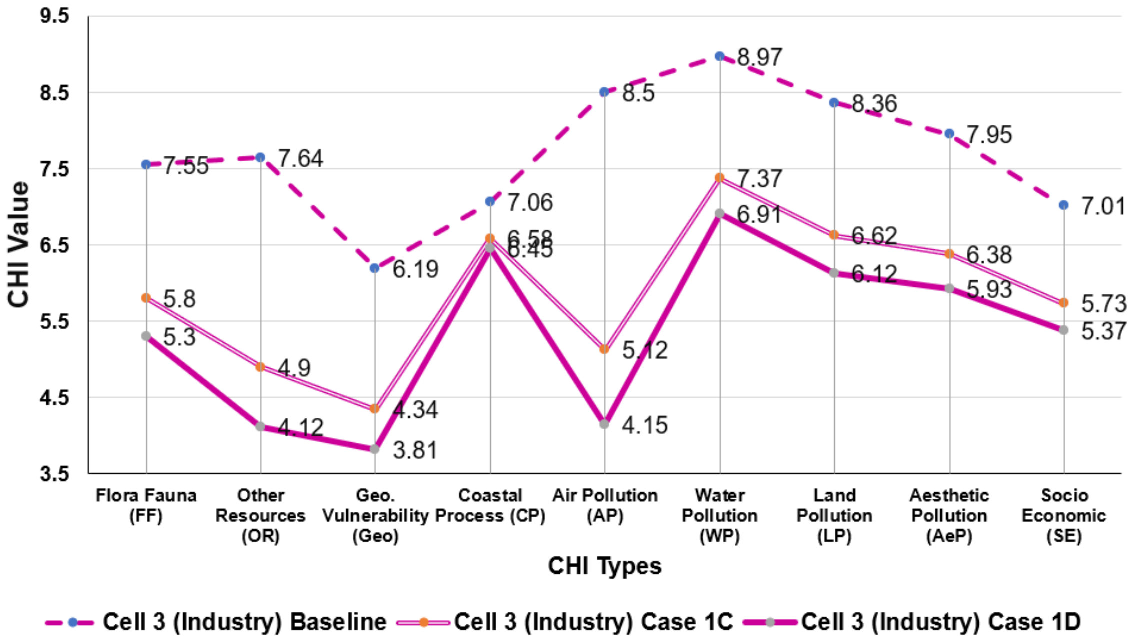


Figure 13. Baseline CHI and changed CHI along cell 3 (C3) due to landuse allocation (Industrial) in zone I and zone II.

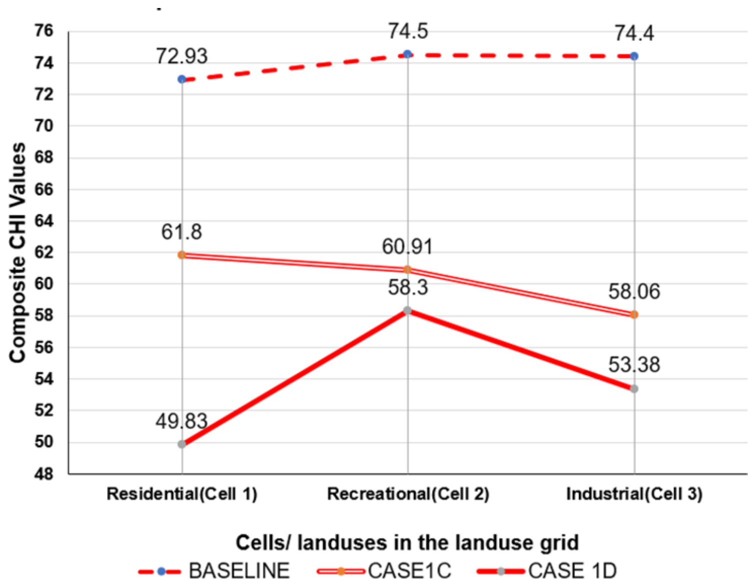


Figure 14. Variation of composite CHI across different cases.

When cases of 1C and 1D are separately compared, landuse impact computed based on CHI drop is maximum for residential landuse, followed by industrial landuse, and the least amongst is for recreational landuse. The outcome of 1C and 1D indicates that the issue of allocating landuses on the base zone (i.e., at the critical interface between the water's edge and the land mass) and the priorities of allocating it to subsequent zones (zone 1 and zone 2) need to be different as the extent to which and how they influence CHIs of different types are different. Additional CHI drops due to allocating large-scale recreational landuse are in the range of 20 to 30%, whereas for large-scale industry allocation, the drop is in the range of an extra 20 to 40%. It may also be observed that wherever applicable, the influence of landuses allocated to zone 2 on CHIs is quantitatively less than the influence of landuses assigned to zone 1.

6.CONCLUSIONS AND LIMITATIONS

This paper presents a conceptual framework for quantifying the impact of landuse on coastal zones from a planning perspective using the index called Coastal zone Health Indicator (CHI), validated in a coastal stretch of Calicut (Kozhikode), Kerala, South India. The framework integrates critical landuses identified through an expert questionnaire survey and their impact on participatory attributes using the Analytic Hierarchy Process (AHP) and the CHI- Landuse Interaction Matrix (CLIM). The proposed framework with CHI benchmarks has the potential to better assess and quantify landuse impacts.

The framework uses a questionnaire survey among experts in related fields of study to gather necessary inputs and utilizes the results of AHP analysis to arrive at CLIM (CHI Landuse Interaction Matrix). The modeling methodology is flexible and adaptable to different coastal contexts and can handle a wide range of situations with required changes. The CLIM logic based on AHP is flexible and can be extended to include more landuse cases and attributes of concern for the coastal zone. Adopting an appropriate policy framework can help regulate the CHI drop to a set percentage, thereby limiting development impacts on coastal zones. Future policy research can focus on redefining the allowed thresholds of CHI drop for various CHI and landuse combinations. The methodology framework quantifies the impact of landuse planning decisions on the coastal zone by tracking corresponding changes in CHI.

The validation process evaluated the impact on CHI's by assigning typical portions of critical landuses to three of the four cells in the base zone, zone 1, and zone 2 of a selected coastal area. The four cases (1A to 1D) analyze the impact on the coastal zone health index (CHI) by introducing different sets of critical land uses into specific zones in the coastal zone.

Case 1A allocates medium-density residential, medium-scale recreational, and medium-scale industrial land uses only to cells 1 to 3 of the base zone. Case 1B allocates high-density residential, large-scale recreational, and large-scale industrial land uses only to cells 1 to 3 of the base zone. Case 1C allocates the same high-density, and large-scale land uses to cells 1 to 3 of the base zone and corresponding cells of zone 1. Case 1D allocates the same high-density, and large-scale land uses to cells 1 to 3 of the base zone, zone 1, and zone 2. The results of these cases help to assess the extent of the impact of allocating various critical land uses on CHI and the compounded and indirect impacts of the allocation.

The findings from the analysis show that when large-scale, high-intensity and high-density land uses are allocated to the base zone, there is a significant decrease in the CHI, indicating severe coastal zone degradation compared to medium-scale land uses. The extent of CHI drop ranges from 50 to 100%. The results also suggest that the extent of the negative impact of a particular land use depends on the CHI category and the scale and intensity of the proposed land use. The allocation of critical landuses, such as industry, recreation, and residential, to different zones of the coastal area can have different impacts on the CHI. In case 1C, the highest drop in CHIs is caused by the landuse of industry, followed by recreation, and the least amount of drop by residential. In contrast, in case 1D, the highest decline in CHIs is caused by industries, followed by residential, and then the least by recreation, which is the opposite of what was seen in case 1C. The study also found that the CHI drop due to the allocation of large scale/intensity landuses to zone 1 and 2 cells is higher by 40-60% in case 1D compared to other cases.

While the framework provides a valuable tool for decision-makers in coastal zone management, it has several limitations that should be acknowledged. Firstly, the framework does not address project-specific impacts as they depend on various factors such as development policies, implementation processes, funding patterns, and so on, making them more challenging to predict and potentially not cost-effective to assess. Additionally, the current representation of landuse assumes a minimum parcel size in a regular shape, which may not always reflect the true nature of landuse allocation. Improving the representation through GIS-based systems and incorporating radial impacts, variable grid sizes, and improved algorithms could enhance the framework's precision in impact prediction.

The current CLIM is designed to model usual landuse categories, but special landuses or sensitive coastal zones may require modifications to fine-tune the impact prediction process. The capabilities of the framework can also be improved by incorporating more specific algorithms and incorporating landuse and attribute-wise changes. The validation part of the study is intended to demonstrate the generic nature of the framework, and future research can focus on incorporating more specific algorithms, more precise parcels of landuse allocations, and refining the permitted CHI drop based on different landuse combinations.

In conclusion, the methodology framework discussed in this paper offers a valuable tool for quantifying the impact of landuse allocation on coastal zones and tracking corresponding changes in CHI. When impacts are evident, the framework can assist decision-makers in formulating governance policies and achieving better coastal sustainability in a planned and systematic manner through adopting appropriate regional variations and mandatory use. The AHP-based CLIM logic is also extendable for more landuse cases and attributes of concern, providing a versatile tool for coastal zone management, especially in coastal city contexts.

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