Framework for Analysing Coastal Vulnerability Due to Sea Level Rise and Coastal Floods using R

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ABSTRACT
Sea level rise is a natural global phenomenon which is aggravated by anthropological activities. Severity of the rise varying in different parts of the world but the stress in general is increasingly threatening human development. Sustenance of a few species and their ecosystem depends on the rate and extent of rise.

Coastal floods are inundations in coastal areas due to rise in sea water level. The inundations could be either temporary (high tide, heavy rainfall, tsunami and cyclones) or permanent (global warming).

Coastal zones are among the highly populated areas having most diverse ecosystem. They are directly affected by the sea level rise phenomenon. This population is mainly dependent on the coastal ecosystem for their livelihood. Continuously increasing sea levels and receding coastlines are concern for policy and decision makers. This emphasises the need for an easy to use tool for rapid scenario generation and frequent analysis.

Current work focuses on a framework for open source tool using R for coastal inundation vulnerability mapping and scenario generation. This tool uses global data sets like ASTER Global Digital Elevation Model along with SRTM elevation data. The tool can be used for India as a whole or for various state/district level analysis. The key inputs for this tool are rainfall information, tide level and rate of sea level rise. The output of the scenario generation will be in .kml, .shp and .tiff file format. Maps can be generated using preloaded vector files.

Keywords
Sea level rise, coastal inundations, vulnerability mapping, open source tool, R

1. INTRODUCTION
Climate change has always been a perpetual global phenomenon affecting ecosystems and forcing them to adapt accordingly for survival. The rate of the climatic change and adaptation of ecosystem, both remained under control till last century. Population explosion along with industrialisation in last century has expedited the rate of climatic change, leading to increase in stress on the ecosystems. These changes are testing the limits of adaptability of the ecosystem and the sustainability of available resources.

Human population is unevenly distributed around the globe. Higher the population density more is the stress on the ecosystem and local resources. Areas within 100 km from coastline are among the densely populated areas around the globe [1]. It is projected that the population in coastal zone will increase leading to further increase in coastal population density in near future [2].

Analysis carried out by Small and Nicholls shows that, population dwelling within 100 km of the shoreline and 100 m of sea level is estimated as 1.2×10^9 people with average densities nearly 3 times higher than the global average density. In the coastal zone, the average population density reduces rapidly as function of elevation than distance. [3]

Poulter et al. stated coastal areas as most vulnerable towards climate change and mainly, sea level rise. They further insisted on worldwide research in the field of coastal vulnerability for planning purpose [4]. The important parameters identified for vulnerability are the stress in the system, sensitivity and resilience of the system [5]. Estimation of potential exposure of coastal communities to flooding is therefore a critical task for long term planning and risk assessment, given the typical life of coastal defence structures of 50–100 years [6].

Accelerated sea level rise and coastal inundations are giving rise to complex effects on the coast and coastal ecosystem. These effects are mainly driven by anthropogenic activities and hence mainly affecting the areas with high population density [7]. This implies that there is a need to study the inundation patterns and coastal vulnerability for the development and planning of a sustainable coastal zone.

2. NEED FOR COASTAL INUNDATION MAPPING TOOL
The case study carried out by Snoussi et al. for Morocco using GIS based analysis for coastal inundation indicated that for understanding the socio-economic vulnerability, it is necessary to map the coastal vulnerability using inundation scenarios. This kind of analysis is needed for policy making and response strategies for coastal zone and also for integrated coastal zone management plan [8]. This emphasizes need for timely inundation scenario generation for the coastal zone and scenario generation tools.

DIVA is a user-friendly tool for assessing coastal vulnerability at global and regional level. This tool is one of the very effective freely available tools for coastal vulnerability assessment. Hinkel and Klein while discussing about this tool, mention the need for decision support tools for decision makers and planners at local scale with high resolution data for coastal inundation and vulnerability

mapping. They also discuss about tools which are easy-to-use, meant not only for experts. [9]

The current tool tries to focus on decision makers and planners at country and local scale. This tool also focuses on a simple-to-use user interface for common users. The use of high resolution digital elevation model makes it a powerful tool for local analysis.

3. FRAMEWORK OF COASTAL INUNDATION MAPPING TOOL

The proposed tool follows expert system approach for the analysis of coastal flooding and vulnerability analysis. This tool uses climatic parameters fetched from user, along with the terrain parameters generated using elevation data (available in the form of digital elevation model). The district map of India can be used by the user to demarcate the area for analysis. The framework for the proposed tool is given in figure 1.

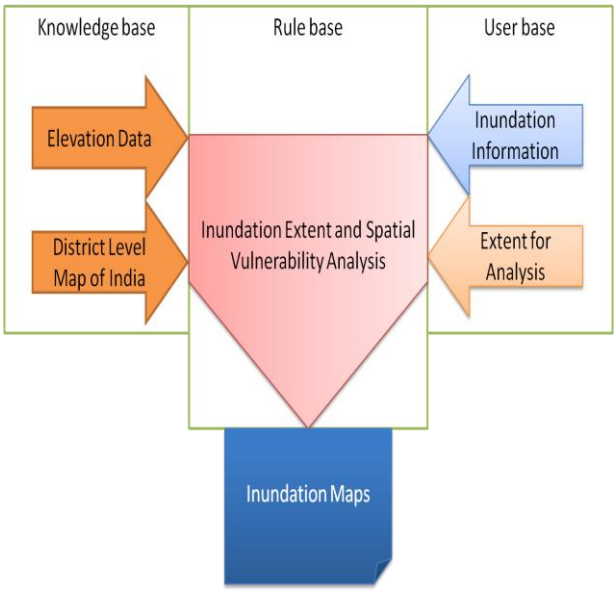

Fig 1: Framework for the proposed tool

As seen in the figure the framework is divided into four components viz. knowledge base, rule base, user base and output. These components are explained in the following section.

3.1 Knowledge Base

It is the inherent data base of the tool, which consists of digital elevation model of India and district level maps of India. Digital elevation models from SRTM and ASTER GDEM are used to generate final elevation data for Indian region. These two digital elevation models are merged and used for masking the data gaps and to increase accuracy. The combined output gives an accurate digital elevation model with 30 meter horizontal resolution. District level map is provided to simplify spatial extent selection for analysis and report generation for the user.

3.2 Rule Base

Rule base is the core of this tool which uses the expert system for generation of inundation and vulnerability map for land resources. The aspect, slope and basin maps are prepared for this purpose and these maps along with contiguity analysis on digital elevation model are used on the area specified by the user for generation of output. The scenarios are generated using inundation inputs provided by the user in the user base. These scenarios are normally combination of sea level rise, rainfall, tidal flooding and cyclonic flooding. The total inundation heights are calculated using these scenarios before inundation analysis.

The analysis for this tool will be carried out using R, an open source programming language. R is an effective and easy to use high level programming language that has proved useful for interactive data analysis. R is being supported by various forums all over the world. R, being easy to use and debug, will prove to be effective for further enhancement of the current tool in future. The source code of R is easy to interpret, this will help to develop the tool further and give better support from user community all over the globe.

3.3 User Base

User base is the data to be fetched from user for scenario generation to demarcate the spatial extent of the analysis. User needs to give flooding level for the various phenomena under consideration, along with the location of cyclone touch point if available. The phenomena under consideration are sea level rise, rainfall, tidal flooding and cyclonic flooding. One phenomenon or combination of phenomena can be given at a time.

User needs to define the spatial extent of the analysis. User can provide the extent using three options; namely,

1) Use the readily available district name or state name from dropdown menu.
2) Select a location (latitude and longitude) along with buffer radius for analysis.
3) Providing minimum and maximum extent of latitude and longitude.

User can save the graphical and statistical results from the analysis. The output can be graphical and/or statistical. The prototype for user interface is given in the figure 2 below.

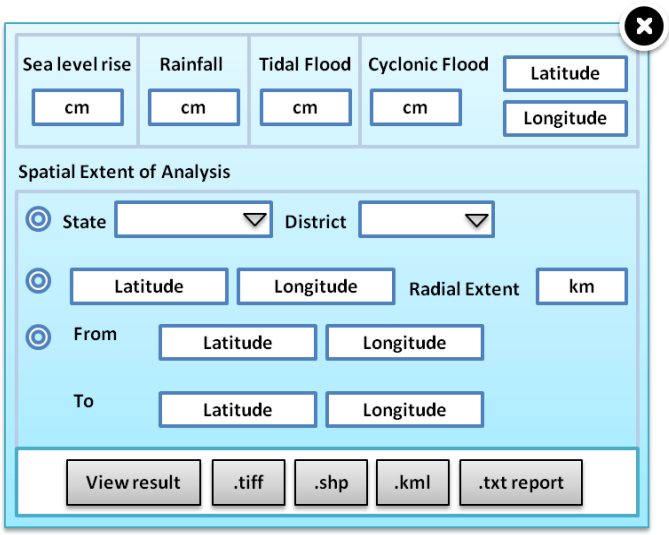

Fig 2: User interface for proposed tool

As it can be seen from the figure 2, user has higher role in the execution of this tool and hence this can prove to be a powerful tool for scenario generations and decision making.

3.4 Output

This tool tries to provide on-screen output in the form of maps. These maps can be saved in different formats as per the need. The formats currently aimed at are .tiff, .shp, .kml for graphical outputs in the form of maps. The areal distribution and spatial statistics can be saved as .txt files. Figure 3 gives a rough idea about the output generated by the tool.

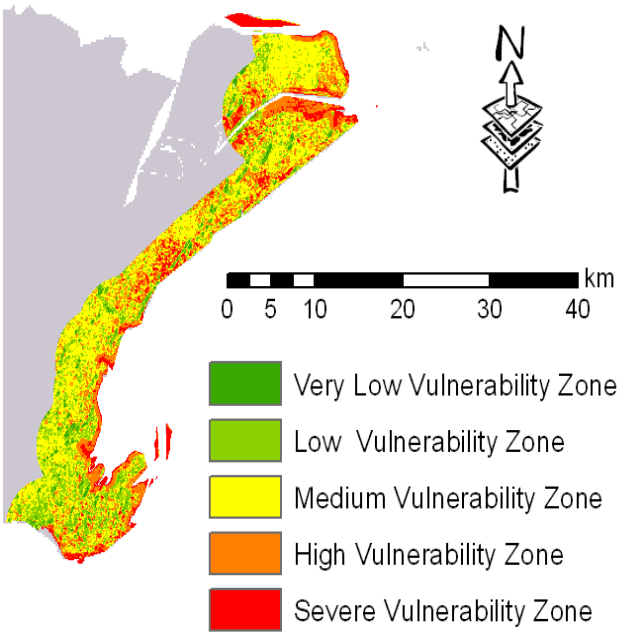

Fig 3: Output of sea level analysis

The figure 3 indicates various inundation classes in the form of vulnerability classes for area under consideration. The table I given below gives format of the .txt file for the report generated for further statistical analysis. The table contains level of inundations and area corresponding to the levels both in per cent and km^2 values.

Table 1. Format of output .txt file

Inundation level	% area	Area in sq. Km
0-50 cm		
50-100 cm		
100-150 cm		

4. DISCUSSION AND SUMMARY

This tool aims at easy-to-use option for people with limited or no knowledge of scenario generation. This should encourage more number of people to get aware about the impact of coastal inundations in the area of their interest.

The usage of high resolution digital elevation model will make this a powerful tool for planners and decision makers for local and regional scale planning and development purpose.

Customizable scenarios can help the experts in the various fields working towards disaster management and mitigation for understanding different combinations and preparing for worst possible scenario based on the output generated.

The proposed tool being an open source tool will be provided with the source code and can be customized to integrate it with other tools or to develop extensions for the proposed tool.

5. LICENSING

The current tool is proposed as free to build upon / free to distribute tool. R is licensed under GNU general public license; therefore, this tool also inherits the same licensing policy. Free Software Foundation (FSF) licensing terms will be followed for the proposed tool. This tool cannot be sold in any form.

6. ACKNOWLEDGMENT

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