FINAL REPORT for APN PROJECT
Project Reference: ARCP2010-07CMY-Bai

Asian Coastal Ecosystems: An Integrated Database and Information Management System (DIMS) for Assessing Impact of Climate Change and its Appraisal

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Project Reference Number: ARCP2010-07CMY-Bai
Final Report submitted to APN

OVERVIEW OF PROJECT WORK AND OUTCOMES

Summary of the project

During the early- to early 21st century era of research to understand climate change and the factors attributed to it, it has become crucial to ensure that those research results, information, and data are accessible to all. The project team composed of researchers from Malaysia, India, Singapore and England has embarked on developing an Integrated Database and Information Management System (DIMS), an easily accessible information outlet. DIMS has been initially developed for the collaborating countries and that includes physical, chemical, and biological parameters. 'DIMS' is expected to be extended for other countries in the Asia-Pacific region in the future through further study and maintenance of the project website. As part of the project dissemination activities; a scientific workshop on "Climate Change and DIMS Technology" was organized from 1-3 December 2010 at the University of Nottingham, Malaysia. The workshop deliberations were on climate change and coastal modeling methodology, effective prediction of environmental changes, Database information and management system (DIMS) architecture, functioning, database schema information in particular metadata and searchable data. Participants learned the above topics particularly in using GIS tools, maps, relational databases, metadata etc. They took part in questionnaires at the workshop and enhanced their networking opportunities

Objectives

The main objectives of the project were:

1. The goal of the DIMS for the Asian Coastal region is to provide a comprehensive collection of hydrologic, geologic, biologic, and spatial information for onshore and offshore ecosystems through a database driven Internet system.
2. To acquire data sets along with discovery of researcher's needs for a data management system and paired with relational database management system.
3. To create country wide compliant metadata will serve as a means of documenting data sets, which will be distributed online, and will be searchable, and of archiving those data sets that are sensitive in nature (not distributed).
4. To prove that project will meet with specific needs in CLIMATE change, few forecast models of the participating countries are being planned to develop and demonstrate it at the regional workshop of this project.
5. To evaluate DIMS by assessing impact of climate change in the selected coastal regions mainly on the participating countries; India, Malaysia and Singapore of this project.

Amount received and number years supported

The Grant awarded to this project was:
US$ 40,000 for Year 1: 2009-2010
US$ 40,000 for Year 2: 2010-2011

Activity undertaken (A sample minutes of the meeting is attached at the appendix)

1. Project initiation meeting 29th April 2009 at UNMC, Malaysia.
2. Project continuation meeting 19-20 Jan, 2010 at UNMC, Malaysia.
3. Project meeting 16-17 Dec, 2010 at Dindigul, South India.
4. Project coordination meeting 6-7 May, 2010 at UNMC, Malaysia.

5. Webpage/portal/web interface (CMS) setup meeting at UNMC 29-30 July, 2010 at UNMC.
6. Project discussion on Linux, Apache, MySQL and PHP installations, 6-7 Oct, 2010 at UNMC.
7. Workshop organization meeting, 8 Nov, 2010 at UNMC, Malaysia.
8. Scientific workshop on Climate Change and DIMS Technology (CCD), 1-3 Dec, 2010 at Kuala Lumpur, Malaysia.
9. Progress meeting, 21 Dec, 2010 at NITTTR, Chennai, South India.
10. Project final meeting and scope for further research, July 12, 2011 at NITTR, Chennai, India.

Results

The geographic information system (GIS) and remote sensing (RS) technologies are very important tool for planning, management and monitoring of natural resources. Thus DIMS project is pursued with the objectives of rehabilitating the country's capabilities and alleviating the climate change impact to develop an integrated information system using these technologies. DIMS should be viewed as an opportunity for the environmental and science community to advance in the field of land and coastal zone management and its changes due to climate change.

Making DIMS in ARCGIS represents the latest of tools to solve the spatial data-handling problem. Proper use of DIMS based on GIS required the data knowledge of the map composition skills of the experienced cartographer, the data base management skill of the data processing person, the scientific insight of geographer, the computer knowledge of a system analyst, and the personnel and organization skill of the manager.

The DIMS technology is considered as an important tool for the project which is charged with managing, improving and preserving the country's climate and its environment. The coastal zone-DIMS concepts are major upsurge in the level of interest and there are grounds for optimizing the significant advances in this direction and are not too far away. At the end, it is concluded that the use of DIMS in coastal zone management is interesting and stimulating. The selected site in the collaborating country has been used for evaluating the database (DIMS) created by modeling for climate change and for coastal impact mapping. The study gives an understanding of the climate change, its impact and the sensitiveness of coasts for potential changes in the climate. The respective chapters following this section will provide detailed information on the modeling results and also as a means for evaluation of the developed DIMS.

Relevance to the APN Goals, Science Agenda and to Policy Processes

i. Science Agenda:-

This project focuses on climate, marine domains and Cross-Cutting & Science-Policy Linkages of Asia Pacific Network for Global Change Research. Thus the creation of database on climate change model (DIMS) and its effectiveness in prediction of Climate change could be shared and experienced among Asian countries.

ii. Policy Agenda:-

The data sharing and accessibility to Asian Coastal region wide data will be beneficial to all researchers working in the region, to resource managers, to policy makers, and to the general public. This clearinghouse of information and data will encourage the synthesis and hence the interpretation phase will act as a foundation for an integrated ecosystem modeling component of the Asian Coastal region.

iii. Institutional Agenda:-

The partners of this project are from well known institutions of leading research that are being supported by UK organization and are involved in the coastal studies in Asia. The project has successfully implemented the linkages among the institutions in Asian and with European Universities

Self evaluation

The primary goal of the project is to develop a comprehensive collection of hydrologic, geologic, biologic, and spatial information for onshore and offshore ecosystems through a database driven Internet system (DIMS) for the Asia pacific region. This has been achieved by the project team with their timely support and dedication. Further, the project met with specific needs in climate change such as forecast models and demonstrated at the regional workshop (CCD2010) of the project. With the continued support from Ministry of Science, Technology and Innovation, Malaysia and APN Japan, this project aspires to bridge the gap in climate change studies and modeling.

Potential for further work

Following are the main activities planned and ongoing after the project tenure ceases.

1. 'DIMS' has been developed for certain regions of Asia. It is planned to extend for other parts Asia-Pacific region.
2. To develop a connectivity model among the participating countries.
3. To develop an adaptation model based on the database host on project web www.globalclimate-engine.org as a means of evaluation of the DIMS.

Publications

1. 11-0045: Ramani Bai V. (2011): A method and device for assessing water quality (patent applied)
2. Copyright © (2010-2015) Database Information and Management System, University of Nottingham Malaysia Campus (applied).
3. Ramani Bai V., Mohan S. and Reza Kabiri (2011). New Database Information Management System for Climate Change – An Online resource. In Leal Filho, W. (ed) " Climate Change and the Sustainable Management of Water Resources", Springer Verlag, Berlin (in Press)
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7. ARCP2007-14NMY-Dutta : Dushmanta Dutta, Monash University, AUSTRALIA; Climate Perturbation and Coastal Zone Systems in Asia Pacific Region: Holistic Approaches and Tools for Vulnerability Assessment and Sustainable Management Strategy
8. ARCP2007-04CMY-David: Laura T. David, University of the Philippines, PHILIPPINES. Integrated Vulnerability Assessment of Coastal Areas in the Southeast Asia.
9. ARCP2007-16NMY-Chen: Zhongyuan Chen; East China. Normal University, CHINA; Asian Mega-deltas: Monsoon Circulation in Relation to Deltaic-Coastal Hazards and Future Mitigation – Millennial to Seasonal Dimensions.
10. ARCP2009-02CMY-Okladnikov, Institute of Monitoring of Climatic and Ecological Systems, Siberia: Human Impact on Land cover Changes in the Heart of Asia.
11. Ramani Bai V and Andy Chan (2010) *Climate Change and DIMS Technology*, Proceedings of the year 2010 Asia-Pacific Network for Global Change Research workshop. Pp. 1-466.

Acknowledgments

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TECHNICAL REPORT

Preface

Climate change and global warming pose serious problems for sustainability of a sound human life with disasters. More researches have been conducted on climate change but it is essential to ensure that those research output are accessible to all. Although many general circulation models have been developed and provided for worldwide; detailed causes and countermeasures have not yet been resolved due to lack of proper database. The project team composed of researchers from Malaysia, India, Singapore and England has embarked on developing an Integrated Database and Information Management System (DIMS), an easily accessible information outlet to everyone.

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1.0 INTRODUCTION

DIMS for coastal decision-making and policy formulation according climate change impact by combining rapid data retrieval with analytical and modeling functions, thus a well-designed coastal zone information system could be significant. As a decision-support tool, DIMS can be considered to aid development of integrated and sustainable coastal management strategies. The coastal zone shows high population density with large number of urban conglomeration and in consequence, a fast population growth. Again as a consequence, coastal zone are characterized by a high concentration of economic and, in particular, industrial activities with all the resulting problems of resource consumption, waste management and technological risk. On coastal water side, fisheries and aquaculture exploits a generally highly productive system. Very specific, and valuable as well as vulnerable, typical coastal ecosystems include estuaries, salt marshes, mangroves, coral reefs etc.

Offshore activities such as industries, as well as mining, are additional forms of exploitation of the coastal zone. In addition, the coastal zone is also the recipient of all water borne waste streams, primarily attributable to agriculture, its fertilizers and agrochemical, and all treated and untreated waste water the hinter land produce in their respective catchment. They all drained in to the coastal waters. Therefore, there is an urgent need for intelligent management of coastal zone. And then it is important, making data base management system (DIMS) so that, can project and model the ecological parameters such as climate change in the ecosystem. Physical changes in turn are implicated in the functioning of our regional climate, and of course in the biophysical and ecological functions of our environments, more and more scientific evidence indicates that environmental changes are occurring at all scales, as a result of climate change and climate variability.

This project emphasizes the urgent need for a new tool to the climate change issue, particularly through the development and application of data management at the scale of regions to assess climate change parameters and models at the local level in order to create a environmental impact assessment. The *key issues of the coasts* are:

- An almost complete lack/ Gaps of basic infrastructure for coastal environmental management;
- The absence of reliable data and base information from which to prepare and implement plans and projects;
- Severely degraded physical infrastructure: roads; irrigation systems; coastal protection dikes, etc.
- Continuing lack of security in some of the coastal areas;
- Major issues in the coastal areas of Malaysia should be identified
- Pervasive poverty; and
- Degradation of productive natural resources, primarily fisheries and forestry resources (including those contained in protected areas) that results primarily from poverty, a lack of physical infrastructure; and lack of security.

1.1 Data modeling in climate change

Some of the key parameters in climate change studies are rainfall, temperature, humidity and etc. It is difficult to relate watershed maps to rainfall trends recorded at different points. A GIS can quickly generate a map with isopleths or contour lines and interpolation maps that indicate differing amounts of rainfall. Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area. Additionally, from a series of three-dimensional points, or digital elevation model, isopleths lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected direction where surface water would travel in intermittent and permanent streams can be computed from elevation data in the GIS. Also, a GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modeling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (What encloses what), and proximity (how close something is to something else).

GIS hydrological models can provide a spatial element that other hydrological models lack, with the analysis of variables such as slope, aspect and watershed or catchment area. Terrain analysis is fundamental to hydrology, since water always flows down a slope. As basic terrain analysis of a DEM involves calculation of slope and aspect, DEMs are very useful for hydrological analysis. Slope and aspect can then be used to determine direction of surface runoff, and hence flow accumulation for the formation of streams, rivers and lakes. Areas of divergent flow can also give a clear indication of the boundaries of a catchment. Once a flow direction and accumulation matrix has been created, queries can be performed that show contributing or dispersal areas at a certain point. More detail can be added to the model, such as terrain roughness, vegetation types and soil types, which can influence infiltration and evapotranspiration rates, and hence influencing surface flow.

These extra layers of detail ensure a more accurate model. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models. Maps have traditionally been used to explore the Earth and to exploit its resources. DIMS in geographical information system, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of anthropogenic activities influencing climate change, DIMS technology is becoming an essential tool to understand the impacts of this change over time.

DIMS based on GIS enables the combination of various sources of data with existing maps and up-to-date information from earth observation satellites along with the outputs of climate change models. This can help in understanding the effects of climate change on complex natural systems. The outputs from a GIS in the form of maps combined with satellite imagery allow researchers to view their subjects in ways that literally never have been seen before. The images are also invaluable for conveying the effects of climate change to non-scientists.

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation.

GIS and related technology will help greatly in the management and analysis of these large volumes of data, allowing for better understanding of terrestrial processes and better management of human activities to maintain world economic vitality and environmental quality. To assess the implications of sea level rise along the coastal line, the Arc GIS package is usually used to determine coastal vulnerability to flooding. Results from oceanographic and climatic research combined with data on sea defenses, elevation values, and patterns of land use. Risk assessment and environmental models developed to estimate flood return periods according to different climate change scenarios by 2100 year. Flood risks modeled as a function of the height and condition of sea defenses, land elevations, and subsidence rates. For the year 2100 (Climate change models) predict significant increases in flood extremes and events. However, the results will be having the uncertainty associated with sea level rise predictions but will be of little practical significance to coastal managers and planners if they cannot use them.

1.2 Coastal process modeling

While monitoring can help identify and evaluate changes that are taking place at the shore, effective management of the coastal zone occasionally requires intervention and manipulation of the processes, controls, feedback and interrelationships at work along, within and across the shore, in order to arrive at more desirable ends. Modeling and simulation of coastal phenomena are extremely valuable techniques for assessing the effectiveness and likely impacts of such intervention.

Traditional modeling of coastal phenomena has mostly relied on experiments with physical models. However, it is becoming increasingly common to us computer-based simulation modeling techniques wherever appropriate. Amongst other benefits, computerized simulation has the potential to overcome scale limitations that may be present in a physical model; may avoid the need for physical destruction or alteration of materials under study; can provide greater degree of control over the temporal aspects of the simulation including compression of long time periods into more manageable extent, temporary halting or even reversal of the model to examine specific aspects in greater detail and may be much cheaper and more manageable than construction of a physical model. Furthermore, development of a successful computer simulation depends on the creation of a robust data model for representing the system variables within the GIS, and this in turn requires a meaningful conceptualization of the phenomena under study. Thus the process of setting up the simulation can itself promote greater awareness of the constituent and relationships in the coastal system.

1.3 Goal and Objective

The goal is to allow resource allocation and environmental management decisions to be based on climate change data and information. The objective of our study will be to provide the DIMS that will allow sharing of ecological and environmental data in coast of Malaysia and climate change parameters that will be impacted on coast, in a timely manner among other departments of the Ministry of Environment as well as other government institutions and NGOs concerned with environmental and natural resources issues.

It is expected in the future that*, a*uthorities and managers capacity will be increased and institutions strengthened in order to make informed decisions regarding sustainable development and climate changes in Malaysia. And also, Information sharing, especially online system, and exchanging promotion policies will be established for concerned institutions such as department of environment, department of drainage and Meteorology. Then, the availability and accessibility of environmental and natural resources data to national government agencies and international community will be enhanced.

2.0 DATABASE INFORMATION AND MANAGEMENT SYSTEM-DIMS: METHODOLOGY

Environmental management is spatial management and geo referenced spatial data is map data in a digital form which mean that each of the earth's features that are stored as spatial data has a unique geographic reference such as latitude and longitude. The increasing use of spatial data and GIS by organizations and researchers is a valuable tool to help solve the planning and management issues in these environments. GIS applications are tools that allow users to create interactive queries, analyze spatial information, edit data, maps, and present the results of all these operations. GIS technology can be used for:

- Environmental impact study;
- GIS data development geographic history;
- Earth surface (based scientific investigations);
- Resource management;
- Asset management and location planning;
- Archaeology;
- Infrastructure assessment and development;
- Urban planning; cartography, for a thematic and time based purpose;
- Criminology;
- Geospatial intelligence;
- Marketing;
- Logistics;
- Population and demographic studies;
- Location attributes applied statistical analysis;
- Warfare assessments; and other purposes.

2.1 DIMS Technology and climate change Management

Determining the coastal zone, monitoring erosion, mapping biological resources, habitat assessment and climate change assessment, land use changes and etc, for the planning and response to nature and also, man -made disasters are some critical concerns in environmental management on coastal zones.

Since the coast all around the world are fast developing and firm management policies have to be established. However, for any management of the shore to be effective, it is necessary for the policies to be based on informed decision-making. This in turn requires ready access to appropriate, reliable and timely data and information, in suitable form for the task at hand. Since much of this information and data is likely to have spatial component, one branch of information technology with apparent potential for contributing significantly to coastal management in a number of ways.

These include:

- The ability to handle much larger databases and to integrate and synthesize data from a much wider range of relevant criteria than might be achieved by manual methods. This in turn means that more balanced and coordinated management strategies may be developed for considerably longer lengths of coast.
- DIMS encourages the development and use of standards for coastal data definition, collection and storage, which promotes compatibility of data and processing techniques between projects and departments, as well as ensuring consistency of approach at any one site over time.
- The use of a shared database(especially if the access is provided via a data network) also facilitates the updating of records, and the provision of a common set of data to the many different departments or offices that might typically be involved in management of a single

stretch of coast. A shared database as DIMS framework implies reduction or elimination of duplicated records, and thus the potential for significant economic savings as well as improved operational efficiency.

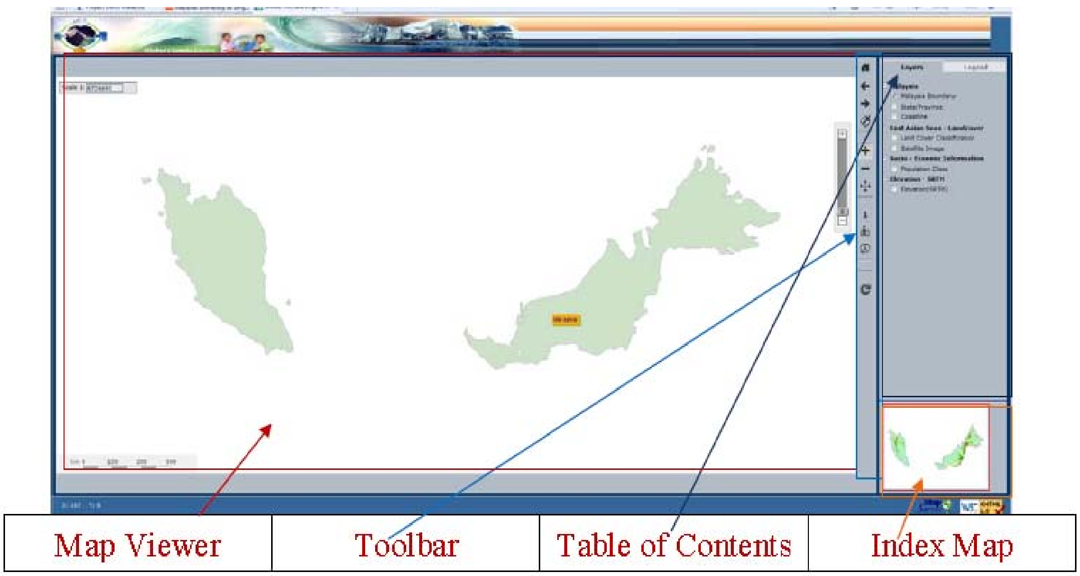

Figure1 Graphical user interface

- Provides efficient data storage and retrieval facilities.
- DIMS also offer the ability to model, test and compare alternate management scenarios, before a proposed strategy is imposed on the real-world system. Computer technology such as ARCGIS allows the consideration of much more complex simulations; their application to very much larger data bases and also enables compression of temporal and spatial scales to more manageable dimensions.

2.2 Database and Information System – Content Management System

The Database and information system http://www.globalclimate-engine.org uses the open source content management system JOOMLA. A Content Management System - CMS is a tool that enables users to create, edit, manage and finally publish a variety of content such as text, graphics, video, documents etc, whilst being constrained by a centralized set of rules, process and workflows that ensure coherent, validated electronic content. This document detailed out the technical and functional characteristics of each module and also it is linked with database schema.

- Hardware
- Software
- System Architecture
- Application Architecture
- Database Design and Schema
- Workflow Management
- Search Engine
- GIS

2.3 Hardware

The University of Nottingham Malaysia has provided with the following VMWARE based system:

VMWARE CPU Intel(R) Xeon(R) CPU E5335 @ 2.00GHz

VMWARE Memory 1024Mb

The http://www.globalclimate-engine.org website is located at /storage/www folder.

2.4 Software

The JOOMLA CMS has been developed using the following software components:

Table 1 List of Software specifications used in DIMS

Technologies / Software	PHP 5.1.6
	JOOMLA Content Management System
IDE	Dreamweaver
Web Server	Apache 2.2.3
Database Server	MySQL Ver 14.12 Distrib 5.0.77

2.5 System Architecture

A JOOMLA framework is a reusable design for a software system (or subsystem). This is expressed as a set of abstract classes and the way their instances collaborate for a specific type of software. Software frameworks can be object-oriented designs. Although designs don't have to be implemented in an object-oriented language, they usually are. A software framework may include support programs, code libraries, a scripting language, or other software to help develop and glue together the different components of a software project.

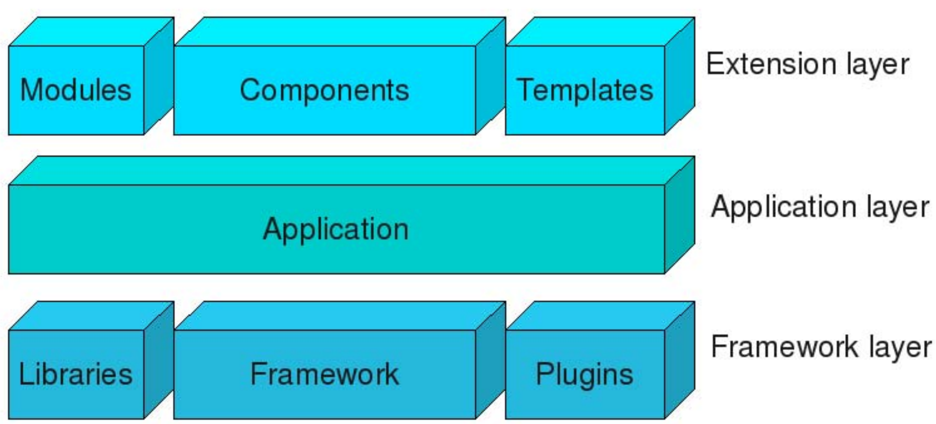

Figure 2 The three tiered system of Joomla

Joomla! 1.5 is a three tiered system:-

The top, Extensions layer, consists of Extensions to the Joomla Framework and its applications as shown in Figure 2:

- Modules
- Components
- Templates

The middle, Application layer, consists of applications that extend the Framework JApplication class. Currently there are four applications included in the Joomla distribution:-

- JInstallation is responsible for installing Joomla on a web server and is deleted after the installation procedure has been completed.
- JAdministrator is responsible for the back-end Administrator.
- JSite is responsible for the front-end of the website.
- XML-RPC supports remote administration of the Joomla website.

The bottom, Framework layer, consists of:-

- the Joomla Framework itself, whose classes are listed below.
- Libraries that are required by the Framework or are installed for use by third-party developers.
- Plugins extend the functionality available in the Framework.

MySQL:

JOOMLA database is created using open source RDBMS(Relational Database Management System) called MySQL. The version used for this development is V5.077. MySQL supports several storage engines that act as handlers for different table types. MySQL storage engines include both those that handle transaction-safe tables and those that handle nontransaction-safe tables. The default MySQL storage engine and the one that is used the most in Web, data warehousing, and other application environments. MyISAM is supported in all MySQL configurations, and is the default storage engine unless you have configured MySQL to use a different one by default.

Apache Webserver:

The Apache webserver is used in APACHE V2.2.3. JOOMLA CMS are deployed in Apache Server Environment. The Apache HTTP Server Project is a collaborative software development effort aimed at creating a robust, commercial-grade, featureful, and freely-available source code implementation of an HTTP (Web) server. Apache is primarily used to serve both static content and dynamic Web pages on the World Wide Web. Many web applications are designed expecting the environment and features that Apache provides.

2.6 Content Management System

JOOMLA have chosen by the University Of Nottingham Malaysia technical personnel over other CMS available in the market.

"A Content Management System (CMS) - JOOMLA is a tool that enables many features even for non technical staff to create, edit, manage and finally publish a variety of content such as text, graphics, video, documents etc, whilst being constrained by a centralized set of rules, process and workflows that ensure coherent, validated electronic content."

Joomla is known for scalability, or ease of growing a Web site from a small set of users to an enterprise level. The framework also has the ability to 'throttle' areas of the site that could cause potential problems during heavy traffic situations.

2.7 Application Architecture

The following is the application architecture for the Graph Generator and Flood Prediction application. The application architecture of Graph Generator and Flood Prediction has 4 different layers: Client Layer, Presentation Layer, Business Layer and Data Access & Integration Layer.

Client Layer:

Client layer is a application front-end that provides communication with application users using web browser (IE, Mozilla, Firefox, and Netscape) that renders pages built with HTML, PHP and JavaScript. It is a thin client which gives the advantage that no additional software needs to be installed on client side, so a thin client requires minimum support for client platform.

Presentation Layer:

Presentation Layer presents the information to the user in the form of Graphical user interfaces. The presentation layer connects to business layer in order to process the user request and displays the responses from the Business layer.

Business Layer:

Business logic layer provides data and transaction processing logic (business logic) for application. This layer coordinates the application, processes requests from presentation layer and provide the response to the user.

Data Access & Integration Layer:

Data layer involves the relational database which stores the Graph Generator and the Flood Prediction application data. All interactions to this layer are done through business logic tier to prevent any potential security issues from arising. PHP connection logic is used to access this layer.

2.8 Database Design and Schema

The main aim is to design a robust schema in order to accommodate the dataset from the national data collection sheet template and regional data collection sheet template. The template will cover, a large and diverse range of coastal and marine aspects including quantitative and qualitative natural and social-economic parameters. In order to host all collected information a detailed robust database schema was designed to accommodate the contents of both national and regional data collection sheet. A detailed schema diagram is attached in Appendix-A

2.9 Graph Generator

Graph generator is a Joomla Component that we developed and integrate into Joomla website. Its main function is to generate a graph based on the tabular data that will be uploaded by application user.

Graph Generator can be separated into 2 sections:

1. **FRONTEND**
2. **BACKEND ADMINISTRATION**

FRONTEND is the normal application user interface, once user reached this frontend page, it will be forced to choose either one of the following options:

1. In Built Data
2. Upload New Data

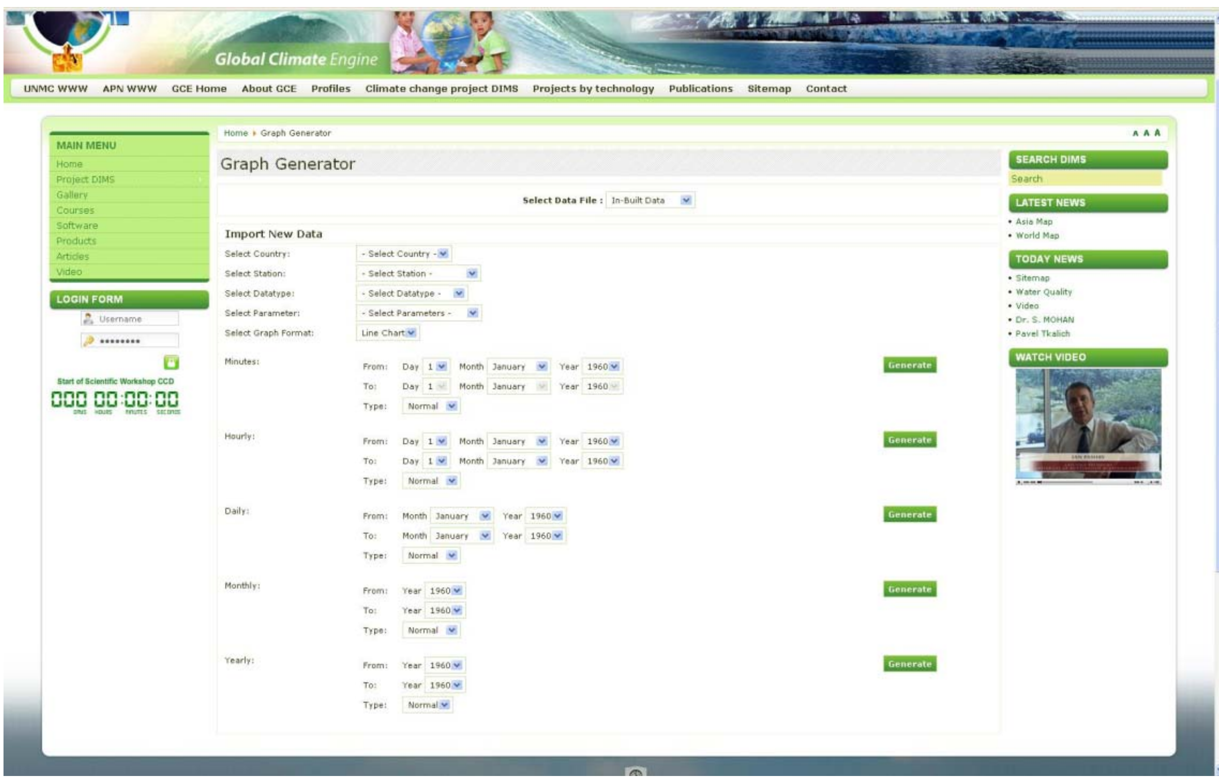

Figure 3 Graphical User Interface – In built data

For **"In-built data"**, the graph generator system will actually read the data from the local database in which has been uploaded and recorded from the Graph Generator Admin Page.

The user, can generate the graph based on the inbuilt data and will able to filter according to the following:

- Country
- Station
- Parameter
- Graph Format
- Minutes, Hourly, Daily, Monthly, and Yearly

User also able to select Graph Type as follows:

- Normal
- Average
- Minimum
- Maximum

Normal graph will produce graph as per in the database. Average graph will produce average plot graph in selected period. Minimum graph will produce minimum plot graph in selected period. Maximum graph will produce maximum plot graph in selected period.

Once the user click "Generate" button after all filter has been selected, the Graph Generator will produce the graph in Flash format in which can be exported to JPEG image format. For "**Upload New Data"** will force user to upload their own data in CSV format.

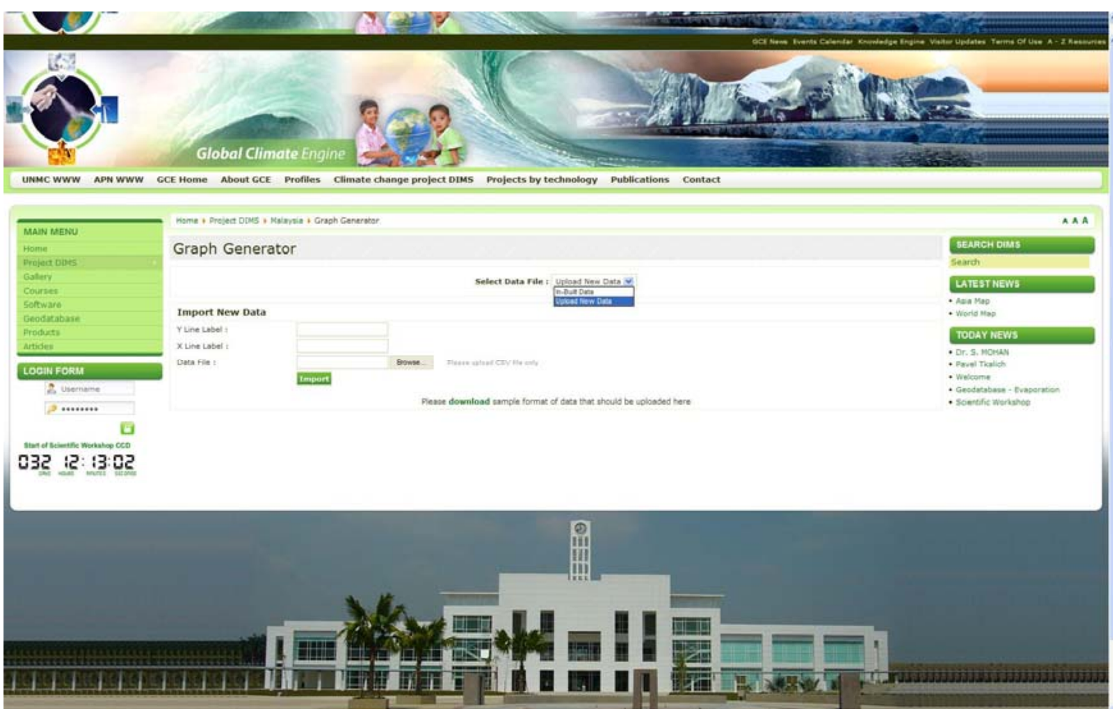

Figure 4 Graphical User Interface – Upload New data

The sample CSV format are as follows :

year,Jan,Feb,Mar,Apr,May,Jun,Jul,Aug,Sec,Oct,Nov,Dec
1962,285.38,352.76,351.268,352.76,242.428,352.76,349.943,349.943,349.943,349.943,352.76,351.268
1963,301.202,242.428,267.923,242.428,331.51,242.428,352.76,352.76,352.76,352.76,242.428,267.923
1965,349.943,331.51,295.798,331.51,352.76,242.428,301.202,331.51,352.76,242.428,352.76,295.798
1972,352.76,285.38,351.268,351.268,242.428,285.38,349.943,285.38,242.428,285.38,242.428,351.268
1975,242.428,351.268,242.428,267.923,331.51,301.202,267.923,301.202,331.51,301.202,331.51,352.76
1984,331.51,267.923,331.51,295.798,285.38,349.943,295.798,349.943,285.38,349.943,349.943,242.428
1991,351.268,295.798,285.38,351.268,301.202,351.268,351.268,351.268,301.202,351.268,352.76,352.76
1995,267.923,351.268,301.202,242.428,349.943,267.923,267.923,267.923,349.943,267.923,242.428,242.428
1996,295.798,242.428,242.428,242.428,352.76,295.798,295.798,295.798,352.76,295.798,242.428,331.51
1999,351.268,331.51,331.51,331.51,242.428,351.268,351.268,351.268,242.428,351.268,331.51,242.428

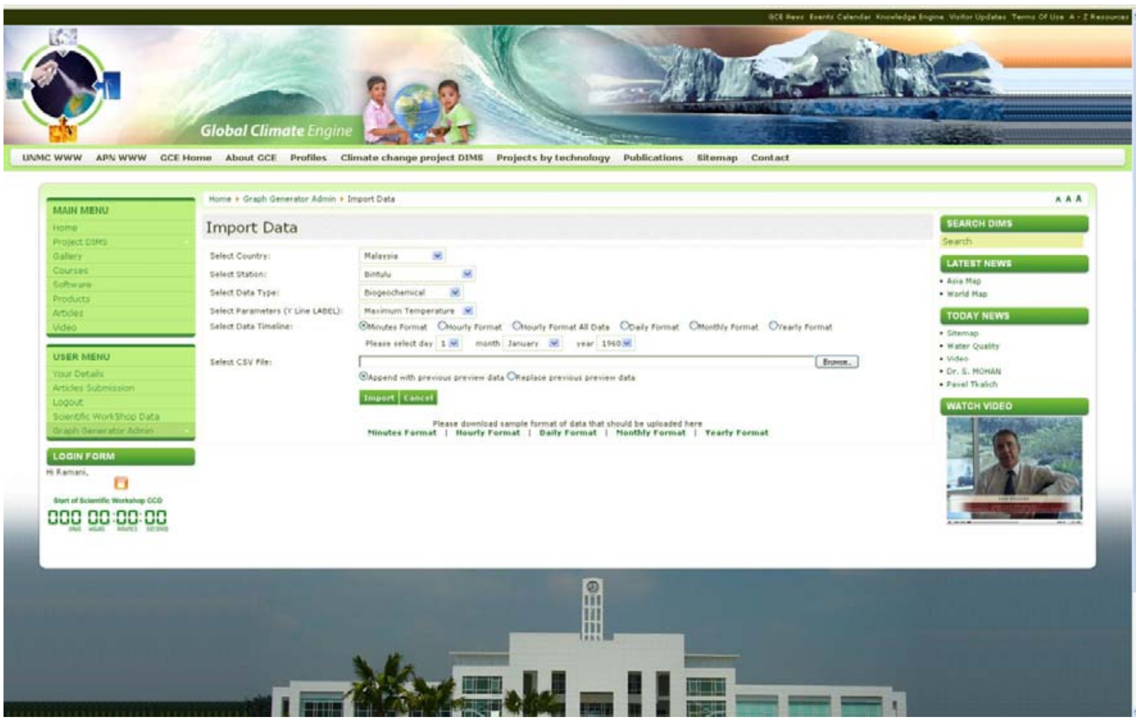

Figure 5 Example: Import data

The sample CSV file also can be downloaded here at http://www.globalclimate-engine.org/components/com_graphgenerator/assets/sample/newdata_sample.csv

Once the user uploaded the csv file, the graph generator will plot the graph in FLASH format, in which later can be exported to JPEG image format.

Backend administration is the administration page for the application admin. In this page, the application admin can upload new data for “Inbuilt Data” selection in the front end page. The following figures are the screen shot of Backend Administration for Graph Generator:

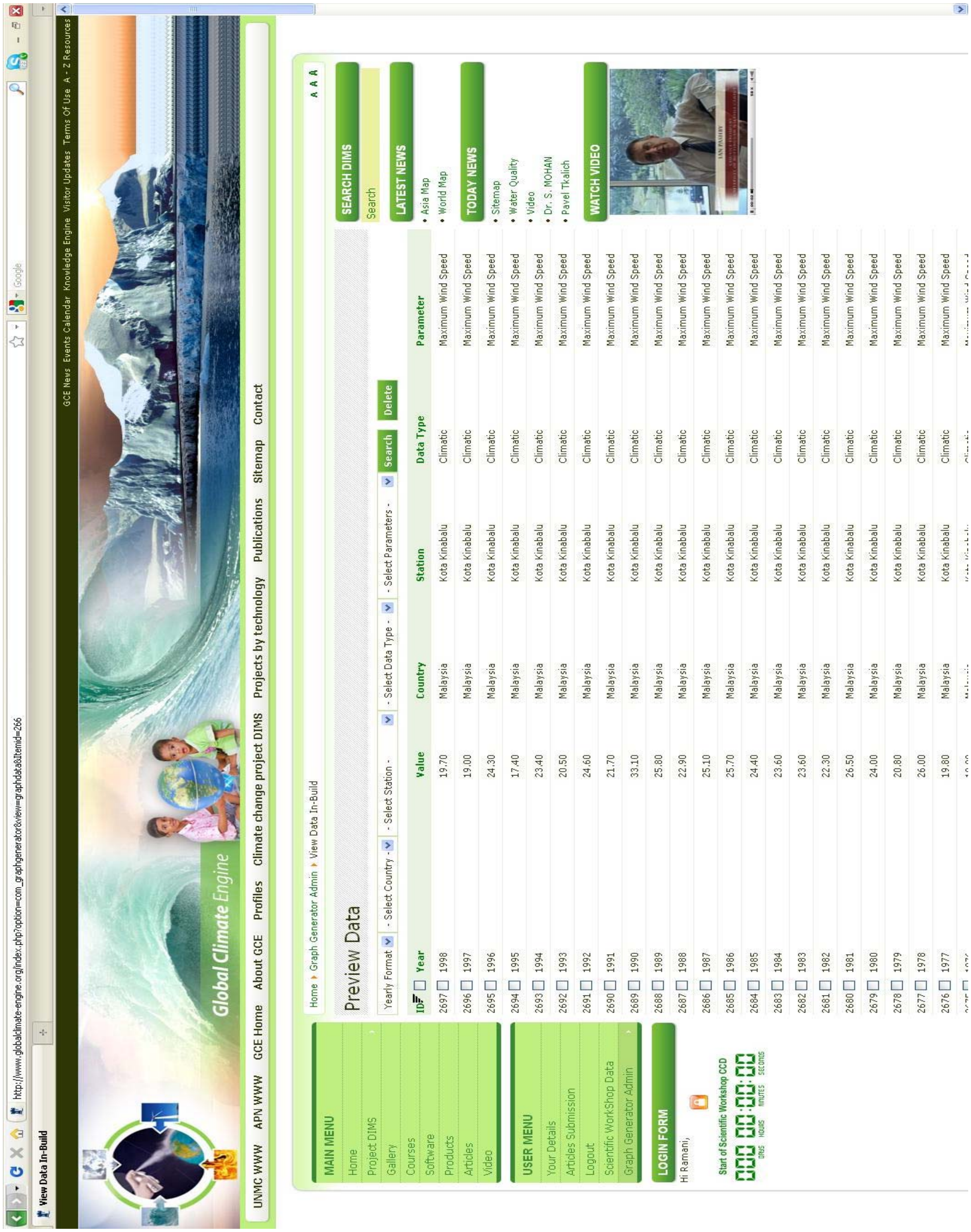

Figure 6 Graphical User Interface – Graph generator

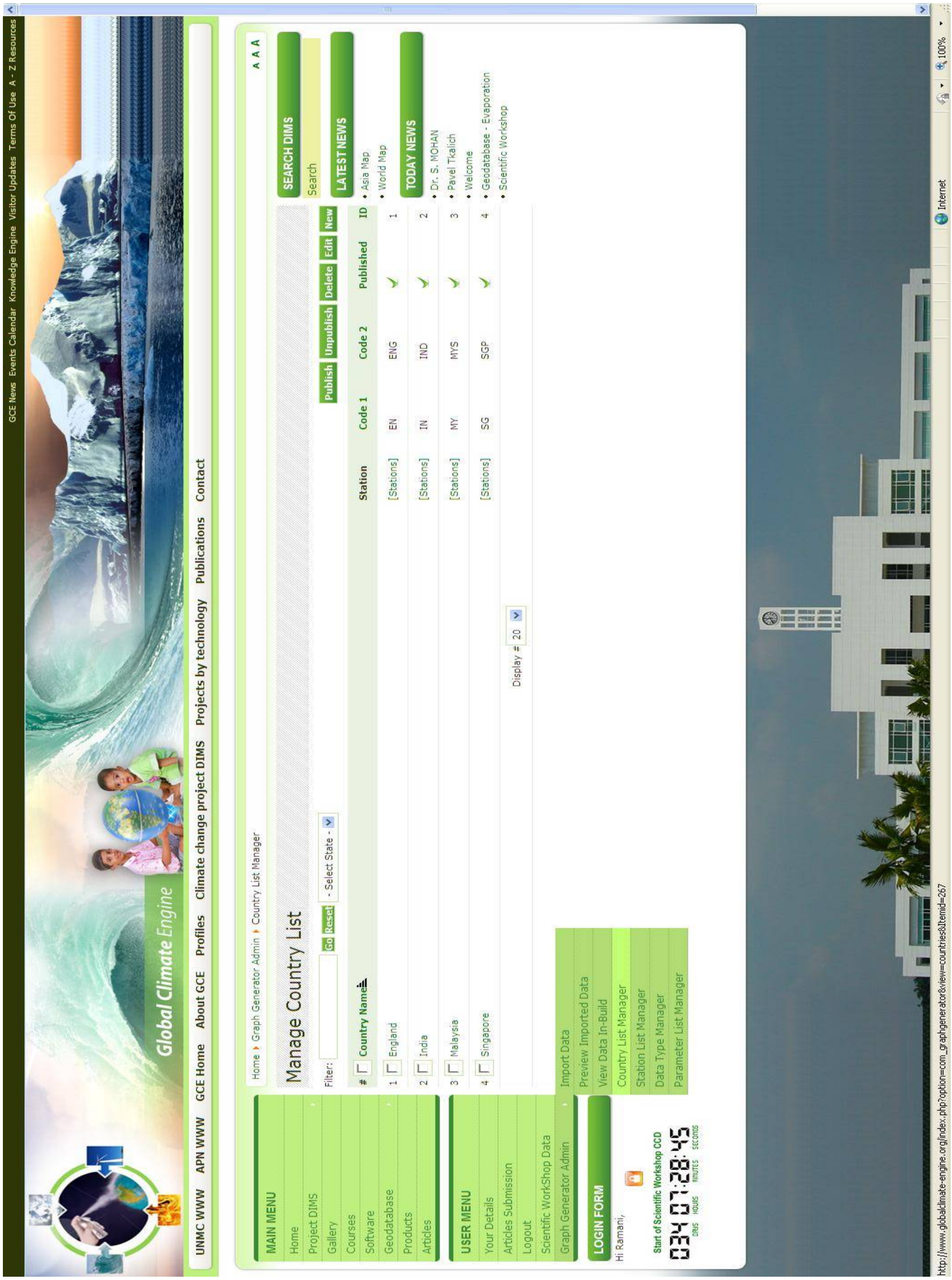

Figure 7 Graphical User Interface – Graph generator

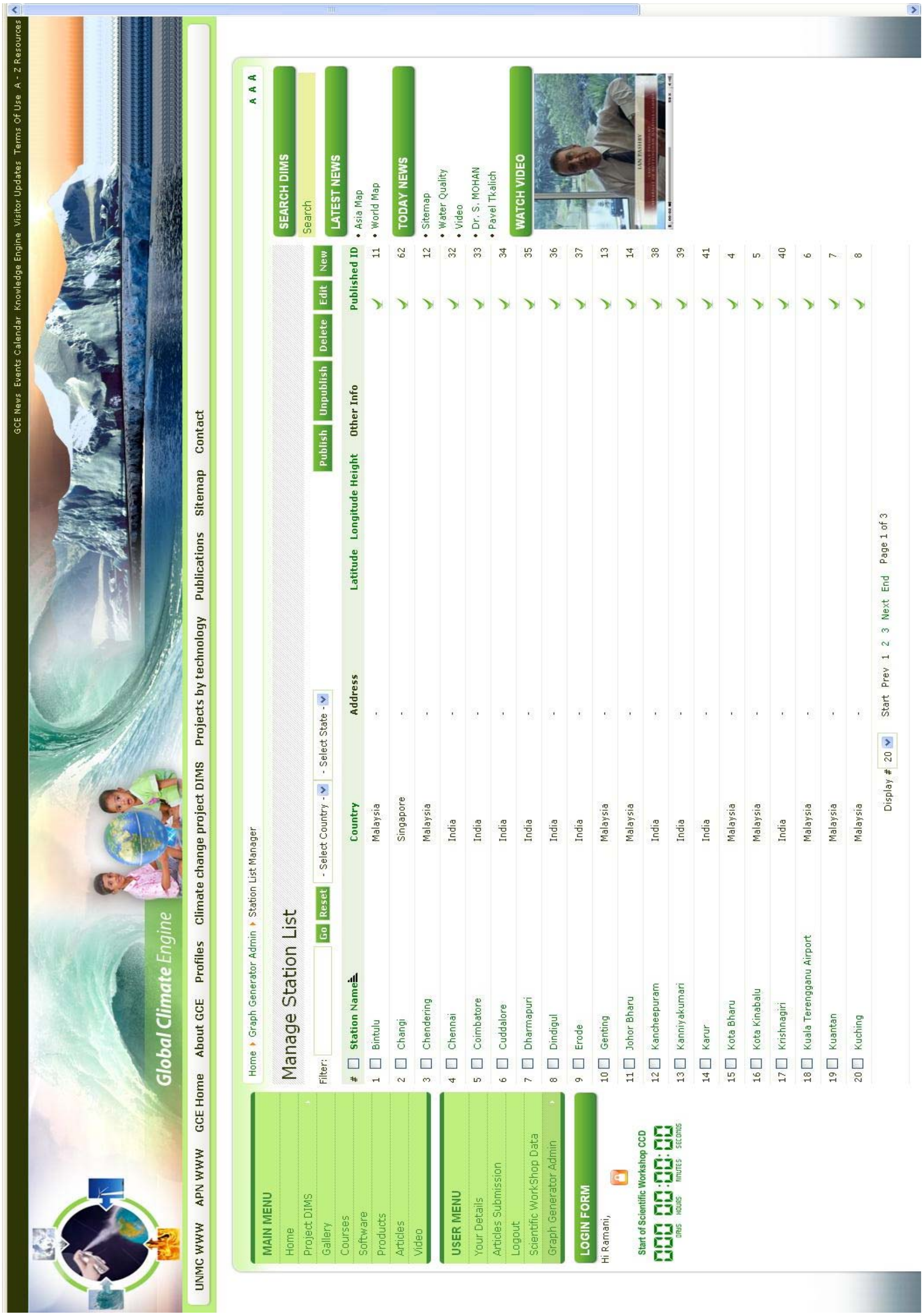

Figure 8 Graphical User Interface – Graph generator

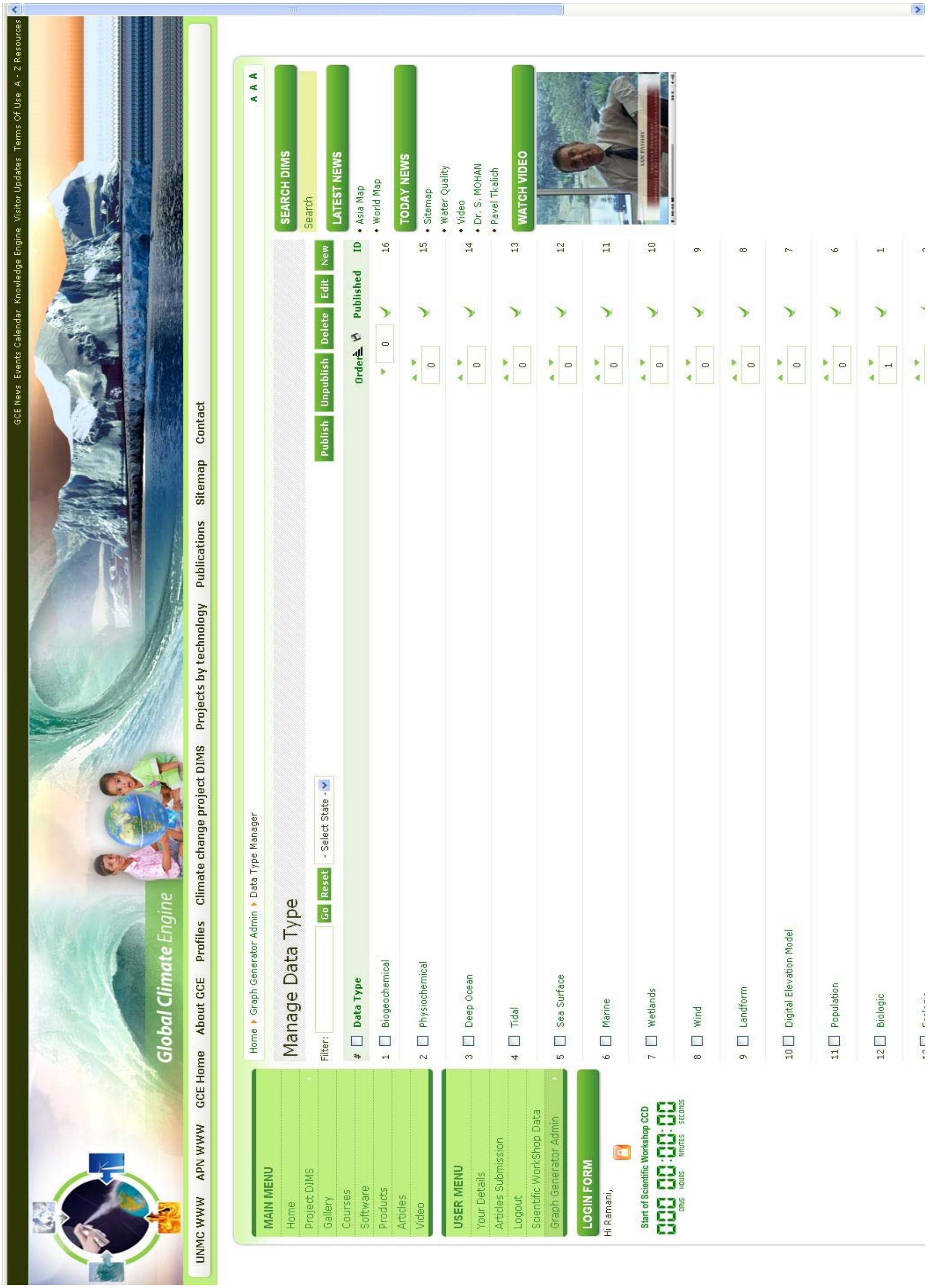

Figure 9 Graphical User Interface – Graph generator

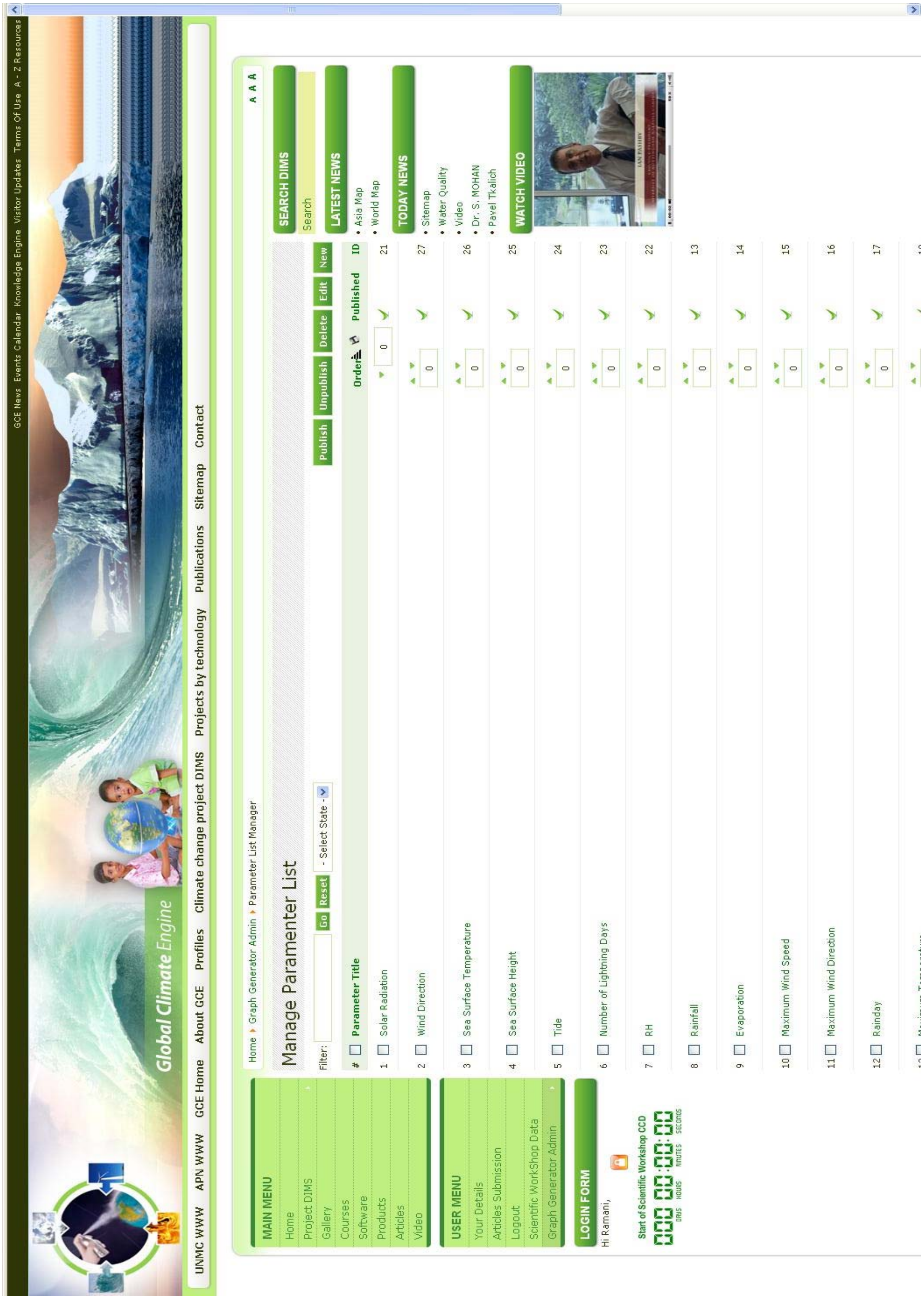

Figure 10 Graphical User Interface – Graph generator

2.10 Flood Prediction

Flood Prediction is a Joomla Component that we developed and integrate into Joomla CMS website. Its main function is to generate a graph based on the tabular data that will be uploaded by application user and predict the flood based on the number of years entered in the input box.

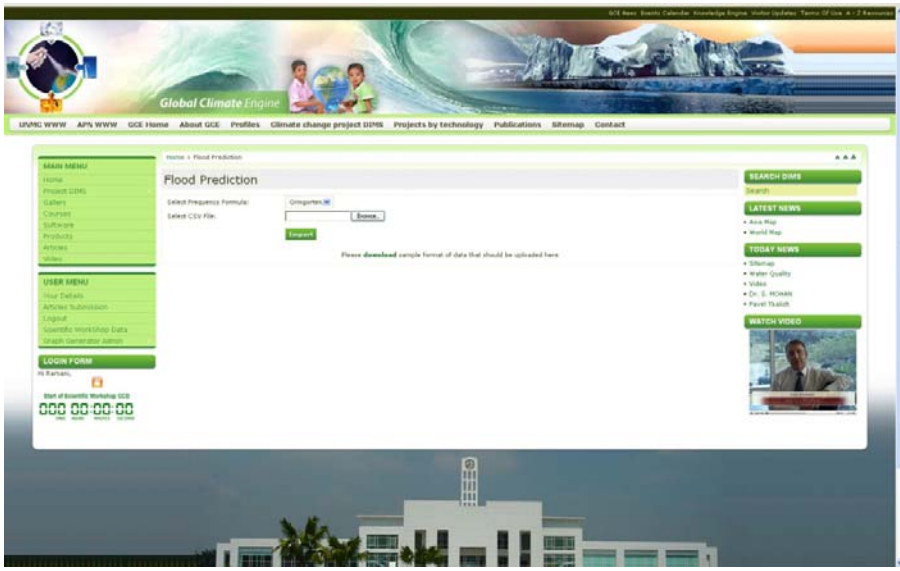

Figure 11 Flood predictions online

sample calculations:

$$\beta = \frac{t_2 k \sin \pi k}{k\pi(k+t_2) - t_2 \sin \pi k}$$

$$\beta = \frac{0.075 \times 0.211 \times \sin(180 \times 0.211)}{0.211 \times 3.14 \times (0.211 + 0.075) - 0.075 \times \sin(180 \times 0.211)}$$

$$\beta = \frac{0.075 \times 0.211 \times 0.615}{(0.211 \times 3.14 \times 0.286) - (0.075 \times 0.615)}$$

$$\beta = \frac{0.009732}{0.14336}$$

$$\beta = 0.067$$

$$x_T = 1 + \frac{\beta}{k}[1 - (T-1)^{-k}]$$

$$x_T = 1 + \frac{0.067}{0.211}[1 - (1.06 - 1)^{-0.211}]$$

$$x_T = 1 + \frac{0.067}{0.211} \times [-.8105]$$

$$x_T = 0.7426$$

This Flood Prediction application will be based on data uploaded in CSV format.

Sample CSV format data for Flood Prediction application also can be downloaded here at http://www.globalclimate-engine.org/components/com_graphgenerator/assets/sample/unmc2.csv

After the data is uploaded, the graph will be generated and user can then enter the no of years they would like to predict in the “Enter number of years you would like to predict based on the uploaded data:” input box. The graph also can be exported to a jpeg image by clicking “Export Image” link.

Sample data are as follows in CSV format:

year,data

1962,285.38
1963,301.20
1965,349.94
1972,352.76
1975,242.43
1984,331.51
1991,351.27
1995,267.92
1996,295.80
1999,351.27

2.11 Database and Information System – Geographic Information System

DIMS-GIS is a online Geographic Information System (- GIS) allows to display climate change related data and information on interactive maps using web mapping server called Mapserver (Open source webGIS server). The mapserver having the web map serving program, the application requests GIS data and MapServer-specific files, namely, Map file and HTML template files. In fact, this file defines every object for the online map, including data layer, scalebar, map, legend, projection and web object.

The objective of object definition is to define how the map will look like and be presented. The defined objects such as map, legend and scale bar are presented on the online map interface. But, the Map file is not used for the designing of the interface, the Template files are used instead. The template file (Mapper) is used for the following tasks, namely, designing the interface, generating mapping tools. This DIMS – GIS framework uses all open source datasets as well as dataset provided by country representatives.

a) System Development

The system development include the organization of spatial data, GUI and interactive Web mapping and development of data management tools - catalog tools to provide meta data information about the spatial layers.

The development of the system is based on web based client-server architecture. The server side software components consist of several servers working in tandem, including Apache, web mapping server, and Java applications for visualization. The web mapping server handles the linkage between spatial objects and non-spatial attribute data stored in a relational database. The web based system will allow the users to interactively query and visualize data

b) Graphical User Interface

The Graphical User Interface (GUI) design contains four parts 1) Map Viewer 2) Tool box 3) Table of Contents 4) Index map. The map viewer will display the various thematic layers compiled through map composition and controlled by set of scripts based on the user selection. The tool box consists of basic and advanced controls for thematic layers in map display. The table of contents basically lists the thematic layers and their display properties such as legend and symbol properties. The Index map provides the thumbnail view of the each country like India, Malaysia and Singapore. The map viewer contains the below thematic layers for each country.

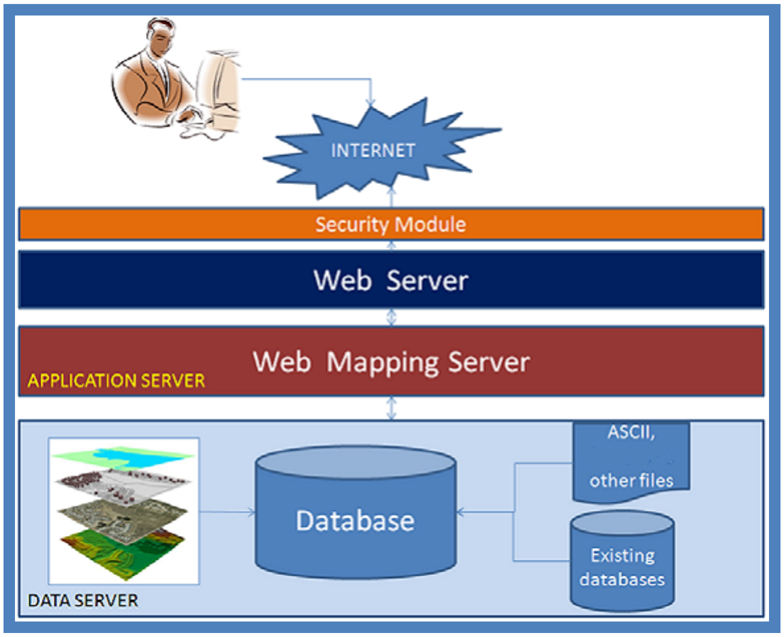

Figure 12 DIMS-GIS System Architecture

Thematic Layers – India:

- Country Boundary
- Coast Line
- City Locations
- State Boundary
- Coral Reef – Boundary
- River_Drainage Network
- Land Cover – Classification
- WMS service - Satellite image from NASA

Thematic Layers – Malaysia:

- Country Boundary
- Coast Line
- City Locations only for West Malaysia
- State Boundary
- Land Cover Classification
- WMS service - Satellite image from NASA
- Elevation – SRTM
- Climate Parameters
  - Annual Rainfall
  - Annual Rainfall Rain day
  - Wind Speed

- ❖ Max. Wind Direction
- ❖ Evopotransportation
- ❖ Normal Precipitation
- ❖ Rain Comparison
- ❖ RH
- ❖ Solar Radiation
- ❖ Temperature Radiation
- ❖ Max. Temperature
- ❖ Mean. Temperature
- ❖ Min. Temperature
- ❖ Temperature Comparison

Thematic Layers – Singapore:

- ➢ Country Boundary
- ➢ Coast Line
- ➢ Land Cover Classification
- ➢ Elevation – SRTM
- ➢ Population Class
- ➢ WMS service - Satellite image from NASA

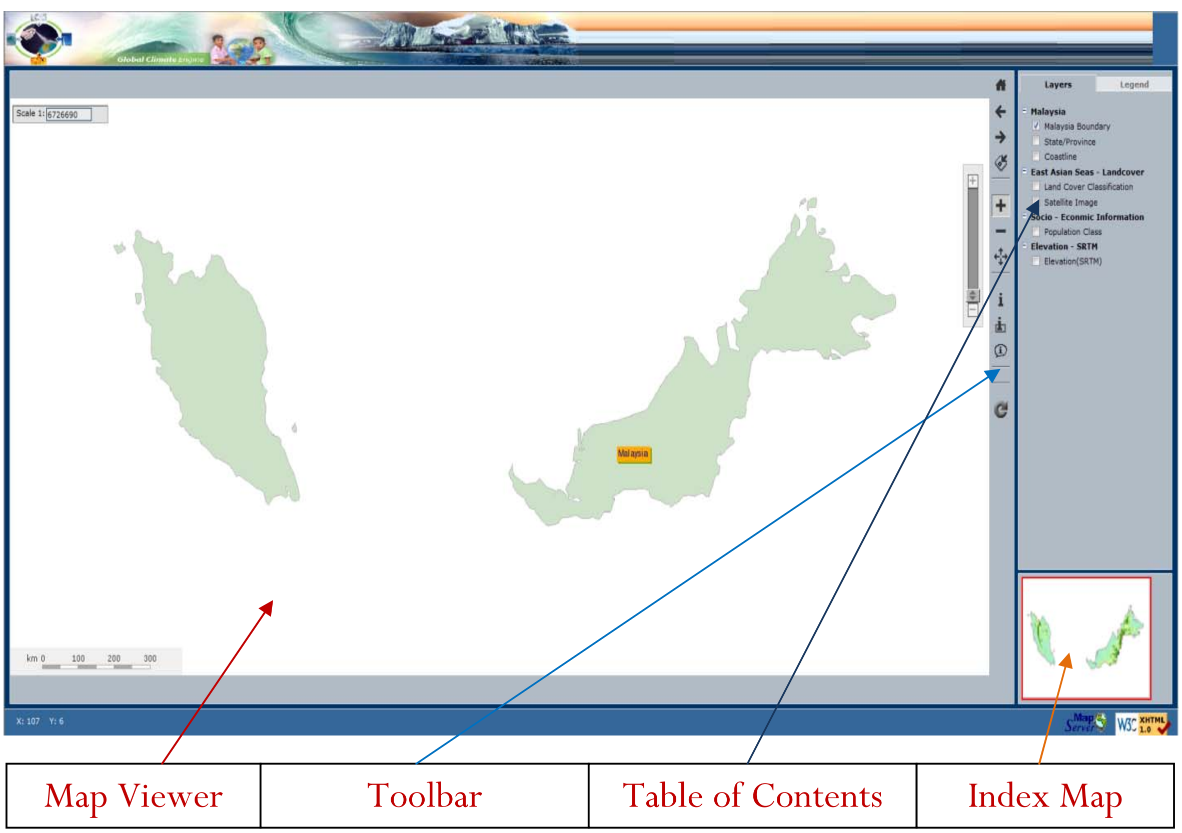

Figure 13 Graphical User Interface - GIS

In the middle of the screen is a toolbar with a variety of mainly navigation-oriented buttons. They perform fundamental operations that one would expect to be able to perform. Some of these buttons require interaction with the display panel in addition to the selection of the button; others just require selection of the button. From the top to bottom, the functions available on the toolbar are:

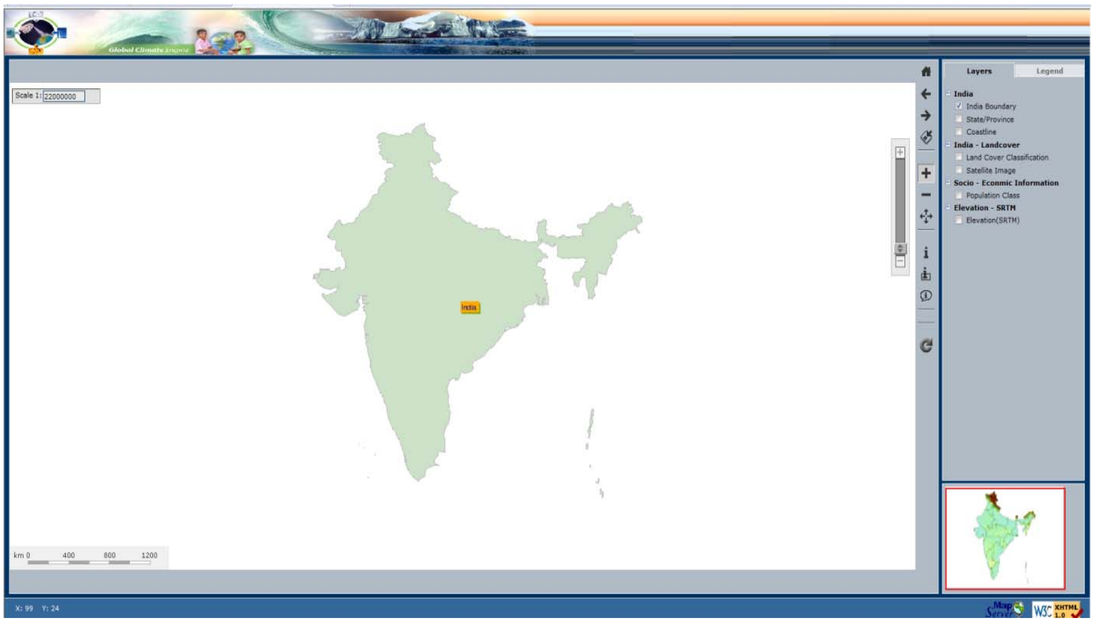

Figure 14 Graphical User interface for India

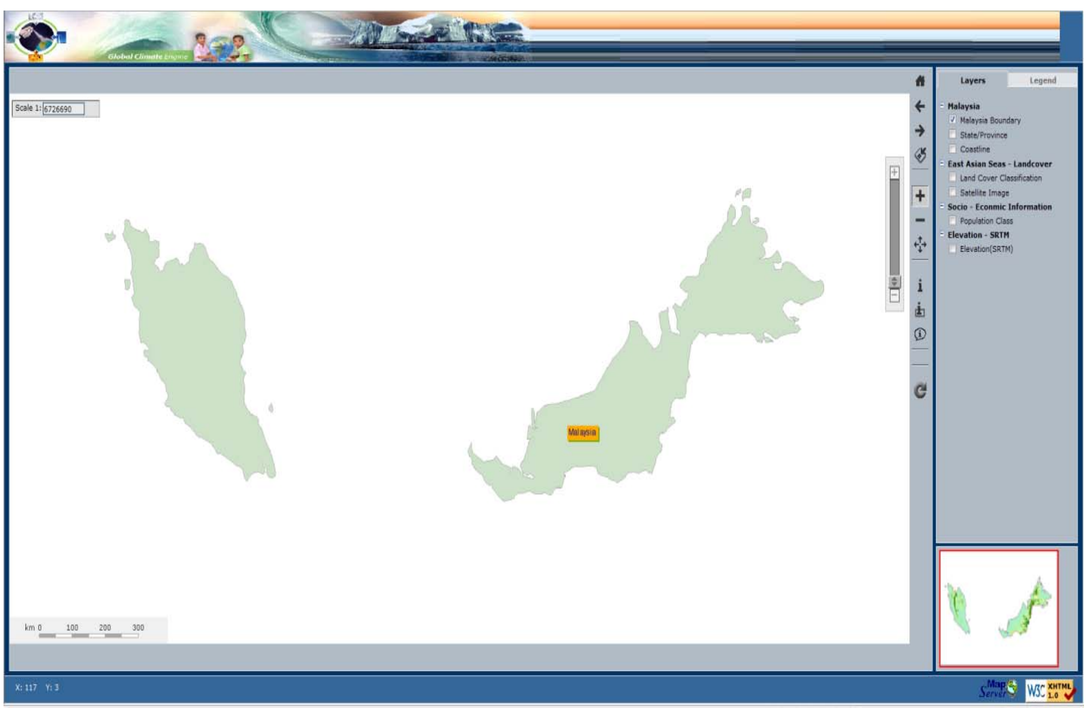

Figure 15 Graphical User interface for Malaysia

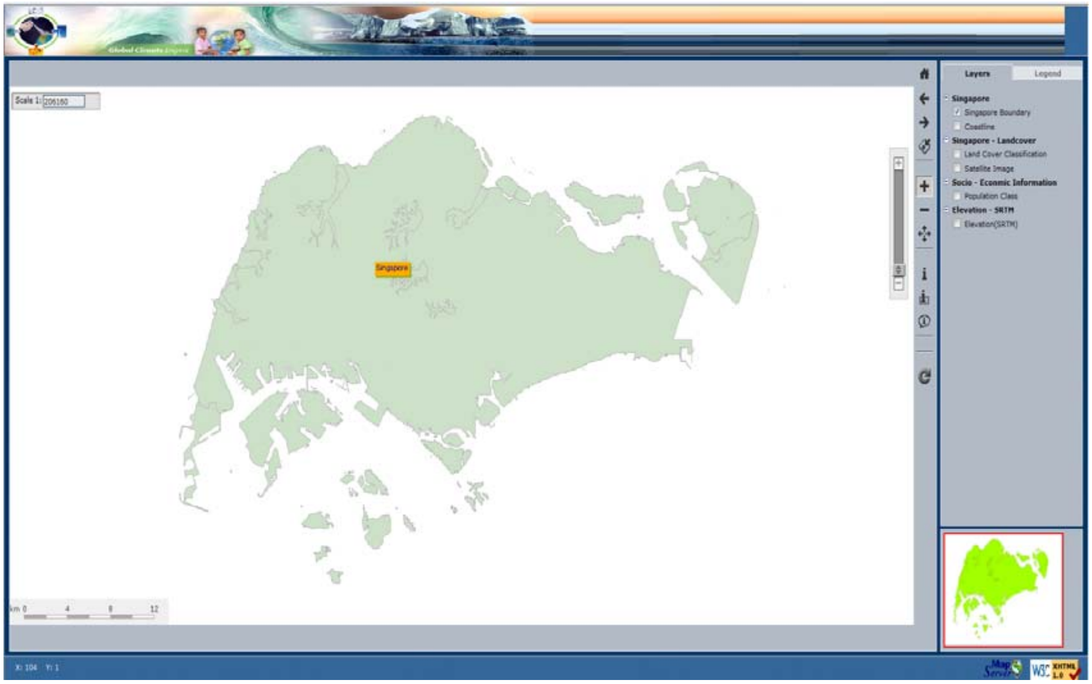

Figure 16 Graphical User interface for Singapore

c) Navigation Tools

The table of contents is named as "Layers" tab. The purpose of this is to allow the user to select and de-select layers of the map. Multiple layers can be selected at any one time as well as allowing for any depth of nested layers.

1. Zoom to Full Extent
2. Zoom to Previous
3. Zoom to Forward
4. Zoom to Selected
5. Zoom in
6. Zoom out
7. Pan
8. Info tools
9. Clear Selection and Zoom to Full Extent

Legend tab, displays the names of the selected layer and the associated colors of the each layer. To access the each countries datasets CMS will have the link to web mapping server. Below the URL to access the each countries web map portal.

For India: http://dims.globalclimate-engine.org/apn/india/map.phtml

For Malaysia: http://dims.globalclimate-engine.org/apn/malaysia/map.phtml

For Singapore: http://dims.globalclimate-engine.org/apn/india/map.phtml

2.12 Database Information and Management system: Catalog & Metadata system

A metadata catalogue system is developed to store, update, and search for metadata that describe the datasets used in the project. The screenshot below shows the metadata population page where data custodians can use this page to create metadata for their dataset. The standard for the metadata is based on the ISO 19115 standard (http://www.iso.org/iso/catalogue_detail.htm?csnumber=26020).

(i) Metadata Population and Update

After populating the metadata, in later times, the custodians can update their metadata through the metadata update page. Below shows the metadata update page that demonstrates a list of metadata that are previously entered. The custodians can click on the buttons, which are located at the end of each metadata record, to either edit or delete the respective record. If the edit button is clicked, a page similar to the metadata population page will be displayed with the metadata information previously entered by the custodians. When the delete button is clicked, the record will be deleted otherwise.

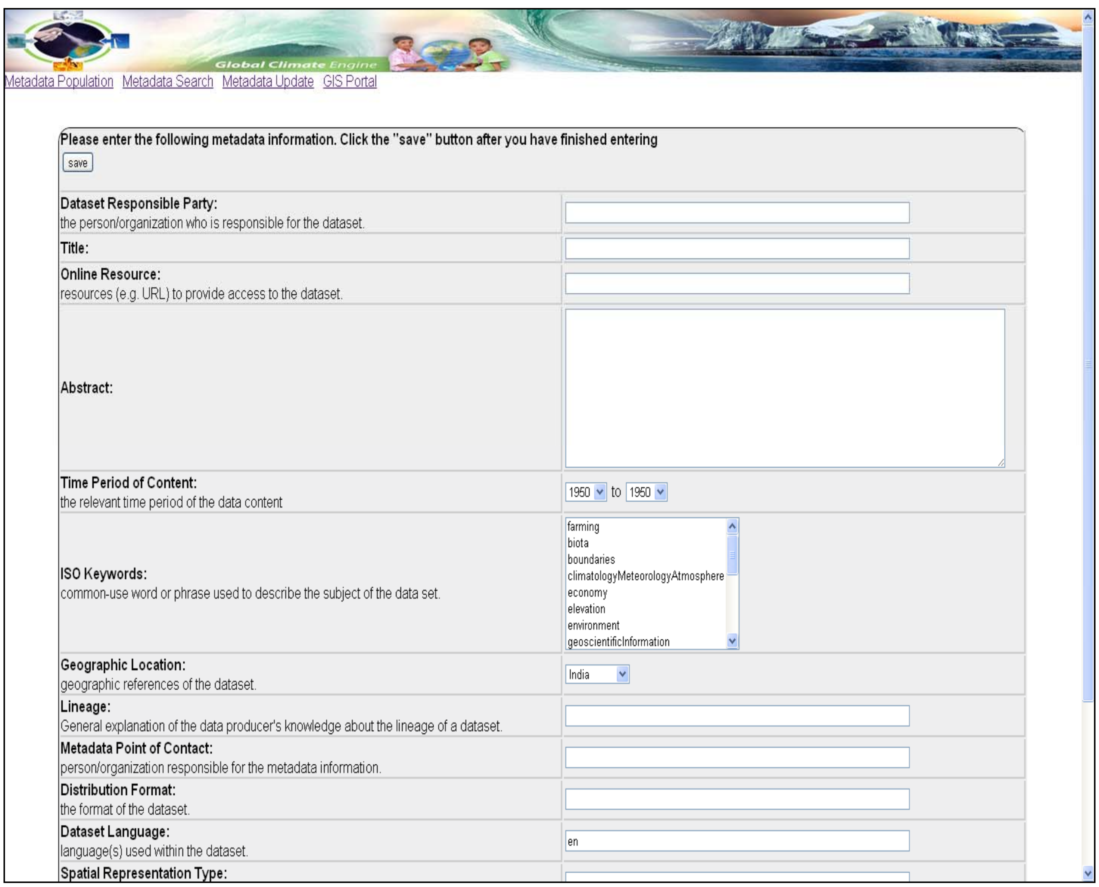

Figure 17 Metadata Population Page

(http://dims.globalclimate-engine.org/Metadata_UNM/MetadataForm)


Global Climate Engine

Metadata Population Metadata Search Metadata Update GIS Portal

You have entered the following metadata records

Record	Title	Abstract		
1	India_Coastline	[...] Coastline of India(2007) [...]	edit	delete
2	India_Countryboundary	[...] Boudaries of India(2008) [...]	edit	delete
3	India_Majorcities	[...] Major cities represents the location of the Major cities in India [...]	edit	delete
4	India_Landcover	[...] Shows the Land cover details of India. Its classified into 6 categories like, Water, Forest, Grass Land, Crop Land, Bare Land and Urban and Built-up [...]	edit	delete
5	India_Stateboundary	[...] Administrative Units represents the boundaries for the first-level administrative units of the world. [...]	edit	delete
6	India_Elevation	[...] NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. The vertical error of the DEMs is reported to be less than 16m. [...]	edit	delete
7	Malaysia_Coastline	[...] Coastline of Malaysia(2007) [...]	edit	delete
8	Malaysia_Countryboundary	[...] Boudaries of Malaysia(2008) [...]	edit	delete
9	Malaysia_Majorcities	[...] Major cities represents the location of the Major cities in Malaysia [...]	edit	delete
10	Malaysia_Stateboundary	[...] Administrative Units represents the boundaries for the first-level administrative units of the world. [...]	edit	delete
11	Malaysia_Landcover	[...] Shows the Land cover details of Malaysia. Its classified into 6 categories like, Water, Forest, Grass Land, Crop Land, Bare Land and Urban and Built-up [...]	edit	delete
12	Malaysia_Elevation	[...] NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. The vertical error of the DEMs is reported to be less than 16m. [...]	edit	delete
13	Singapore_Coastline	[...] Coastline of Singapore(2007) [...]	edit	delete
14	Singapore_Countryboundary	[...] Boudaries of Singapore(2008) [...]	edit	delete

Figure 18 A list of previously entered metadata in the metadata update page

(ii) Metadata Search

The screenshot below shows the search page for metadata. Using this page, the users can search metadata with the search term appeared in the ISO keywords and/or title and/or abstract of the metadata. As can be seen in the screenshot, the user entered “landcover” as the search term.

When the search button is hit, the returning result as demonstrated in the screenshot below shows the metadata that contain the search term “landcover”. When the “detail” link is clicked, the full detail of that metadata will be displayed, as illustrated in Figure 21.

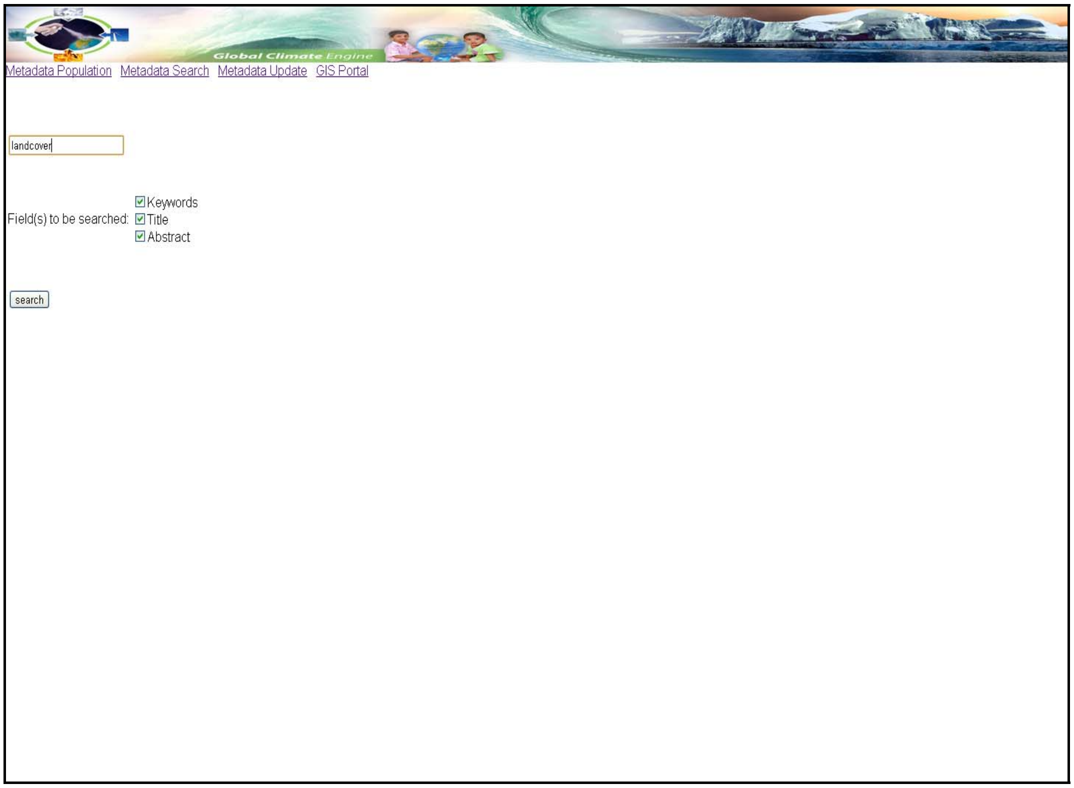

Figure 19 Search Interface

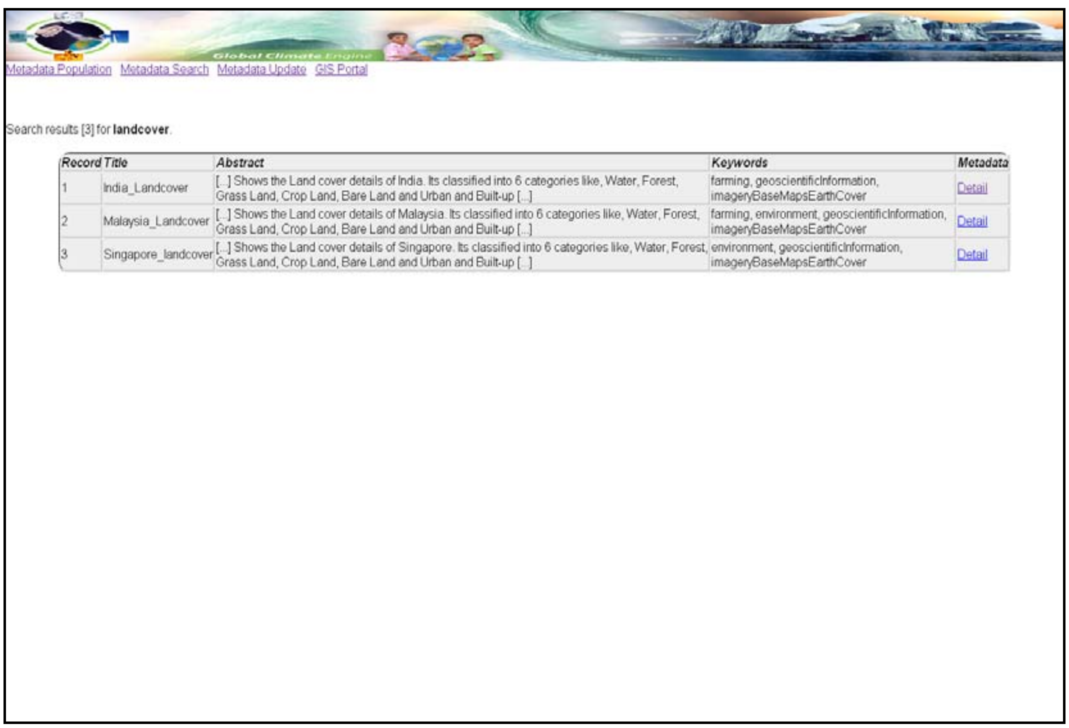

Figure 20 Result Return Page

Return to the Result Page

ISO Metadata for India_Landcover

Dataset Title:	India_Landcover
Metadata Date:	20111115
Dataset Responsible Party:	
ISO Keywords:	farming, geoscientificInformation, imageryBaseMapsEarthCover
Online Resource:	India_Landcover
Dataset Abstract:	Shows the Land cover details of India. Its classified into 6 categories like, Water, Forest, Grass Land, Crop Land, Bare Land and Urban and Built-up
Time Period of Dataset:	Begin Date 2005 End Date 2010
Geographic Location(s):	India
Distribution Format:	Tiff file
Dataset Language:	en
Spatial Representation Type:	Raster
Reference System:	GCS_WGS_1984
Lineage:	East Asian Seas GIS
Metadata Point of Contact:	
Metadata Standard Name:	ISO 19115 Geographic Information - Metadata
Metadata Language:	en
Metadata Standard Version:	1.0

Figure 21 Metadata Details

(iii) The Metadata GIS Portal

The meta data GIS Portal, is also developed to visualize the spatial data along with their metadata. The below screenshot is the main interface of the meta data GIS Portal. The interface is divided into three panels. The left panel shows a list of spatial data available, the middle panel shows the spatial data, and the right panel demonstrates corresponding metadata.

To include the spatial data for display, the users need only check on the checkbox of the spatial data, as shown in the left panel. After hitting the “Display Map with Metadata” button at the bottom of the left panel, the spatial data and their respective metadata will be retrieved from the database and displayed in the middle and right panels respectively. Please note that any update done in the metadata update page, will be instantly refreshed in this GIS Portal page.

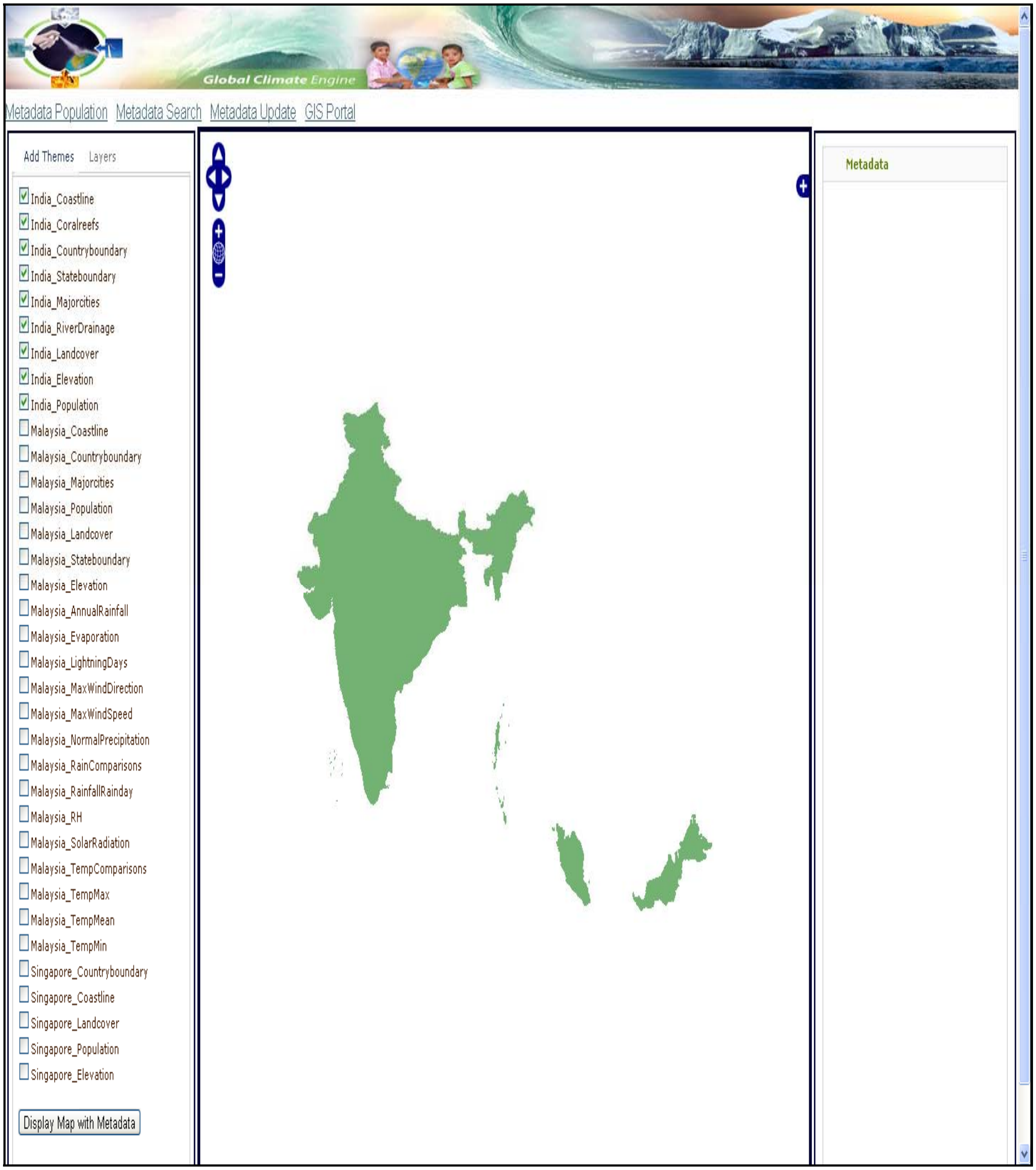

Figure 22 The main interface of the GIS Portal

(http://dims.globalclimate-engine.org/Metadata_UNM/GISServer)

The following three screenshots (Figure 23-25) illustrate the examples where the spatial data describing the specific country are included in the portal.

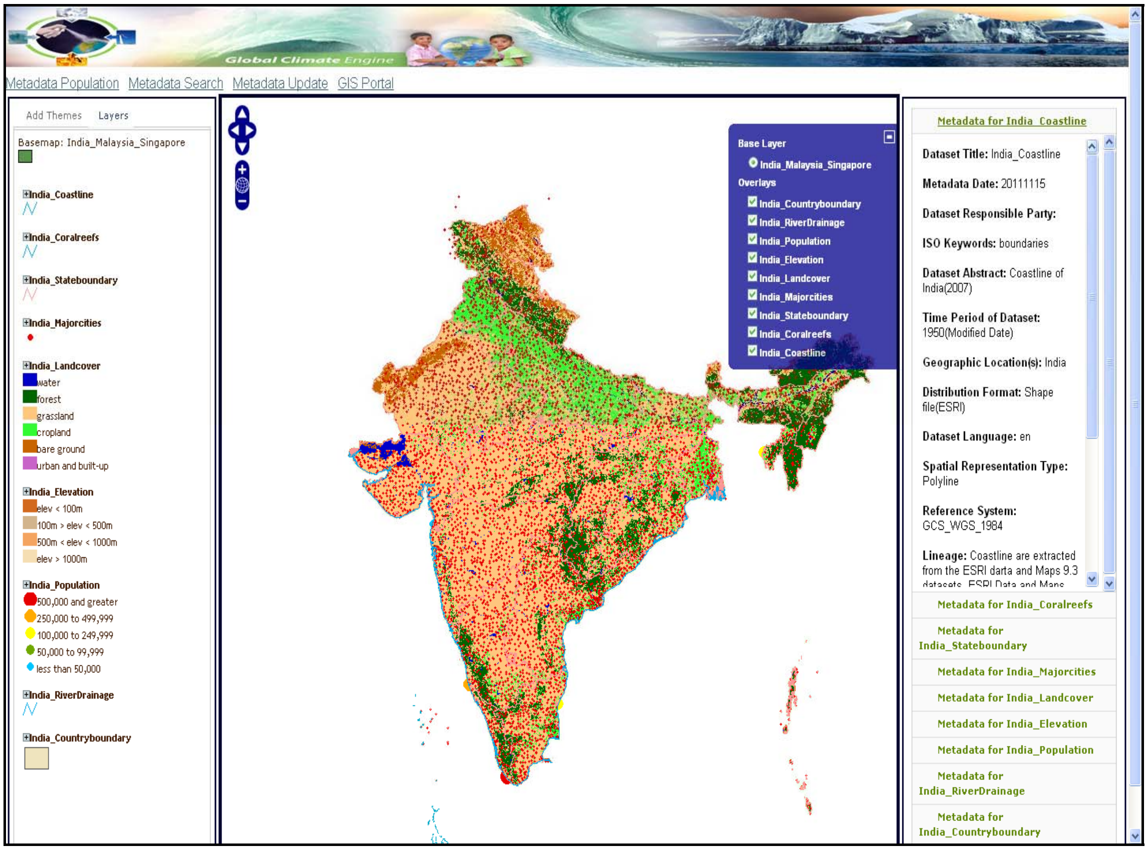

Figure 23 The GIS Portal displays the spatial data for India with metadata

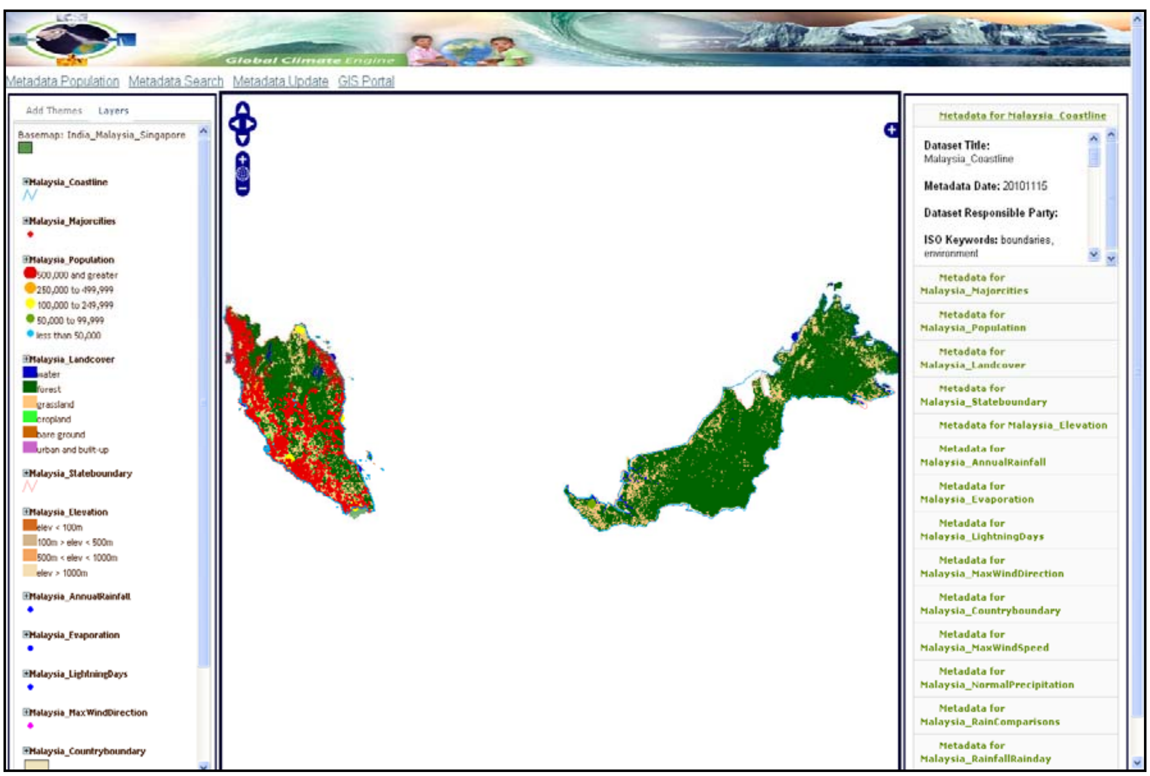

Figure 24 The GIS portal for Malaysia

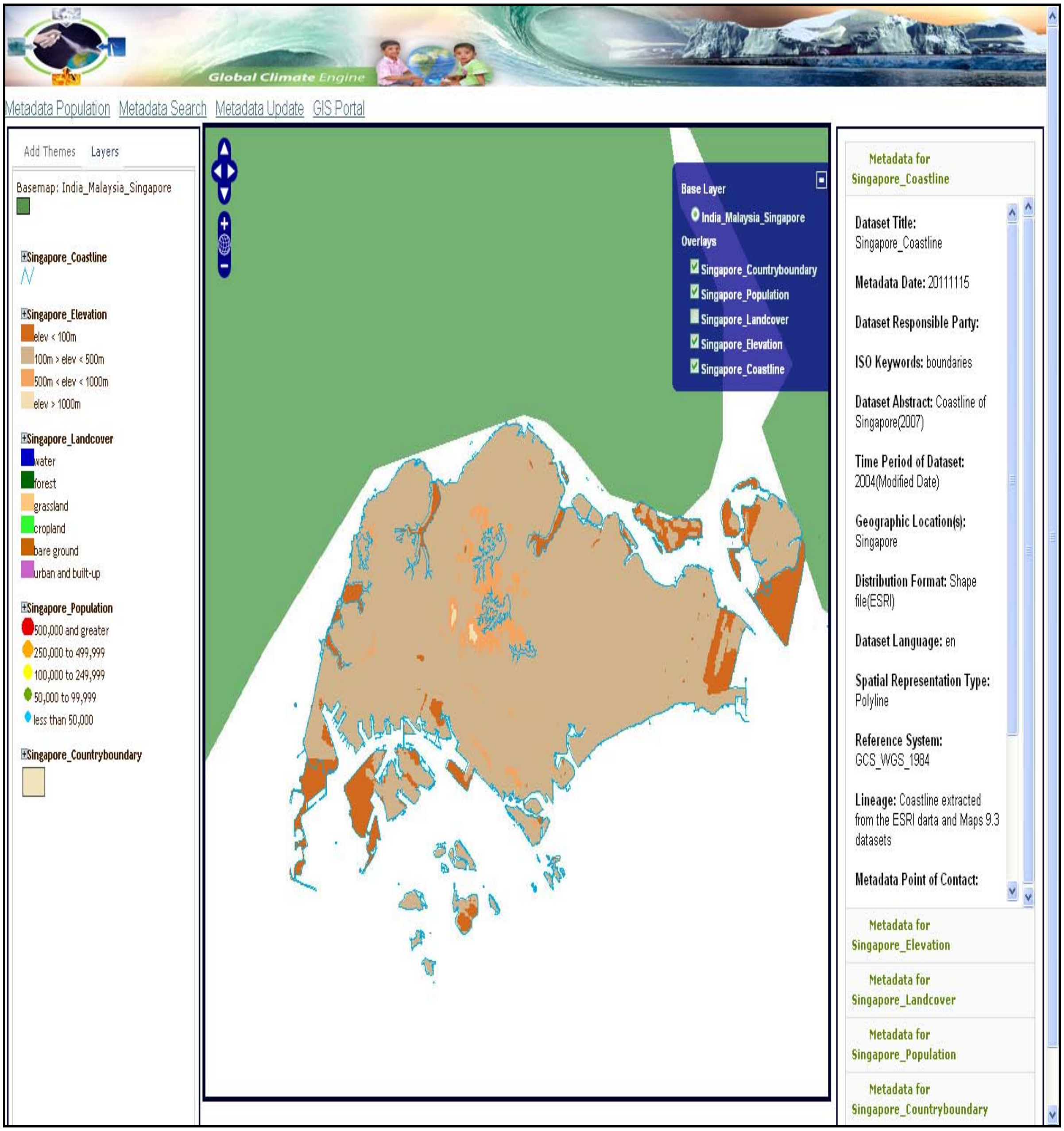

Figure 25 The GIS Portal shows the spatial data and their metadata for Singapore

Figure 26 Searchable database – a sample

2.13 Results

DIMS should be viewed as an opportunity for the environmental community to advance in the field of coastal zone management and its changes due to climate change. Making DIMS in ARCGIS represents the latest of tools to solve the spatial data-handling problem. Proper use of DIMS based on GIS required the data knowledge of the map composition skills of the experienced cartographer, the data base management skill of the data processing person, the scientific insight of geographer, the computer knowledge of a system analyst, and the personnel and organization skill of the manager.

The coastal zone DIMS concepts are currently enjoying a major upsurge in the level of interest and there are grounds for optimism in believing that the significant advances in this direction is not too far away. At the end, it is concluded that the use of DIMS in coastal zone management in interesting and stimulating.

Due to the fact that geographic information system (GIS) and remote sensing (RS) technology is very important tool for planning, management and monitoring of natural resources, the DIMS project in pursuing its objectives of rehabilitating the country's capabilities and alleviating the climate change impact is keen to develop an integrated information system. In this matter, DIMS technology is considered a particularly important tool for the project which is charged with managing, improving and preserving the country's environment.

3.0 CLIMATE CHANGE MODEL AS PART OF VALIDATION OF THE DEVELOPED DIMS

Climate change is recognized as a significant human-induced global challenge and also a global threat that is being experienced at a regional level. It is having a number of detrimental effects on the global environment: particularly in the coastal zone where oceans meet the terrestrial environment. Climate change will have adverse impacts on food security, and economic development of many countries. Efforts to address climate change began in almost all countries and started working towards the implementation of recommendations of the United Nations Framework Convention on Climate Change in 1992. The importance and significance of the vulnerability of natural and human systems to climatic changes and adaptation to such changes is increasingly being realized. Thus, there is a growing recognition of the vulnerability and impacts of climate change on the key sectors of economic development, namely agriculture, water resources, coastal and other eco systems. The Intergovernmental Panel on Climate Change (IPCC) has clearly concluded that the impact of human activities on climate is unequivocal (IPCC, 2007) and the main debate is the assessment of extent and magnitude of climate change. The Fourth Assessment of the IPCC provides the latest understanding on the science, impacts, vulnerabilities, adaptation and mitigation of climate change.

As per the IPCC 4th assessment report (IPCC, 2007), most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. It also concluded that discernible human influence now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.

Constructing climate change scenarios for the future is the first step of any assessment, as this drives the changes in the impacts on natural resources. In order to do so, examination of the current trends of climate is also essential. This assessment examines the trends in observed seasonal temperature and precipitation over India using a century long data. This is done in the context of the changes in climate that are being observed globally. Since one of the drivers of climate is the greenhouse gases and their concentration, the chapter reviews the current knowledge about the changes in global and regional and national climate in the very near future i.e 2030's. The nature of the models available for projecting global and regional climate has been briefly outlined.

3.1 Coastal region of India

The coastline of India extends to 75,500 km as per the notification (CRZ, 2010). The coastal plains of India lie to both the eastern and western side of the peninsula. The western coastal plain of the peninsular plateau extends from Gujarat in the north to Kerala in the south. It lies between the Arabian Sea and the Western Ghats, and is a narrow strip of plain area ranging from 50 to 100 km in width, except in Gujarat. The Indian coastline can be divided into the Gujarat region, the west coast, and the east coastal plains. In this study only part of east coast has been considered for the demonstration of the usefulness of the developed database systems for climate change modeling.

The eastern coastal plain lies between the Eastern Ghats and the Bay of Bengal. It extends from West Bengal in the north to Tamil Nadu in the south. It covers about 1,03,000 km^2 with a population of about 83 million. The four major units of the eastern coastal plains are the Tamil Nadu coast, the Andhra coast, the Utukal coast and the West Bengal coast. The eastern coastal plains are more even, fertile and broad as compared to the western coastal plains. Almost all the major rivers form deltas on this coast. Numerous lakes are found along the coast; Chilka and Pulicat are famous lakes among them.

This area is a wide coastal plain comprising four deltas: the Mahanadi, the Godavari, the Krishna and the Cauvery, besides the intervening tracts of older tertiary marine sediments. In addition, a part of the Ganges-Brahmaputra delta falls on Indian territory near Kolkata. The total area of the East coast exceeds 20,000 km^2 with a population of 19.9 million. The coastal plain is widest in the deltaic regions, having well defined morphological units parallel to the shoreline. Sandbars often form in front of the river mouths, for example, the Godavari and the Mahanadi rivers. Sand dunes occur along the coast, sometimes extending up to 10 km inland. The dunes support a thin vegetation of Palmyra Palms and thorny scrubs. Some of these dunes are still active under wind actions and migrate slowly towards east and southeast. Adjoining the line of sand dunes along the coast, are lagoons formed by coastal uplift; the Chilka Lake and the Pulicat Lake areas are the largest and most important of these. The Chilka Lake is located on the southwest edge of the Mahanadi delta. It is the largest brackish water body in India, its area varying between 800 to 1150 km^2 from the winter to monsoon months. The salinity also varies seasonally. Farther south, on the border of Andhra and Tamil Nadu is the Pulicat Lake, a brackish backwater lake. It occupies an area of approximately 800 km^2 and is connected to the sea.

Agriculture has been the dominant occupation in the coastal plains since ancient times. However, the three sub-regions differ appreciably in their agricultural characteristics. While rice cultivation is always predominant, jute in Utkal, tobacco and oil-seeds in Andhra Pradesh and the groundnut and cotton in Tamil Nadu create a regional distinctiveness in agriculture. Large-scale industry is not significant due to a lack of raw materials. Tamil Nadu is the most industrialized state.

The temperature in the coastal regions exceeds 30°C coupled with high levels of humidity. The region receives both the northeast and southwest monsoon rains. The southwest monsoon splits into two branches - the Bay of Bengal branch and the Arabian Sea branch. The Bay of Bengal branch moves northwards crossing northeast India in early June, while the Arabian Sea branch moves northwards and discharges much of its rain on the windward side of the Western Ghats. Annual rainfall in this region averages between 1,000 mm (40 in) and 3,000 mm (120 in).

With climate change, it is projected that the sea level may rise further than what it is today and with warming of the oceans, the intensity and frequency of cyclonic activities and storm surges may increase leading to large-scale inundation of the low-lying areas along the coastline. In this context, this chapter reviews the existing trends of these parameters based on observations. It also analyses the projections using modeling techniques.

3.2 Database

High-resolution (1°x1° lat/long) daily gridded rainfall data available from 200 well distributed stations over India, collected from the Indian Meteorological Department (IMD) over the years 1961-2008 have been used in this assessment. This data has been collected from 24 observation stations of IMD in India. The data is available for 1 January to 31 December for each year. However, analysis in this study is restricted to the Indian Summer Monsoon season, June to September, since nearly 80% of the annual rainfall over the coastal India occurs during this period.

The monthly maximum and minimum temperature data from 24 stations well distributed over the coast country during the period 1961-2008 have also been used in the present study. Temperature data from 24 stations have been converted to monthly anomaly time series for the period 1961-2008, with reference to the respective station normal values, and interpolated onto a 5°x5° grid. Annual and seasonal temperature series for the period 1961-2008 have also been constructed for the east coast.

Further, the global monthly air temperature $5^o x 5^o$ gridded data from Climatic Research Unit (CRU), University of East Anglia for the period 1961-1998 have been used for evaluating the model skills in baseline simulations of the mean surface air temperature.

Though the impacts of the sea-level rise are local in nature, the causes of sea-level rise are global and can be attributed to several non-linearly coupled components of the Earth system. At long-time scales, global mean sea level change results from mainly two processes, mostly related to recent climate change, that alter the volume of water in the global ocean; thermal expansion and ii) the exchange of water between oceans and other reservoirs - glaciers and ice caps, ice sheets, other land water reservoirs - including through anthropogenic change in land hydrology, and the atmosphere. Some oceanographic factors such as changes in ocean circulation or atmospheric pressure also cause changes in regional sea level, while contributing negligibly to changes in the global mean. Though global sea-level rise has been studied extensively during the last two decades based on tide-gauge data, the same is not true of trends in regional sea level. The variability seen in regional sea level is less well understood owing to two causes. First, the distribution of tide gauges is not uniform over the globe, and not many records from the tropics are long enough for a reliable estimate of sea-level trends. Second, vertical land movements make problematic the determination of changes at the coast, where the tide gauges are located. Global Positioning System (GPS) measurements to determine vertical land movements are often not available.

3.3 Data gaps and Uncertainty in modeling

Climate: Presently the climate projections are based on the regional model HadRM3, using a single socio-economic scenario (A1B scenario) that drives the trends of the greenhouse gases in the model. Further, there are inherent uncertainties in the key assumptions about and relationships between future population, socio-economic development and technical changes that constitute the basis of the IPCC SRES Scenarios. The uncertainty in emissions can be allowed for by making climate projections for a range of these SRES emissions scenarios. Also, an imperfect understanding of some of the processes and physics in the carbon cycle and chemical reactions in the atmosphere generates uncertainties in the conversion of emissions to concentration.

Uncertainties also arise due to the incomplete description of key processes and feedbacks in the model. This can be reduced by running ensembles of future climate projections using the same model and the same emission or concentration scenarios. Further, regionalization techniques carry with them errors in the driving general circulation model (GCM) fields.

The resolution of the regional climate model (RCM) should be high enough to resolve the fine-scale details that characterize regional forces. The PRECIS at 50km resolution can provide good simulations of daily precipitation over the broad plateau region in India. However, detailed projections for inner Himalayan valleys, the hills in the North-East and the Western Ghats require a much higher resolution. Therefore, it is perceived that a higher resolution model (at least 25km x 25km or less) will be more appropriate for capturing the orography of the Indian region.

The projections of climate for the present work have been derived from PRECIS, an atmospheric and land surface model having a high-resolution, which is locatable over any part of the globe. PRECIS, which has been developed by the Hadley Centre, UK is run at Indian Institute of Technology Madras at 50 km x 50 km horizontal resolution over the east coast of India domain. The model simulations are carried out for the period 1961-1998 and 2051-2100 (A2 and B2 scenarios) for various surface as well as upper air parameters, on daily and monthly scales. Some basic parameters like rainfall, surface air temperature, mean sea level pressure and winds are analysed to get the projection scenarios towards the end of this century.

3.4 Global Climate Models

The need for understanding and constantly improving the representation of different feedback mechanisms and processes requires the use of 'hierarchy of models'. This provides a linkage between theoretical understanding and the complexity of realistic models. Simpler model formulations either restrict the number of physical processes considered or the spatial domain – single column or one- or two-dimensional latitudinal. Use of hierarchy of model also means complementing global circulation models with regional models of higher resolution over a particular area. Studies on longer time scales, such as glacial to interglacial cycles, have used Earth Models of Intermediate Complexity. Understanding the present climate and making reliable future projections at global and regional scales, therefore requires the use of a variety of modeling tools. The construction of regional climatic scenarios for climate impact studies requires many steps, where each step is associated with a set of models and thus a range of uncertainty. The tools for assessing climate change generally used are the global climate models also known as the generation circulation models which generally have a spatial resolution of 250-300 km. However, they are unable to capture the climate at smaller scales as they do not capture the typical driving factors such as the topography of these smaller regions and the land use pattern. The sections below give a brief description of the two types of models being used globally for climate change projections in the future.

The General Circulation Models (GCMs) are the most advanced tools currently available for simulating the global climate system that includes complex physical processes in the atmosphere, ocean, cryosphere and land surface. These models synthesize the current understanding of oceanic and atmospheric circulation, assimilated through "continuous interplay among theory, observations and, more recently, model simulations" (IPCC, 2007).

The models are thus constituted of mathematical equations derived from physical laws describing the dynamics of atmosphere and ocean. GCMs depict the climate using a three-dimensional grid over the globe, typically having a horizontal resolution of 250 - 300 km, with about 20 vertical layers in the atmosphere and about 30 layers in the oceans. Such coarse resolution, does not allow representation of physical processes, such as those related to clouds.

IPCC (2000) issued a special report on emission scenarios (SRES) that presented more than 40 scenarios based on different visions of how the world may develop in the 21st century, the sources of energy it will use, and how the communities will solve their problems. These scenarios are grouped into four families A1, B1, A2, and B2 as illustrated in Table 2.

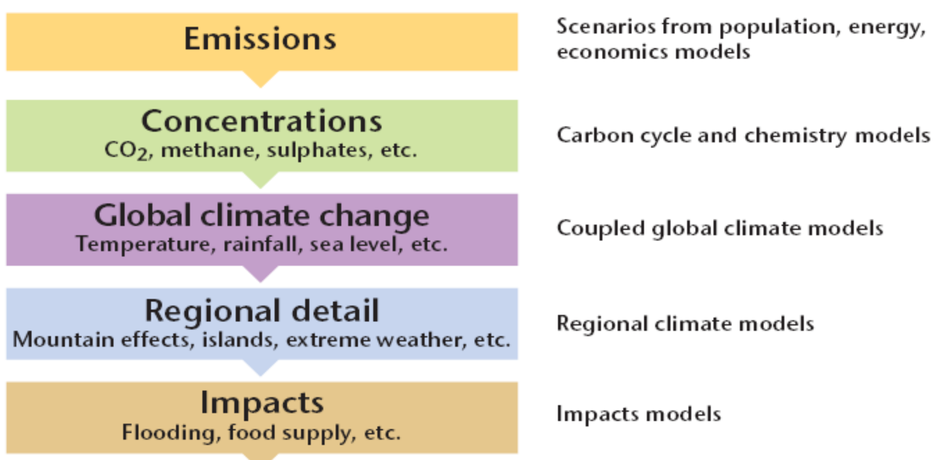

Figure 27 Predicting the Impacts of Climate Change. Source: Hadley Centre (2001)

First, scenarios of future emissions of GHGs (carbon dioxide, methane, nitrous oxide, etc.) and aerosols are constructed. The next step is to translate these emission scenarios to concentrations of GHGs in the atmosphere.

TABLE 2 ASSUMPTIONS USED TO CONSTRUCT FUTURE SRES GREENHOUSE GAS SCENARIOS

Scenario	Description
A1	very rapid economic growth; low population growth; rapid introduction of new and more efficient technology; economic and cultural convergence and capacity building people pursue personal wealth rather than environmental quality
A2	strengthening regional cultural identities; an emphasis on family values and local traditions; high population growth; less concern for rapid economic development
B1	rapid change in economic structures "dematerialization" and introduction of clean technologies; emphasis on global solutions to environmental and social sustainability; concerted efforts for rapid technology development; dematerialization of the economy
B2	emphasis on local solutions to economic, social, and environmental sustainability; a heterogeneous world with less rapid, and more diverse technological change; strong emphasis on community initiative

3.5 Assessing Climate Change Impact

India has a unique climate system dominated by the monsoon, and the major physiographic features that drive this monsoon are its location in the globe, the Himalayas, the central plateau, the western and Eastern Ghats and the oceans surrounding the region. The global models, however, fail to simulate the finer regional features, and the changes in the climate arising over sub-seasonal and smaller spatial scales. Keeping these limitations in view, the assessment describes the simulations and projections of climate for 2030's at a sub-regional scale, using PRECIS (a regional climate model developed by the Hadley centre, UK) that has a resolution of 50 km by 50 km. The model was run for the A1B socio-economic scenario that assumes significant innovations in energy technologies including renewable, which improve energy efficiency and reduce the cost of energy supply.

About 20% of the population of India lives in the coastal areas, a larger percentage of this being in coastal cities, such as Mumbai, Chennai and Kolkata. One of the major factors responsible for the degradation of coastal ecosystems is the growth in human population that requires space for settlement and other resources, like soil and water. To systematically pursue such assessments, the most fundamental requirement is the availability of reliable estimates of future climatic patterns on the regional scale, which can be readily used by different impact assessment groups. This needs a systematic validation of the climate model simulations and development of suitable regional climate change scenarios and estimations of the associated uncertainties. This assessment examines the trends in observed seasonal temperature and precipitation over India using a century long data. This is done in the context of the changes in climate that are being observed globally. Since one of the drivers of climate is the greenhouse gases; the concentration of which are likely to increase in the future, the current knowledge about the changes in global and local climate that may occur in the very near future i.e. 2030's. In doing so, the nature of the models available for projecting global and regional climate is discussed.

Water is the most critical component of life support systems. India shares about 16% of the global population but it has only 4% of the total water resource. The irrigation sector, which uses 83% of water, is the main consumer of this resource. The main water resources in India consist of precipitation on the Indian territory–estimated to be around 4000 cubic kilometers per year (km^3/year) – and transboundary flows, which it receives in its rivers and aquifers from the upper riparian countries. Precipitation over a large part of India is concentrated in the monsoon season during June to September/October. Due to various constraints of topography there is uneven distribution of precipitation over space and time. Precipitation varies from 100 millimeters (mm) in the western parts of Rajasthan to over 11,000mm at Cherrapunji in Meghalaya. Out of the total precipitation, including snowfall, the availability from surface water and replenishable groundwater is estimated at 1,869km^3. It has been estimated that only about 1,123km^3, including 690km^3 from surface water and 433km^3 from groundwater resources, can be put to beneficial use (Gupta and Despande, 2004).

Table 3 shows the water resources of the country at a glance (MoWR, 2010). Further, extreme conditions of floods and droughts are a common feature, which affect the availability of water for various purposes. It is also estimated that a total of 40 million hectares (mha) of area is flood-prone and this constitutes 12% of total the geographical area of the country. Droughts are also experienced due to deficient rainfall. It has been found that an area of 51mha is drought prone and this constitutes 16% of the total geographical area. Added to this is the growing demand for water. The population of the country has increased from 361 million in 1951 to 1.13 billion in July 2007. Accordingly, the per capita availability of water for the country as a whole has decreased from 5,177 cubic metres per year (m^3/year) in 1951 to 1,654m^3/year in 2007.

On the other hand, National Communication to United Nations Framework Convention on Climate Change (NATCOM, 2004) stated that climate change is likely to adversely affect the water balance in different parts of India due to changes in precipitation and evapotranspiration and rising sea levels, leading to increased saline intrusion into coastal and island aquifers. Increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Increased rainfall intensity may lead to higher runoff and possibly reduced recharge. Further, the National Water Mission, which is a part of the National Action Plan on Climate Change (MoWR, 2010), identifies the threat to water resources in India due to climate change in terms of the expected decline in the glaciers and snow fields in the Himalayas; increased drought-like situations due to the overall decrease in the number of rainy days over a major part of the country; increased flood events due to the overall increase in the rainy day intensity; effect on groundwater quality in alluvial aquifers due to increased flood and drought events; influence on groundwater recharge due to changes in precipitation and evapotranspiration; and increased saline intrusion of coastal and island aquifers due to rising sea levels. The National Water Mission has been, therefore, set up to undertake integrated water resources management for the conservation of water, minimizing wastage and ensuring equitable distribution both across and within the states. Clearly the impact of climate change on water resources in India adds another dimension to the complexity of managing and using water resources. Climate change may alter the distribution and quality of natural resources, which will definitely affect the livelihood of its people.

Knowledge of the climate system, together with model simulations, confirm that the past changes in greenhouse gas concentrations will lead to a committed warming and future climate change because of the long response time of the climate system, particularly the oceans. Committed climate change due to atmospheric composition in the year 2000 corresponds to a warming trend of about 0.1°C per decade over the next two decades i.e. up to 2020's, in the absence of large changes in volcanic or solar forcing. About twice as much warming is expected, that is around 0.2°C per decade. Sea level is expected to continue to rise over the next several decades. During 2000 to 2020 under the A1B scenario, the rate of thermal expansion is projected to be 1.3 ± 0.7 mm yr^{-1}, and is not significantly different under the A2 or B1 scenarios. These projected rates are within the uncertainty of the observed contribution of thermal expansion for 1993 to 2003 of 1.6 ± 0.6 mm yr^{-1}. According to IPCC AR4, the rise in temperature by the end of the century with respect to 1980-1999 levels would range from 0.6°C to 4.0°C and the sea level may rise by 0.18 m to 0.59 m during the same period. Warming compared to 1980 - 1999 for six SRES scenarios and for constant year 2000 concentrations, given as best estimates and corresponding likely ranges are shown in Table 4-5.

Table 4 Water Resources of India km^3

Quantity	**Amount in km^3**
Estimated annual precipitation (including snowfall)	4000
Run-off received from upper riparian countries	500
Average annual natural flow in rivers and aquifers	1869
Estimated utilisable water	1123
(i) Surface Water	690
(ii) Ground Water	433
Water demand _ utilization (for year 2000)	634
(i) Domestic	42
(ii) Irrigation	541
(iii) Industry, energy & others	51

(Source: National Water Mission under National Action Plan on Climate Change, MoWR, GOI, 2010)

3.6 Projections of precipitation

The projections of precipitation indicate a 3% to 7% overall increase in all-India summer monsoon rainfall in east coast region during 2030's when compared to the base data of 1970's. Spatial patterns of monsoon rainfall indicate a significant decrease in the monsoon rainfall in future except in some parts of the southern peninsula. The PRECIS model run for 2030's indicates that the annual rainfall in the East coast varies from a minimum of 858±10mm to a maximum of 1280±16mm. The increase in 2030's with respect to the 1970's is estimated to be 2 to 54 mm, an increase of 0.2% to 4.4 % respectively. The maximum increase in rainfall is projected to happen in March, April and May in 2030's, with rainfall set to increase by 14 mm on an average with respect to the same period in 1970's. The winter rainfall is projected to decrease by 6 mm with respect to 1970's.

Table 5 Projected global average temperature rise and sea level rise at the end of the 21st century

	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
Case	**Best estimate**	**Likely range**	**Model-based range excluding future rapid dynamical changes in ice flow**
Constant Year 2000 concentrations	0.6	0.3-0.9	NA
B1 scenario	1.8	1.1-2.9	0.18-0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 Scenario	2.4	1.4-3.8	0.20-0.43
A1B scenario	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1FI scenario	4.0	2.4-6.4	0.26-0.59
Source: IPCC, AR4, 2007			

3.7 Projections of mean annual surface Temperature

PRECIS simulations for 2030's indicate an all-round warming over the Indian subcontinent associated with increasing greenhouse gas concentrations. The annual mean surface air temperature rise by 2030's ranges from 1.7°C to 2°C as in the three simulations. The seasons may be warmer by around 2^{o}C towards 2030's. The variability of seasonal mean temperature may be more in winter months. In the east coast region, the surface annual air temperature is set to rise from 28.7°C to 29.3°C. The standard deviation in the temperatures varies from 0.6 to 0.7 respectively. The rise in the temperature with respect to 1970's is of the order of 1.6 to 2.1°C. The maximum increase in temperature is for March, April and May in all the simulations and is ranging from 1°C to 3.3 °C.

3.8 Projections of sea level rise

Model-based projections of global average sea-level rise at the end of the 21st century (2090–2099) made for a number of climate scenarios indicate that the sea level may rise from a minimum of 0.18 m minimum to a maximum of 0.52 m. Globally, sea level is expected to continue to rise over the next several decades. The sea-level rise at short-term time lines are mainly due to committed thermal expansion, caused by constant atmospheric composition at year 2000 values. Regional variations in sea level change occur also through changes in ocean density and circulation. For the north Indian Ocean region, this variation has been projected to be less than 0.05 m by 2100 relative to the global mean for A1B scenario. In the absence of availability of regional projections, global projections can be used as a first approximation of sea-level rise along the Indian coasts in the next few decades as well as towards the end of the 21st century.

3.9 Projected coastal inundation due to sea- level rise

Impacts at the coast depend on on-shore topography. Coastal regions having a gentle topography are more vulnerable than those having a steep topography. The east coast of India is more vulnerable than the west coast, because the former is low-lying and more prone to the occurrence of cyclones than the latter (Shetye et al., 1990). The most vulnerable region was identified in the east coast region is the Nagapattinam coast and it has been estimated that considerable area will be inundated for a sea-level rise of 1m that has been estimated.

3.10 Projected Water Availability

The east coast region also exhibits wide variability in the change in precipitation under the 2030s scenario. The northern portion of the east coast show an increase in precipitation for the 2030s scenario in some parts, and the increase varies from a small fraction to about 10%. However, some parts show a marginal reduction of up to about 3%. The southern portion of the east coast, which comprises mainly the Tamil Nadu area, shows a decrease in precipitation of up to 5%. The trend in water yield in the east coast region also reflects that there is considerable precipitation change in the coastal region (Gosain at al., 2006).

3.11 Conclusions

Climate change and its impact assessment is an inter-disciplinary area that cuts across physics, chemistry, biology, earth sciences, hydrology, agriculture, economics, technology development, etc. Therefore, multiple data sets are required even to simulate the current situations by different models. Thus there is an immediate need to get data on climate, natural ecosystems, soils, water from different sources, agricultural productivity and inputs and socio-economic parameters amongst others in order to get a reliable prediction. In this context, it is essential to have accessibility to databases that reflect national and regional concern. Efforts should be made to establish an effective mechanism for sharing and accessing this data in formats that can be easily deciphered.

Many studies on climate impact assessments utilizing models that have been developed in other countries and there is an urgent need to develop a climate change model for each region as the rainfall and monsoon conditions are entirely different in different countries.

To enhance the level of climate change research, especially in climate change modeling, urgent need of capacity building is essential in India. In this context, scientific cooperation and collaboration is essential, be it in the area of climate modeling, impact assessment, integrated impact assessments, research on mitigation of climate change concerns and adaptation to impacts of climate change. Extensive networking of researchers within India, through platforms such as the Indian Network for Climate Change Assessment, can be used to create a critical mass of researchers who can carry forward the work on science, impacts and mitigation of climate change in India.

More importantly, it is necessary to develop adaptation plans in terms of agricultural practices including cropping pattern, energy alternatives, water conservation measures etc need to be developed at *regional levels. These adaptation plans may be developed for the short-, medium- and long-term periods, taking into account the requirements of planning for a perceptible future in the short term and the very nature of climate change issues, which are long term.

4.0 COASTAL SYSTEM MAPPING WITH DIMS (AS PART OF VALIDATION OF THE DEVELOPED DIMS)

Coastal system mapping (CSM) offers a new approach to the synthesis and formalisation of scientific understanding of coastal behavior at a meso-scale that is commensurate with the challenges of managing impacts of sea-level rise and climate change (French and Burningham, 2009b).

4.1 CSM principles: Hierarchical feature-element-intervention classification

At a large-scale (i.e. at the scale of conventional sediment cells; Bowen and Inman, 1966; Davies, 1974; Motyka and Brampton, 1993), the coastal system can be defined with reference to a set of high-level *features*. Each feature contains a set of lower-level *elements,* which include individual landforms such as cliffs, beaches etc.. Features and elements are typically connected by sediment transfer pathways, which define the sediment budget system. Divergences or breaks in the continuity of the drift system define sub-cell or cell boundaries.

The logic behind the selection of features and elements in a UK context is summarised in Whitehouse *et al.* (2008, 2009). A slightly expanded provisional list of features for more general application is summarised here in Table 6 and the elements in Table 7. These sets can be expanded as required to suit local or regional coastal characteristics. In brief, features include larger-scale headlands, bays, stretches of open coast etc. Elements contain component landforms such as beach, tidal flat, dune, cliff etc. A variety of structural (e.g. seawall) and non-structural (e.g. beach re-profiling) *interventions* are also identified at the element scale. These provisional sets of components can obviously be modified to suit a particular regional context.

4.2 Alongshore versus cross-shore zonation

At a feature scale, coastal systems are considered to be essentially linear in character. Features therefore generally pick out the main alongshore characteristics. Cross-shore zonation is mapped at the element scale, and this extends over the presently active offshore – nearshore – backshore zones as well as the hinterland (which might contain relict coastal and estuarine landforms). This approach has been partly informed by the 'coastal tract' concept (Cowell et al. 2003) and also by the coastal simulator framework proposed by Hanson et al. (2010).

The logic behind the selection of features and elements in a UK context is summarised in Whitehouse *et al.* (2008, 2009). A slightly expanded provisional list of features for more general application is summarised here in Table 6 and the elements in Table 7. These sets can be expanded as required to suit local or regional coastal characteristics. In brief, features include larger-scale headlands, bays, stretches of open coast etc. Elements contain component landforms such as beach, tidal flat, dune, cliff etc. A variety of structural (e.g. seawall) and non-structural (e.g. beach re-profiling) *interventions* are also identified at the element scale. These provisional sets of components can obviously be modified to suit a particular regional context.

Table 6 Summary of coastal feature set. This can be extended as required to suit a given regional coastal context

Feature	Remarks
Offshore	Offshore feature used to group seabed types and banks (both of which are considered to interact at the element scale)
Open coast	
Headland	
Bay	
Spit	
Cuspate foreland	
Inlet	
Tombolo	
Barrier island	
Island	Used to define non-barrier islands that are not mapped in detail but which exert an influence on the coast
Estuary	
River	
Updrift coast	Use to bound part of larger littoral drift system
Downdrift coast	

Table 7 Summary of coastal element set. Note the inclusion of various types of intervention (including non-structural management interventions)

Element	Remarks
Cliff	
Dune	
Lagoon	
Beach	

Shore platform	
Fringing reef	
Tidal flat	
Saltmarsh	
Mangrove	
Channel	Classification of banks follows Dyer and Huntley (1999).
Inlet-associated bank	
Headland-associated bank	
Offshore bank	
Beach ridge	
Offshore reef	
Seabed sand	
Seabed gravel	
Low ground	Implies low-lying hinterland that has been marine-influenced during Holocene; potentially re-activated by sea-level rise or breakdown of coastal barriers.
High ground	Implies land above present tidal influence and which has not been marine-influenced during Holocene; a potential sediment source.
Intervention	
Seawall	Structure
Revetment	Structure
Detached breakwater	Structure
Long terminal groyne or jetty	Structure
Reclamation embankment	Structure
Groynes	Structure
Outlet	Structure
Weir	Structure
Harbour	Structure

Dredging	Management intervention
Sediment recharge	Management intervention
Sediment bypassing	Management intervention
Sediment recycling	Management intervention
Beach re-profiling	Management intervention
Made ground	Management intervention

At some locations, it may be appropriate to recognise a more complex cross-shore zonation. Barrier islands, for example, might contain beach, dune, tidal flat etc, and be backed by channels and further tidal flat, saltmarsh, seawall etc.

4.3 System linkages: sediment budgets and influences

The various component landforms and engineered structures are connected by two kinds of link. Sediment transfer links define long-term average movements of sediment. Influence links represent interactions where no exchange of sediment is involved – for example, the influence of a seawall on the beach (and vice-versa). Linkages can be directional (either one-way or two-way) or left undefined where we do not have enough information to assign a clear preferred direction. In cases where the sediment budget is well understood, the relative magnitude of individual fluxes can be indicated by weighting their line thicknesses. In this case, the system map becomes a tool for displaying sediment budget information in a qualitative or semi-quantitative way.

In some situations, separate sediment and influence links must be defined. For example, a coastal bank may receive sediment from a headland (a mass flux) whilst also reducing wave energy along its landward coast (an influence). Curved links can be used in these cases to avoid overlapping lines.

4.4 Mapping conventions

It is important that system maps adopt a consistent symbolic representation. The scheme presented in Figure 28 is designed to be generic and is not specific to any particular software. However, all the graphical components shown can be created in the CmapTools package that is described in this tutorial. Key aspects of the mapping scheme include:

- a symbolic distinction between Features, Elements and Interventions.

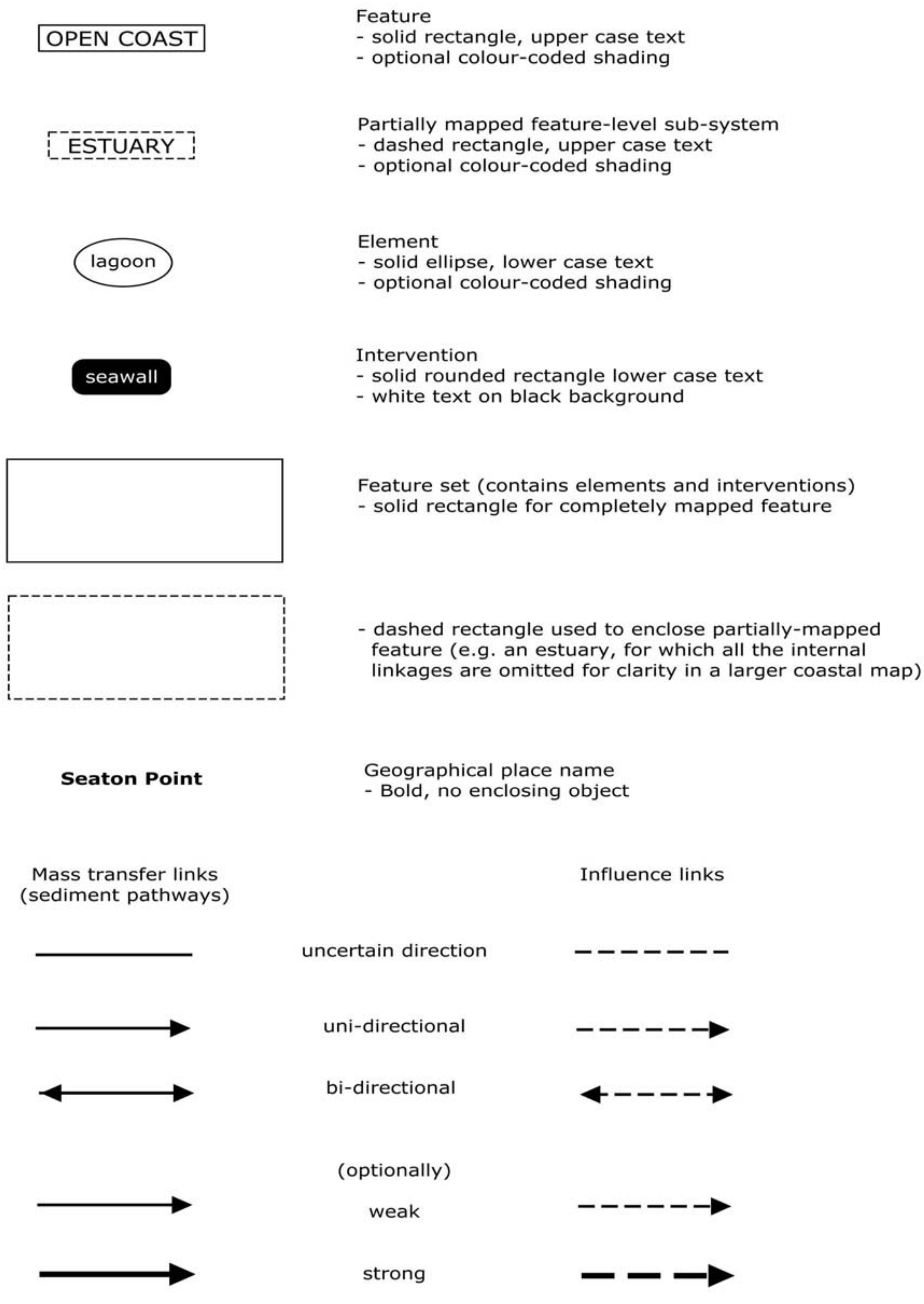

Figure 28 Convention for coastal system mapping

- a distinction between features that are mapped completely and those that are partially mapped (e.g. estuaries included in a broader coastal map but not represented in detail for reasons of clarity).

- a distinction between sediment and influence links and the ability to represent both the direction and relative strength of these.

Depending on the application, it is necessary to decide whether to arrange the system components in a *geographical map*, scaled against real-world co-ordinates, or in the form of a *topological map*, which may be more visually communicative. Geographical maps can be constructed on top of a base map or image of a region of interest. This is convenient for short stretches of coast (e.g. a single bay-headland system) for which high quality aerial imagery is available. Topological maps may be better for larger systems or where the structure of the system is more important than the actual location of the components.

4.5 Workflow for the production of a coastal system map

The principal stages in the production of a coastal system map are summarised below and diagrammatically in Figure 29.

Stage 1: Specify region of interest and define problem

First, specify a region of interest. Next, define the nature of the problem. This might be part of a 'brainstorming' exercise to synthesize expert opinion on the behaviour of a given stretch of coast; it might be a requirement to undertake broad-scale mapping as a framework for modelling; or it may stem from a need to provide context for more local management decision-making (e.g. the evaluation of alternative management options for an estuary mouth in the context with wider aspects of estuary-coast interaction).

Stage 2: Decide how the mapping process will be undertaken

Decide on whether CSM is to be carried out as a consensus-building exercise involving a large team of experts (possibly including non-experts and stakeholders) or as a more direct synthesis of understanding by a single expert or small team working closely together. Consensus-based mapping can take the form of interactive brainstorming sessions in a workshop setting but might also be accomplished by comparison and merging of maps produced independently by a set of experts. These options are particularly suited to cases where the system is not well understood or where they are likely to be differences of opinion. Systems that are relatively well understood by the scientific community might be more amenable to a more direct mapping by a small team working closely together, or even an individual expert.

Stage 3: Choose between geographic or topological mapping

Decide whether a geographic map or a topological map is appropriate: this will depend on the nature and scale of the application.

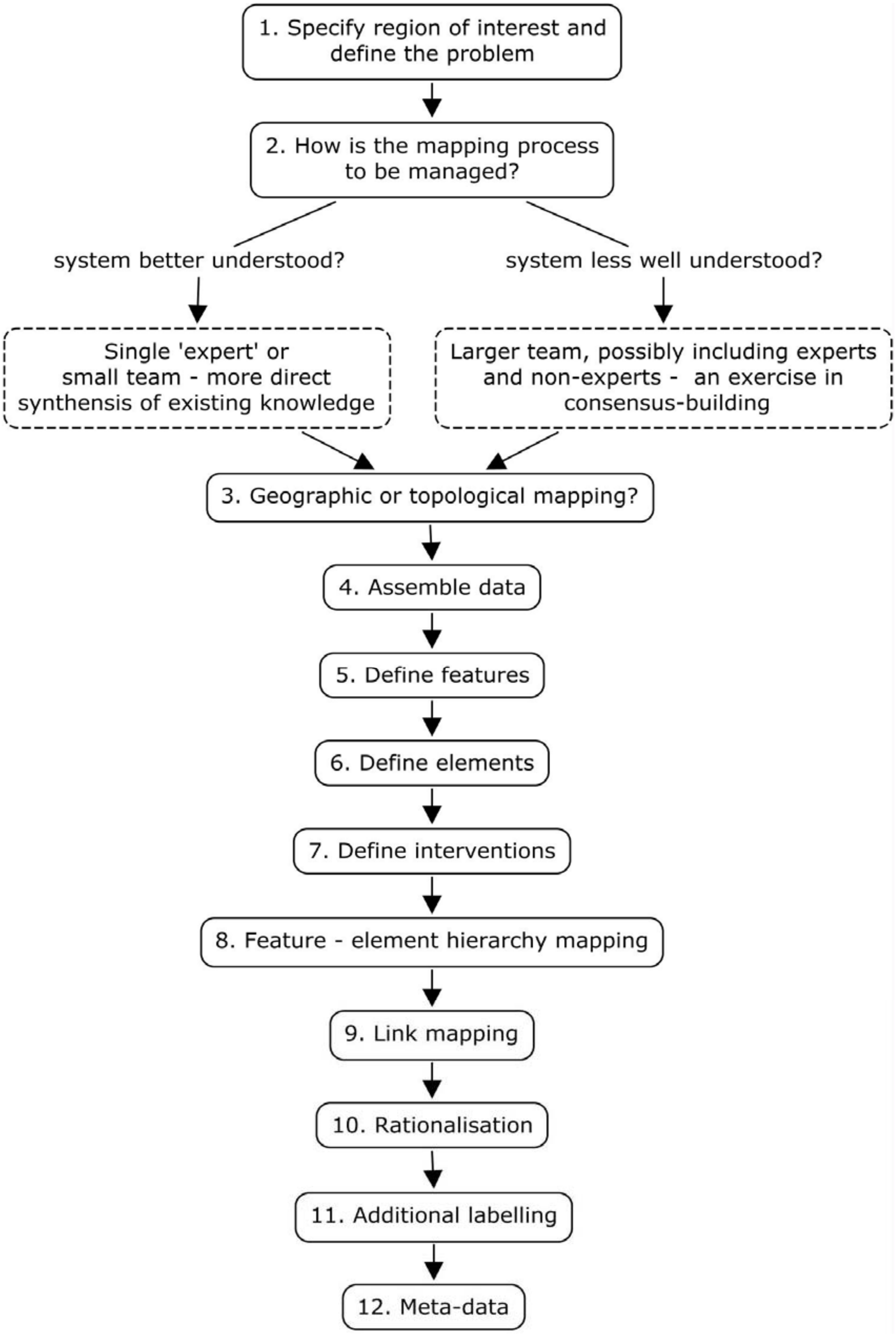

Figure 29 Flow chart for CSM

Stage 4: Assemble the required information and source materials

Assemble data sources, including large-scale base-mapping or aerial imagery (e.g. scanned aerial photographs, Google Maps images, Lidar data); research papers and reports; quantitative datasets (e.g. sediment budgets, tidal and wave climate information, modelled sediment transport rates etc.); and other sources of information (e.g. historical photographs, anecdotal evidence). For geographic mapping, aerial or satellite imagery at a suitably high resolution can be loaded directly into CmapTools to provide a background on which system components can be arranged.

Stage 5: Define features

Identify principal coastal (and offshore) features along the contemporary shoreline. This can be done directly within CmapTools (with or without a digital base map loaded). For larger systems, however, it may be easier to set up a spreadsheet to hold both the feature- and element-level classification, along with any meta-data such as place names or map co-ordinates.

Stage 6: Define elements

Identify coastal (and offshore) elements associated with each feature, taking account of hinterland, backshore and foreshore characteristics.

Stage 7: Define interventions

Identify any structural or non-structural interventions. In some situations, a structure may replace an element in the natural cross-shore assemblage (e.g. a seawall may replace a cliff). Alternatively, interventions may act to constrain the behaviour of elements (e.g. in the case of beach recharge, which constitutes an additional sediment source within the littoral system).

Stage 8: Feature – element hierarchy mapping

At this stage, feature and element symbols need to be created within CmapTools based upon the coastal classification assembled in spreadsheet form (these may already have been created graphically if a separate spreadsheet database has not been created). It is important that mapping should conform *exactly* to the conventions set out in Figure 28. Groups of elements and interventions are then used to create what CmapTools terms 'nested nodes'; these define their affiliation with higher-level features. Nested nodes (i.e. the features) can be expanded to reveal full element-level detail or collapsed to display only the features.

Stage 9: Link mapping.

Connectivity is mapped at the element-level according to the link types given in Figure 28. Line weightings can optionally be used to denote the strength or either sediment transfers or influences if this level of understanding is available.

Stage10: Rationalisation.

Rationalisation of the elements is usually necessary to highlight the system structure and avoid a dense matrix of elements within each feature. Rationalisation involves merging adjacent elements that can be considered to behave as a single unit.

Stage 11: Labelling of features and elements.

In CmapTools, geographic place names or other labels can be added to the feature or element symbols, and this can be selected to appear when these are pointed to by the screen cursor. Additional label text can also be added to the system maps to improve readability.

Stage 12: Addition of meta-data.

CmapTools allows the inclusion of additional information within an undisplayed but searchable field. Geographic co-ordinates and hyperlinks to relevant images, research literature or datasets can be inserted here. System maps may be stored in conventional image formats and, if associated with georeferencing information, exported into a GIS or DIMS layer.

4.6 Case study: Ennore Port to Pulicat inlet, southeast India

Ennore to Pulicat Lake inlet

This section presents a worked example in which a section of coast between the recently constructed port at Ennore and the Pulicat Lake inlet, southeast India, is mapped using the procedure set out in the previous section. This involves the import of an aerial photograph the region of interest into CmapTools, and the identification a set of system components and the links between them on top of this base image.

The coast between Ennore and the southern end of Pulicat Lake is a low-lying sedimentary coast, formed on the extensive coastal plains under the influence of a strong northerly littoral drift of sand-sized material (Rao et al., 2009). The geeographical setting and topographic context is shown by Figure 30 in which the APN - Global Climate Engine DIMS has been interrogated to display NASA-SRTM terrain data for a larger portion of southeast India. Figure 31 shows more detailed imagery for the regional of interest.

The high sediment transport rate means that the various estuaries of the region tend to have well-developed spits and entrance shoals, and there is a tendency towards inlet shoaling and closure. This is especially true of the inlet to the large brackish lagoon at Pulicat, which has shallowed significantly over the last few decades (Kumar et al., 2010). The continuity of the littoral drift is interrupted by two sets of features. First, extensive shoals occur northeast of Ennore, heading offshore for several km in a roughly northeasterly direction (Rao et al., 2009). Given that these coincide with the change in shoreline orientation, from around 17° to the south and 350° to the north, it is tempting to interpret these as headland-attach banks, in the sense of Dyer and Huntley (1999). Second, extensive jetties and breakwaters punctuate the southern portion of the coast in the vicinity of Ennore. The most prominent of these are the large breakwaters constructed to protect the new port at Ennore, constructed in 2001. The northern and southern breakwaters are 1.5 km and 0.8 km in length respectively, and smaller structures occur to the north, with a smaller jetty anchoring the southern shore of the Ennore Creek inlet.

Selection of this region of interest corresponds to Stage 1 of the CSM flowchart presented in Figure 29. With respect to Stage 2 of the flowchart, it is assumed that this demonstration involves a preliminary synthesis of existing knowledge of geomorphologic processes and landform evolution by a single 'expert' as a precursor to a more detailed field or modeling study. As such, the details that follow are purely indicative of the methodology and should not be interpreted as a definitive analysis of this particular region.

4.7 CmapTools software installation and start-up

The latest versions of CmapTools and installers for MacOS-X, Windows, Linux and Solaris can be downloaded from http://cmap.ihmc.us

On installation, a project directory is created to hold CmapTools project files. This demonstration case study has been put together using CmapTools for Windows, and the default project location is

C:\Documents and Settings\Username\My Documents\My Cmaps

An explorer window showing the contents of this directory is displayed at startup. Existing maps (Cmaps) can be selected and opened, and new maps created.

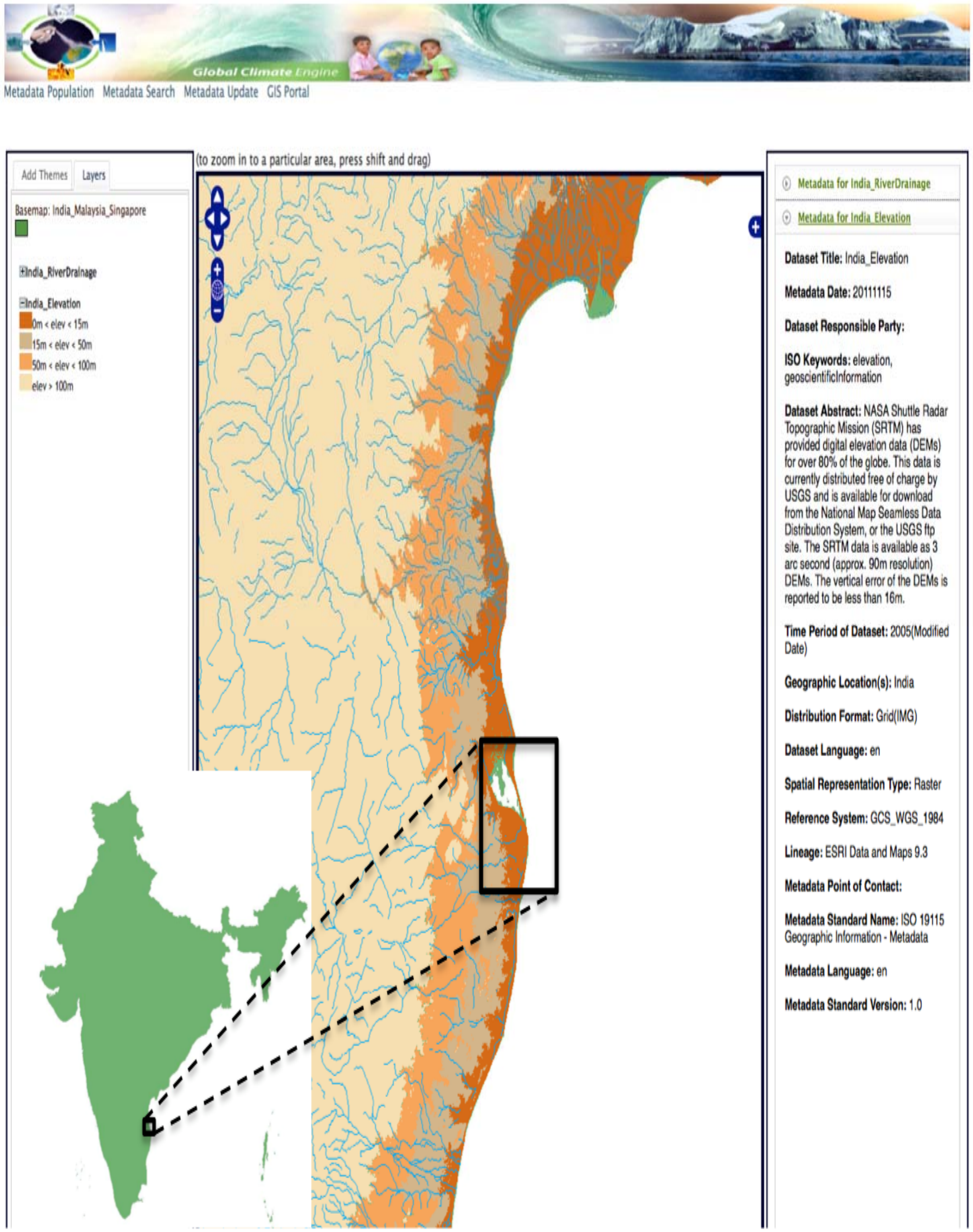

Figure 30 Chennai – Pulicat coastal region of interest in southeast India

Figure 31 Coast between Ennore and the southern inlet of Pulicat Lake (courtesy of GoogleMaps), Southeast India. Rectangle shows region of interest for demonstration example

To set up a new Cmap project select *File – New Cmap* from the explorer menu. An untitled map window appears (Figure 32). Select *File – Save Cmap* from the menu of the Cmap window to open a dialogue that allows the user to save this.

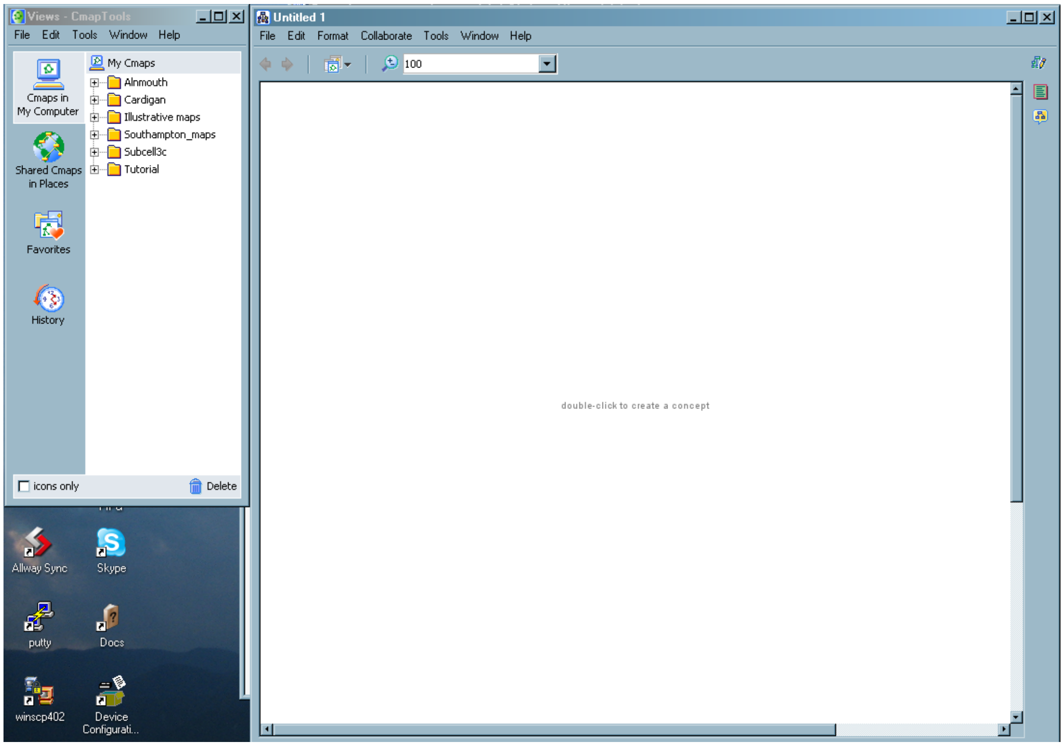

Figure 32 CmapTools explorer menu (displayed on startup) and untitled map window

To import a geographical map base image. The next stage of the process is to decide what kind of map we are going to produce (Figure 28, stage 3). Here, we are going to construct a geographical map over a base image of the region of interest, with image in Figure 31 as the main data source (Figure 28, stage 4). Google Maps has been used as the primary data source here on account of the high spatial resolution of the imagery compared to the satellite-derived topographic and optical image products that are currently stored within the APN - Global Climate Engine DIMS.

The image is loaded from the Cmap window menu, by selecting *Format – Background – Add* (Figure 34). A Style Palette appears with tabs for *Font* (includes typefaces, point size, bold, italic, underline, alignment options); *Object* (allows selection of different shapes, fill colours and shadow effects, and allows control over object alignment); *Line* (controls line colour, thickness, style, the form of curved lines, and the creation of arrowheads); and *Cmap* (which allows control over background colour, scaling and the background image).

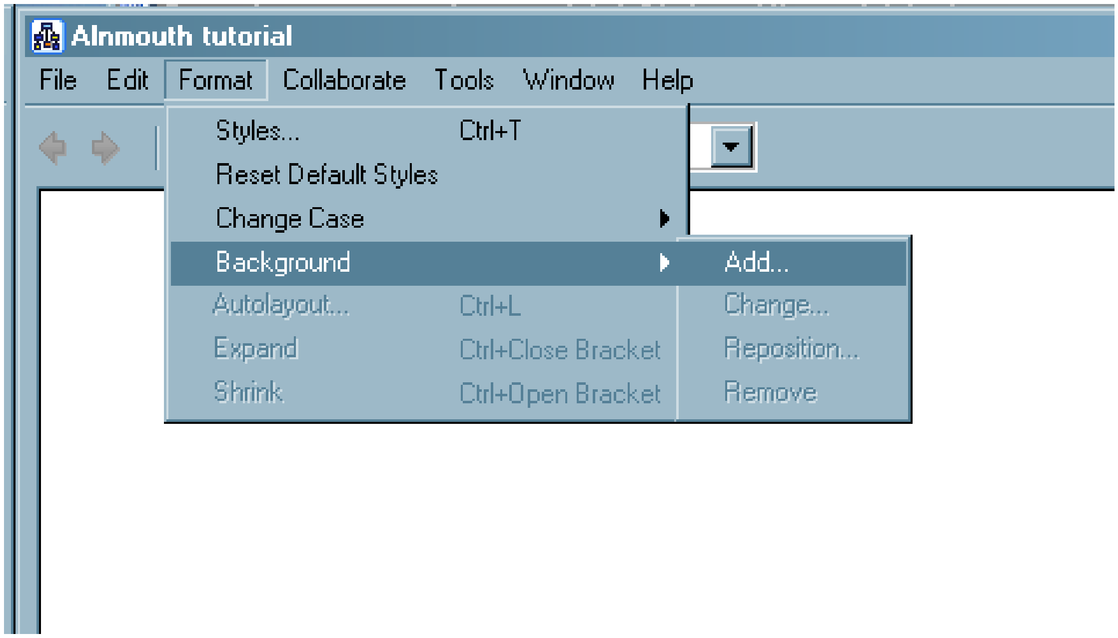

Figure 33 New map window

4.8 Identification of feature-level system components

Stage 5 of the coastal mapping process (Figure 29) involves defining the principal coastal features with reference to the classification of Table 6. The key features here are fairly simple: the Inlet of Ennore Creek, a short stretch of Open Coast, the Harbour at Ennore, another longer stretch of Open Coast, the Inlet of Pulicat Lake, and an Offshore zone that includes the important Ennore shoals.

In CmapTools, individual system 'components' are referred to as 'concepts'. The blank map window invites the user to "double-click to create a concept". The type feature can then be typed into the dialogue box that appears. In Figure 35, additional text has been used to annotate feature place names for ease of reference. This information can also be added to individual feature labels. Simply select a feature, then from the main Cmap window pulldown menu, select *Tools – Add info* – and enter required description in the Mouse Info box. This will then be displayed when the cursor moves over a feature. Figure 35 shows this being done for the inlet south of Ennore Port.

Identification element-level components: Stage 6 of the coastal mapping process (Figure 29) involves defining the elements associated with each feature, with reference to the classification of Table 7. Figure 36 shows the mapping of the cross-shore zonation of the barrier island feature around Ennore Port in terms of hinterland (low ground), backshore (here interpreted mainly as dune, with some artificial 'made ground') and foreshore (beach). Note also, how the *object* tab of the Style Palette has been used to define the correct ellipsoidal element symbols in accordance with Figure 28.

Figure 34 Cmap window with background image, and Style Palette

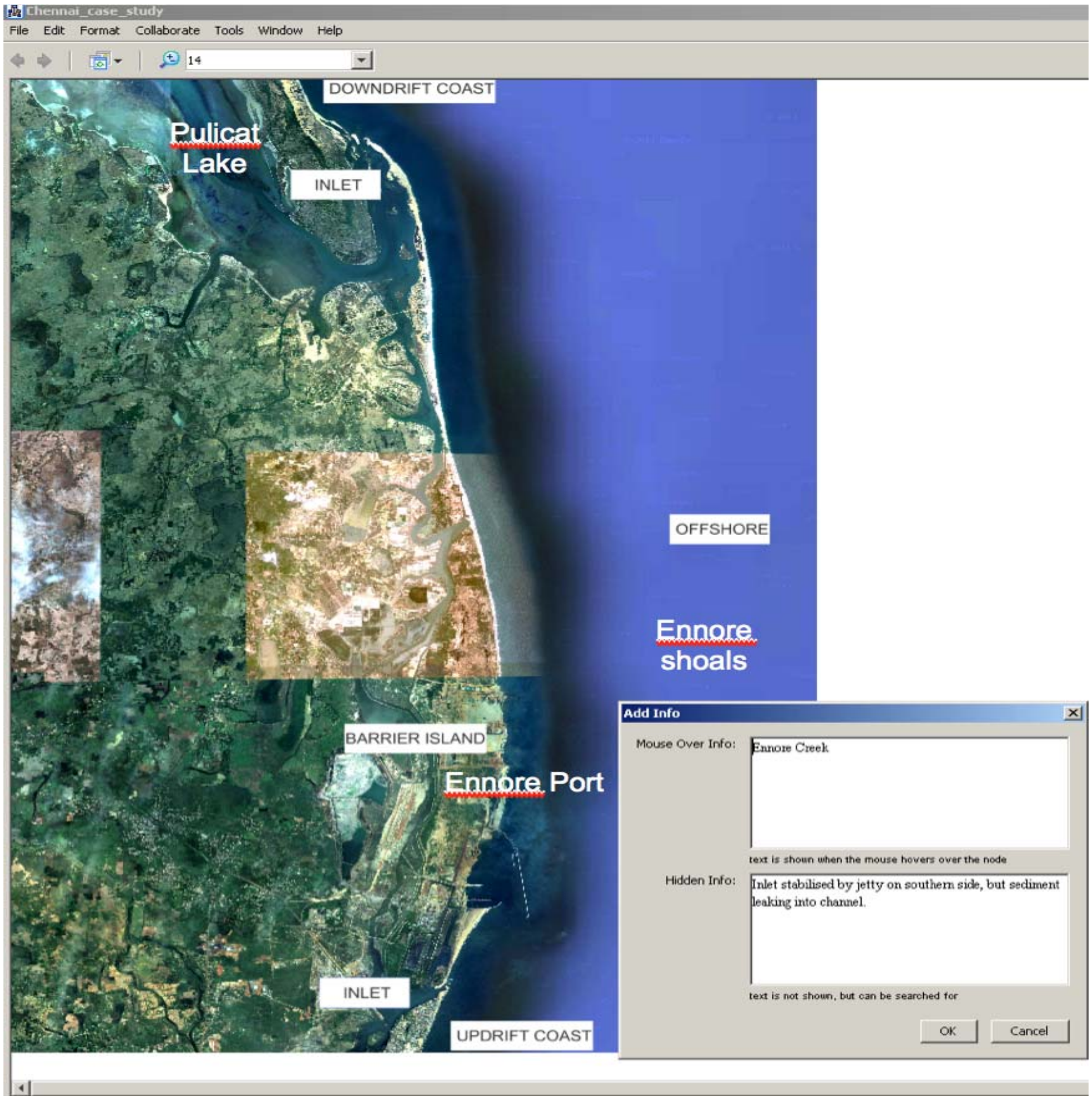

Figure 35 Addition of labels for principal features, including 'Mouse Over Info'

Identification of engineering interventions: Stage 7 of the coastal mapping process (Figure 29) involves defining the structural and non-structural interventions associated with each feature, again with reference to the classification of Table 7. As Figure 35 shows, interventions are primarily structural, in the form of jetties to protect harbours from waves and control littoral drift. However, Ennore Port is also subject to dredging, a non-structural intervention that influences the sediment budget.

For more complex systems, or if topological rather than geographical mapping is being used, it may be better to systematically record the result of stages 5 through 7 on a spreadsheet. At this stage it is necessary to formally group elements and interventions with their 'parent' features. CmapTools allows the creation of 'nested nodes' that are attached to a 'parent node'. Feature-level groupings are created by selecting all the elements / interventions (and the label) of the feature (either with control-click, or by dragging a selection rectangle) and, from the menu bar, selecting Tools – Nested Node – Create. Figure 36 shows this in progress for the inlet feature.

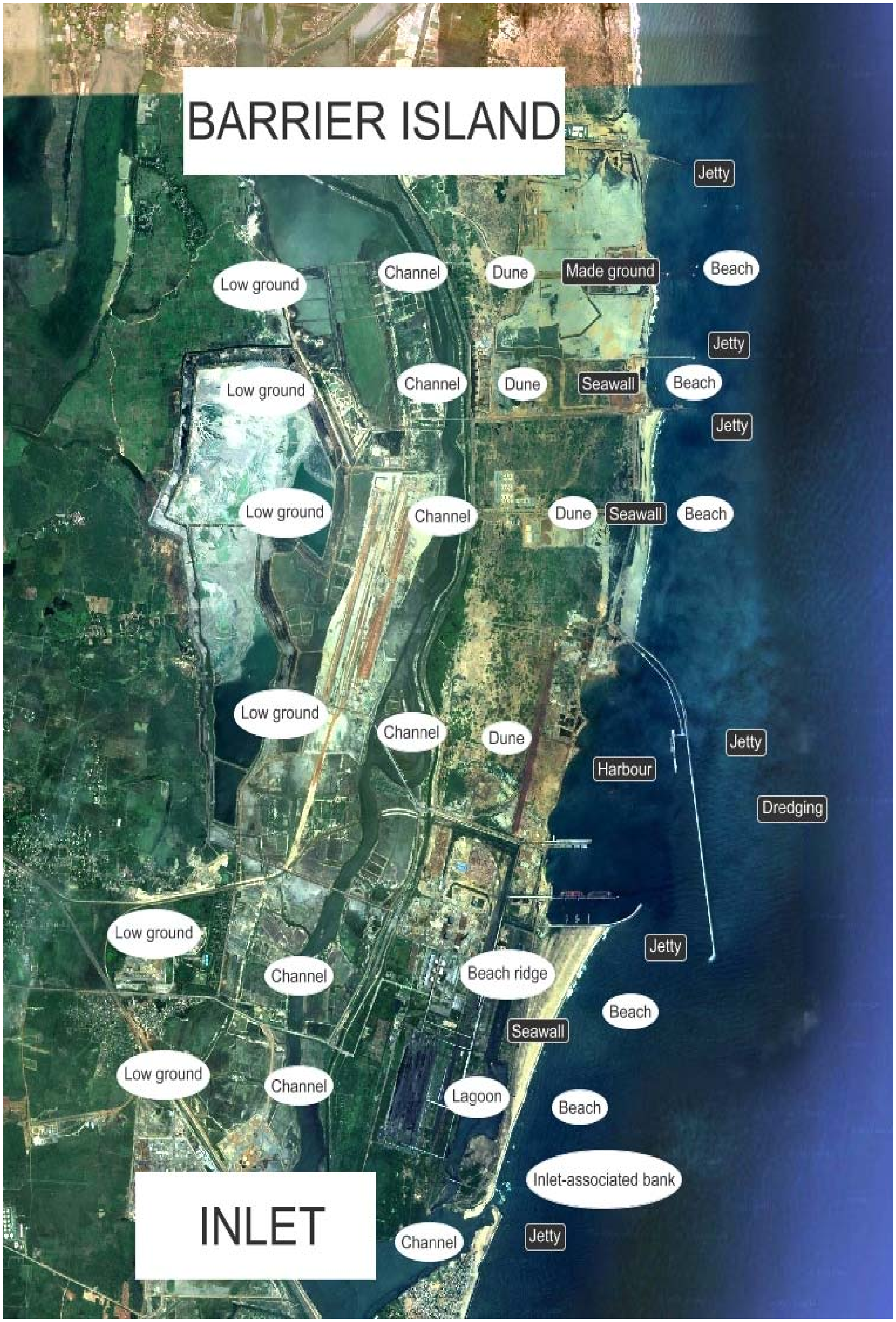

Figure 36 Addition of labels for principal elements of the coast around Ennore Port

Figure 37 Newly-created inlet feature, prior to formatting using Style Palette.

This will create a new feature container that can be re-formatted to comply with the scheme in Figure 28 (i.e. removal of the object background colour, and enforcement of a rectangular outline shape; line colour may also be changed to white if the background image is dark). The tab on the right hand edge of the feature box allows the detail to be collapsed or expanded. In collapsed mode, the feature reverts to a single label, which should be renamed. As with the initial feature labels, 'Mouse over info' can be added to indicate place names when the cursor is moved over them.

Figure 38 shows the element and intervention sets for the inlet feature and the southern portion of the Ennore barrier island.

4.9 Link mapping

This involves defining the various linkages that connect system components at the element and intervention scale. In CmapTools, links are created by clicking on a starting component, clicking again on the arrow icon that appears at the top of the symbol, holding the *shift* key down, and clicking on a destination component.

> [NB: If the shift key is not held down, the link is created together with a label box that accepts some text. Use of the latter is not formally part of the coastal system scheme procedure set out in out Figure 28, although it could be used to hold specific information if desired (e.g. quantitative data on sediment flows, where these are known).]

Figure 38 Element groups for inlet and barrier island features.

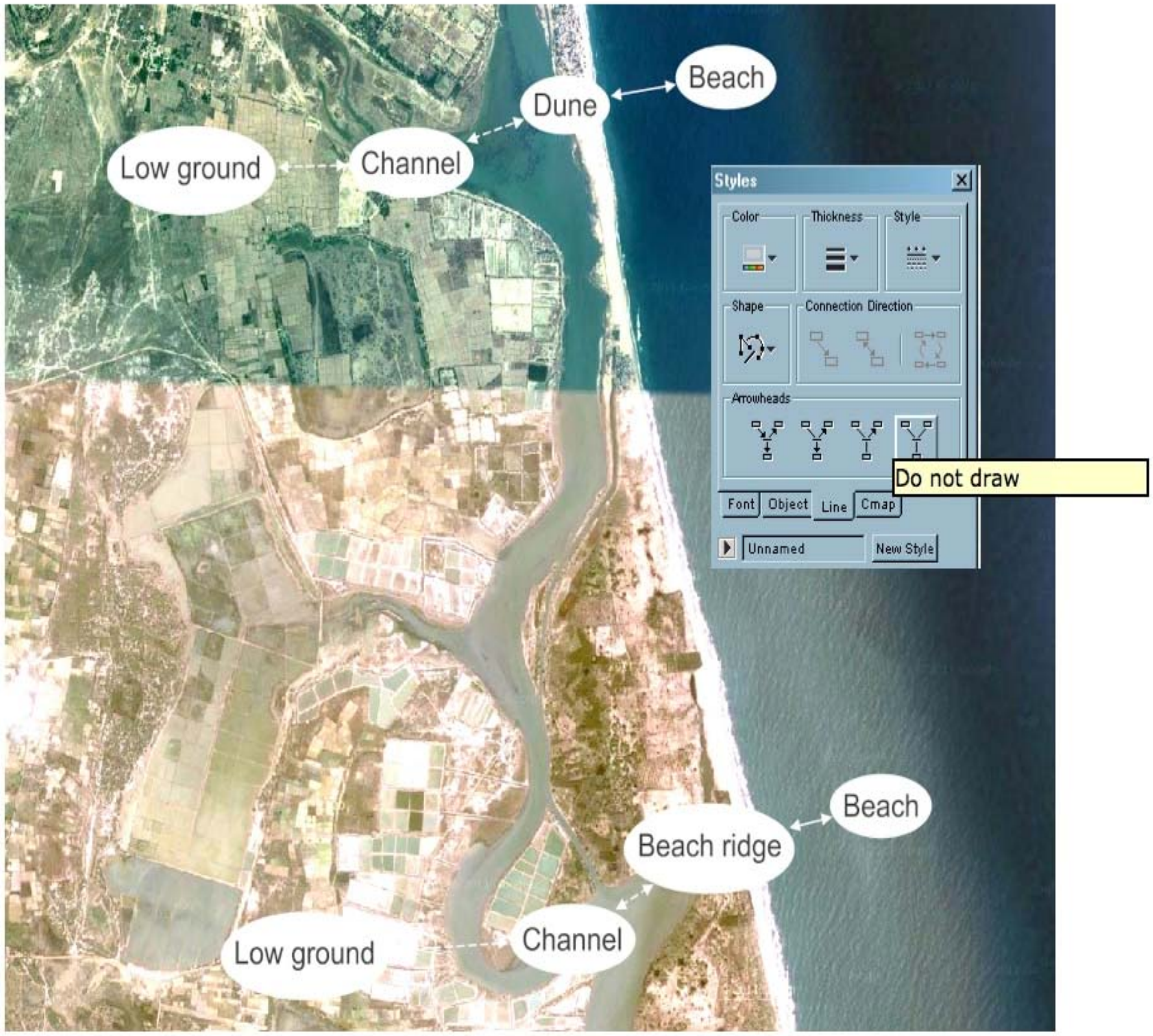

Figure 39 Link creation in the vicinity of the Pulicat inlet.
(The Style Palette Line tab is used to determine whether to draw arrowheads always (first option), under various conditions (options 2 and 3), or not to draw arrowheads (option 4; as indicated in figure). Directionality can also be determined once a given link is selected).

Figure 39 shows the details of link creation for the mapping of the cross-shore zonation of the barrier island in the vicinity of the Pulicat inlet feature in terms of hinterland (low ground), backshore (here interpreted as a channel and either dune or beach ridge) and foreshore (beach).

It is easiest to create all links initially using simple lines with no arrows to indicate direction. This can be done by checking the 'Do not draw Arrowheads' option on the Line tab of the Style Palette (Figure 39). Once all the links are in place, line styles can be changed to indicate whether links represent sediment transfers or influences, and to add directional (or bidirectional) arrows.

Figure 40 shows a full set of links defined for our tutorial example, and Figure 41 shows the area around Ennore in more detail. Hinterland – backshore links are defined as influences, on the basis that no exchanges of material are currently taking place. The backshore is considered to influence the hinterland (invariably low ground here) through flood risk and the protective effective of dunes and beach ridge landforms.

Beach – dune linkages are depicted as bi-directional sediment exchanges. Jetties are considered to exert directed influences on the position / stability of inlet channels and both updrift and downdrift beaches. Dredging of Ennore Port and disposal offshore to the northwest in the vicinity of the Ennore Shoals constitutes a directed sediment transfer. These offshore shoals also influence the coast to the north of Ennore by reducing wave action and Tsunami run-up (Kumar et al 2008).

4.10 Rationalization

The next task (stage 10 in Figure 29) is to rationalize the map to remove any redundant elements (or interventions). The aim here is to represent the essence of the system and its functional links using the minimum number of components. The most obvious candidates for rationalization are the common low ground of the hinterland and areas of beach that share a common backshore characteristic. Figure 42 illustrates this.

4.11 Meta-data

The completed coastal system map can be used as a repository for various kinds of data, such as reports and images. For example, we might want to associate photographs taken of local details with the associated components of the map.

This demonstration has been informed by analysis of aerial imagery and published research, so it might be useful to save key papers (or their abstracts) within the system map. For example, we might associate the offshore sands with a key paper on littoral transport on this coast (taking due account of any publisher copyright restrictions if the map is to be publically available). This is done by selecting the offshore sands symbol on the map and using *Add & Edit Links to Resources* to append a copy of the article. Navigate to the resources folder in the upper part of the dialogue box, select the relevant resource (in this case a PDF reprint) and click *Add to List*. The item is added to the list of resources below. The list contains editable fields (Figure 43). Embedded resources can be accessed from within the map itself (Figure 44).

4.12 Additional labeling

Additional text for geographic place names or other annotations can be added at this point (stage 11 of Figure 29). Likewise, meta-data can be added.

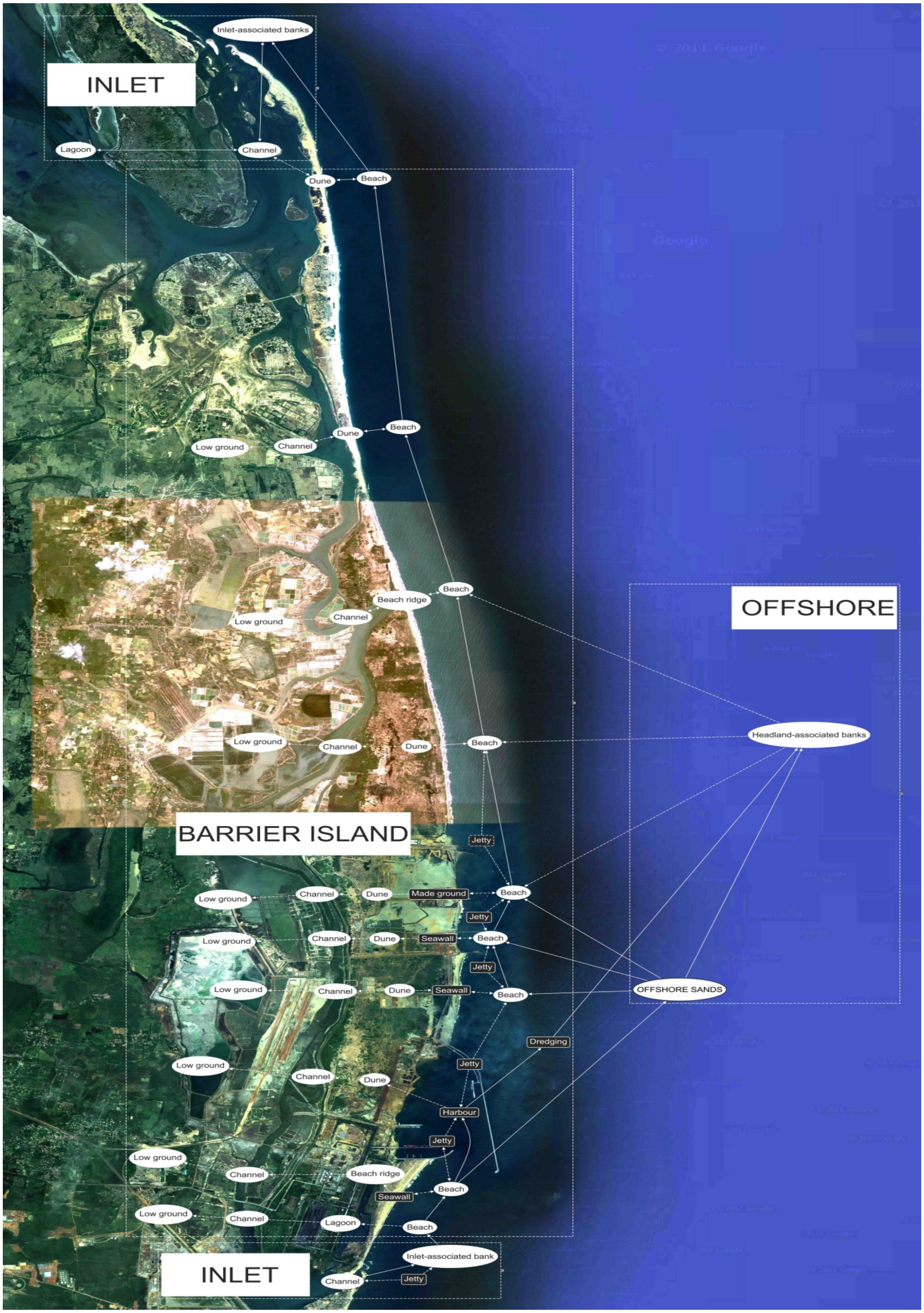

Figure 40 Completed link mapping.

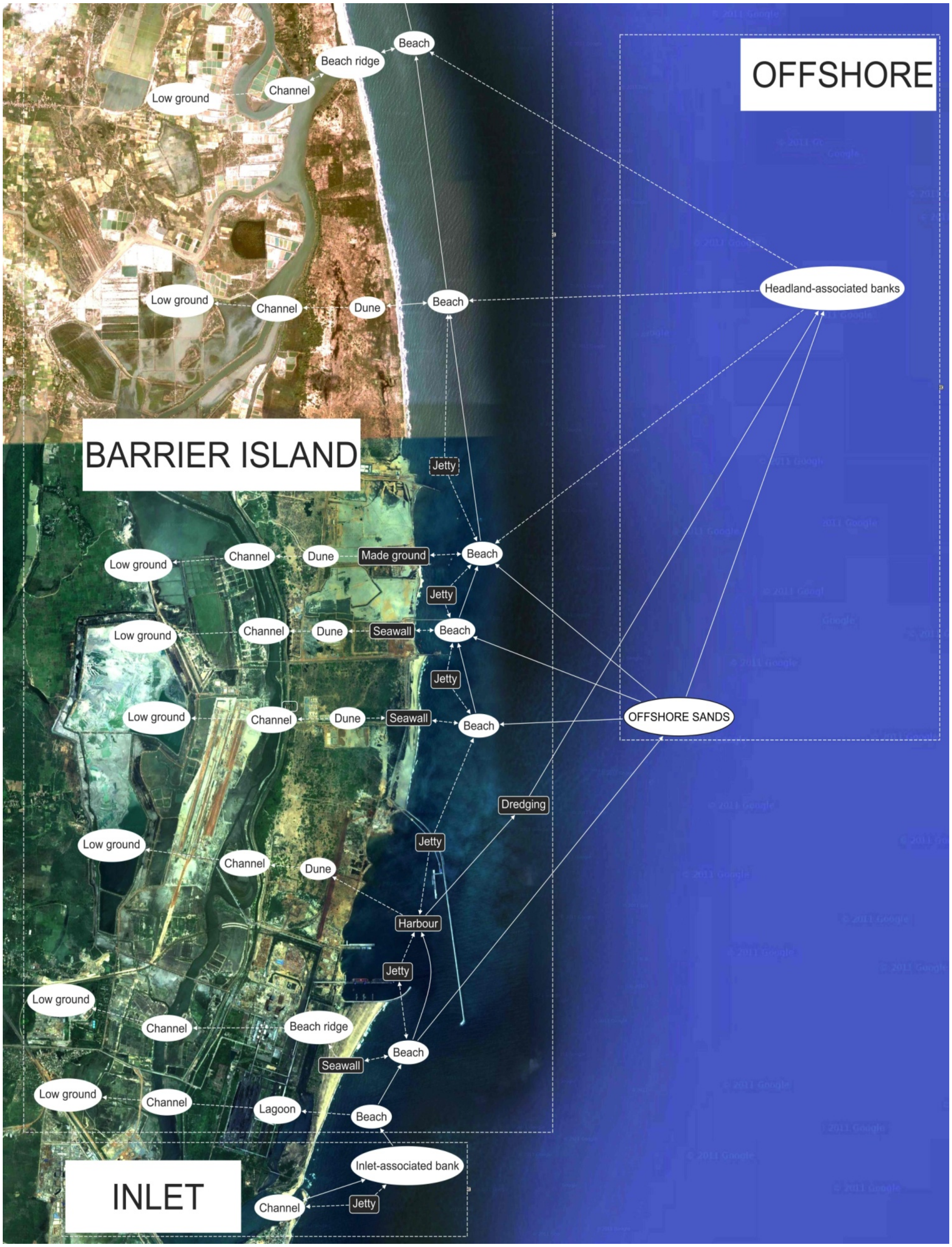

Figure 41 Detail of map for Ennore Port area. Note use of solid and dashed lines for sediment and influence links and arrows to indicate direction of influence.

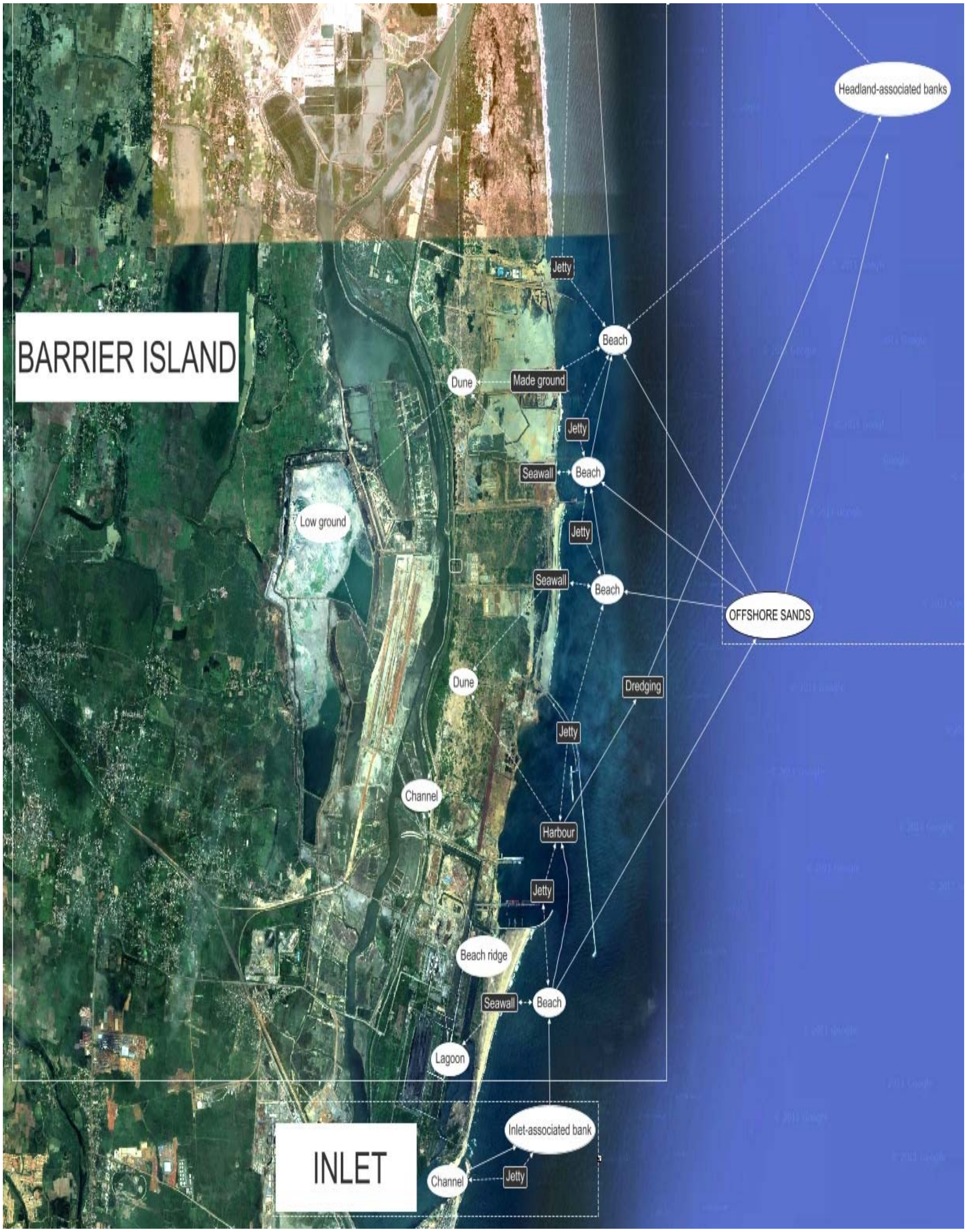

Figure 42 Detail of map for Ennore Port area showing rationalisation to preserve system structure by elimination of shared elements within features.

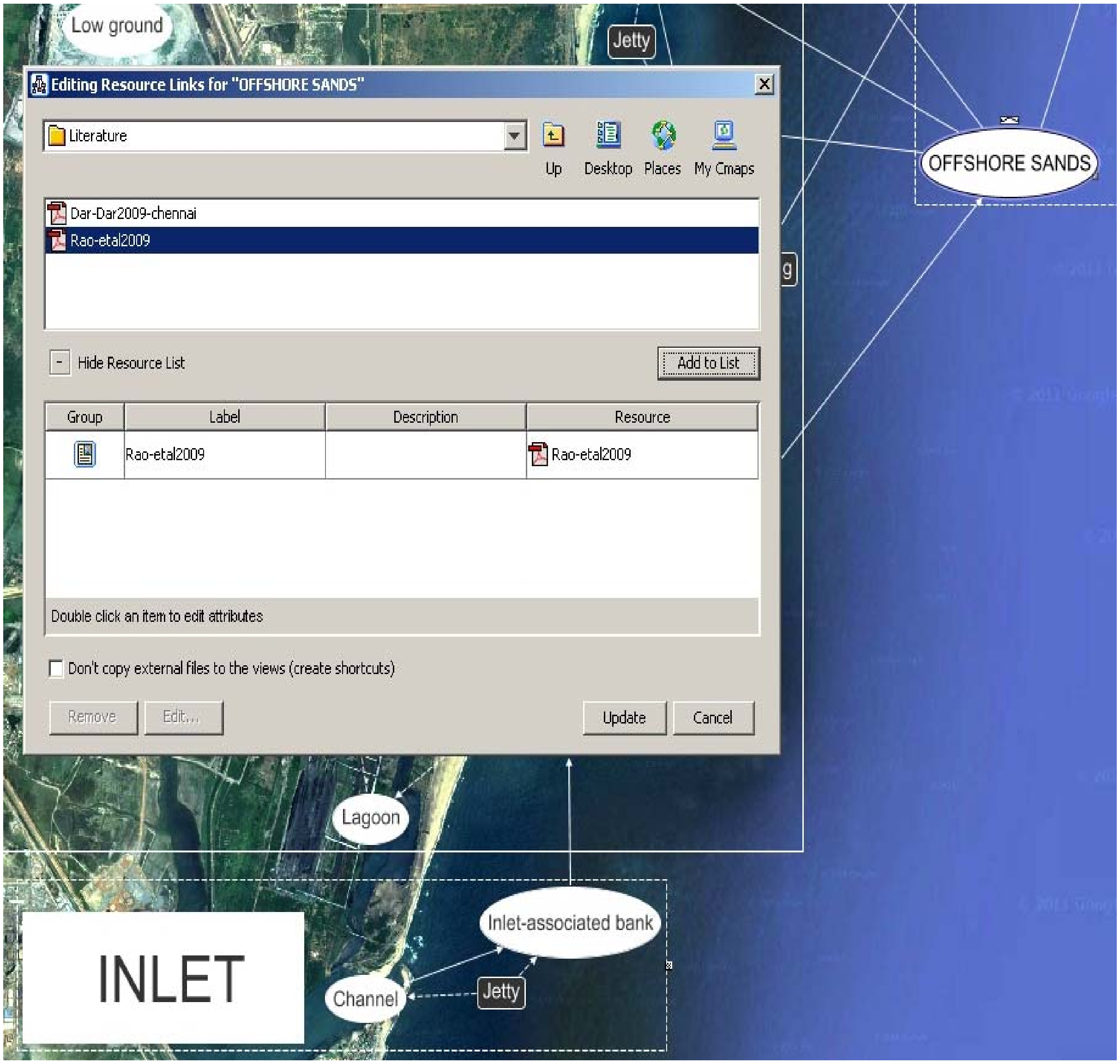

Figure 43 Linking of digital photograph resources to a specific system component using the *Add & Edit Links to Resources* option.

4.13 Linkages with APN - Global Climate Engine DIMS

This demonstration has been undertaken as a contribution to Asia Pacific Network (APN) Project: ARCP2010-07CMY-Bai Asian Coastal Ecosystems: An Integrated Database and Information Management System (DIMS) for Assessing Impact of Climate Change and its Appraisal. The DIMS covers India, Malaysia and Singapore and contains various data layers including topography, land cover, climate data, population as well as satellite imagery. The topographic data layer is derived from the NASA Shuttle Radar Topography Mission (SRTM). This has a horizontal resolution of three-arc-second (about 90m) outside the USA, and relative and absolute vertical accuracies of ±6 and ±16m respectively. This is rather too coarse than that required for accurate representation of low-lying coastal terrain and assessments of vulnerability to inundation through sea-level rise.

Figure 44 Viewing embedded photographic resources by selecting from list associated with system component.

Accordingly, this data layer provides only a gross topographic context for the CSM case study presented here.

In principle, however, the DIMS platform is able to store higher resolution data, such as airborne Lidar-derived DEMs (typical horizontal resolution 1 to 2 m and vertical accuracy ±0.10 to 10.15m; French, 2003) and aerial photography that would be suitable for coastal and estuarine applications on a scale of 10 – 100 km.

System maps can also be exported in a flat image format and, if georeferenced, imported into the DIMS as a data layer. In this way, conceptual model layers can support more quantitative anlysis performed with the conventional data layers.

4.14 Concluding remarks

This demonstration illustrates the production of a geographical system map on the basis of a geomorphological reconnaissance accomplished using online aerial photographic resources. Aerial imagery alone is often sufficient for a first-order mapping exercise. For more detailed investigations it is necessary to refer to the scientific literature as well as first-hand field experience.

Strict adherence to the procedures (especially the symbolic conventions of Figure 28 and the process summarised in Figure 29) should minimise inconsistencies in maps produced by different experts. There will always be scope for interpretation, of course, and maps produced by different individuals will invariably differ in detail. Rather than being seen as a limitation, 'operator variance' of this kind should, in fact, be viewed as an extremely valuable aspect of the knowledge formalisation process.

CSM can be an effective tool for formalising knowledge contained in disparate scientific publications and research reports, and presenting this information in a way that emphasises large-scale behaviour. Comparison and subsequent merging of maps produced in isolation by a small team of experts can work well for small systems where the mapping effort is not demanding in terms of time and supporting resources. A group activity, where two or more experts work together to produce a map that reflects their shared opinions may work better for larger systems, where the creation of the map involves more time and effort.

Coastal system maps can be used to inform the selection and implementation of predictive modeling tools, such as historical trend analysis or numerical coastal morphodynamic models. A system map can also provide the framework for more quantitative analysis of the sediment budget.

In electronic form, CmapTools project files can function as a repository for the results of quantitative analyses and predictive modeling. For example, the system linkages can be annotated to include quantitative estimates of the sediment mass fluxes, and model results files and research reports can be linked to system components. Georeferenced system map images can also be uploaded as a layer into a larger GIS or DIMS.

Appendix 1: Conferences/Symposia/Workshops/Exhibitions/Invited Lectures:

1. UNIQ2008: New Software for Better Water Quality Index using Neuro-Fuzzy logic. *Exhibition of Malaysian Technology Expo (MTE 2008)*, 19-21 Feb, 2009, PWTC, Malaysia. (Awarded **Silver** Medal).

2. Groundwater Model for Investigating Seawater Intrusion Hazards. *Proc. of Int. conference on Disaster Mitigation and Management (ICDMM-2009)*, 16-18 Dec, 2009, PSNA, Tamil Nadu, India.

3. Integrated decision support system for assessing quality of water. *Int. exhibition on Information Technology Education & Exposition (ITEX10)*, 14-16 May, KLCC, Malaysia. (Awarded **Gold** Medal).

4. Climate change modeling for environmental wealth. *2nd International Conference & Exhibition on Waste to Wealth*, 27-28 July 2010, Putra World Trade Centre, Malaysia.

5. *4th Session of the IAG Working Group on Geomorphological Hazards (IAGEOMHAZ) & International Workshop on Geomorphological Hazards* organized by Manonmaniam Sundaranar University, Tirunelveli and UNAM, Circuito Exterior, Ciudad Universitaria, Mexico, 21-23 July, 2010, Kanyakumari, South India.

6. Real Time Water Quality. *Workshop on Sustainable Urban Stream Restoration (rehabilitation)* by UNIVERSITAS 21, 12-14 Nov, 2010, Delhi, India.

7. *3-Day Scientific Workshop on Climate Change and DIMS Technology*, 1-3 Dec, 2010 organized by University of Nottingham Malaysia Campus, KLTC, Kuala Lumpur.

8. *Lecture delivered at IEM water resources technical division* on 'Water Quality Modeling with Changing Climate', 28th April 2011, WISMA IEM, Malaysia.

9. Real time water Quality. *2011 British Invention, Innovation and Technology Show and International Invention of the Year Awards*, 19-22 Oct, 2011, Alexandra Palace, London, United Kingdom. (Accepted for evaluation of the product).

10. Database Information and Management System (DIMS). *2011 British Invention, Innovation and Technology Show and International Invention of the Year Awards*, 19-22 Oct, 2011, Alexandra Palace, London, United Kingdom. (Accepted for evaluation of the product).

Appendix 2: Funding sources outside the APN:

1. Science fund projects, Funded by Ministry of Science, Technology and Innovation, Malaysia.
2. University of Nottingham Malaysia Campus.
3. UK funded -Environment Agency funded project: Characterisation and prediction of large scale, long-term change of coastal geo-morphological behaviours.

Appendix 3: List of young scientists:

1. Dr. Janardhanan. G, Visiting Faculty, Center for Environmental Management, National Institute of Technical Teachers Training & Research, Ministry of Human Resource Development, Government of India, Taramani, Chennai.

2. Mr. Chandrasekar. J, Research Engineer, Physical Oceanography Research Laboratory, Tropical Marine Science Institute is an institution, National University of Singapore.

3. Mr Suresh Natesan, Research Engineer, Physical Oceanography Research Laboratory, Tropical Marine Science Institute is an institution, National University of Singapore.

4. Mr Soon Kean Huat, Research Associate, Physical Oceanography Research Laboratory, Tropical Marine Science Institute is an institution, National University of Singapore.

5. Mr. Fakhrul Anwar Bin Hussin, Information Services, University of Nottingham Malaysia Campus.

6. Mr. Fazli. M, SKSA Technology Sdn., Bhd., Malaysia.

7. Mr. Reza Kabiri, Research Assistant, University of Nottingham Malaysia Campus, Malaysia

8. Mr. Punithan Palanivel, Project Assistant, University of Nottingham Malaysia Campus, Malaysia

Appendix 4: Glossary of terms:

CCD – Climate Change and DIMS Technology
CMS – Content Management System
CRU – Climate Research Unit
CSM – Coastal System Mapping
CSV – Comma Separated Value
DEM – Digital Elevation Model
DIMS - Database and Information Management System
GCM – General Circulation Model
GHG – Green House Gas
GIS – Geographical Information System
GPS – Global Positioning System
GUI – Graphical User Interface
IMD – Indian Meteorological Department
IPCC – Intergovernmental Panel on Climate Change
NATCOM – National Communication to United Nations Framework Convention on Climate Change
NGO – Non-Governmental Organization
RCM – Regional Climate Model
RDBMS – Relational Database Management System
RS – Remote Sensing
SRES – Special Report on Emission Scenarios
SRTM – Shuttle Radar Topography Mission

Appendix 5: Speakers and Participants of Climate Change and DIMS Technology Workshop

SCIENTIFIC WORKSHOP ON CLIMATE CHANGE AND DIMS TECHNOLOGY – CCD 2010

The University of Nottingham
Malaysia Campus

TRITY TECHNOLOGIES
www.tritytech.com

1-3 December 2010
University of Nottingham Malaysia Campus
Kuala Lumpur