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Web-GIS integrated open source mashup technology as a cue for integrated management in coastal megacities

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Abstract

Coastal resource management is a significant component of the sustainable development alongside the dynamic coastal zone overlapping urban regions. The Stakeholder requirements for the strategic coastal resource planning prerequisite a systematic approach to fill the critical gap on the subject of information, knowledge, data and GIS (Geographical Information System) services in coastal cities. In order to facilitate this, we introduce an open source Web-GIS based decision support framework stated as the Coastal management information system (CMIS) which has been developed to integrate data and knowledge coupled with GIS services for the Mumbai megacity, developed using the open source platform based on PHP and Map Script. CMIS consists of three key components – Data Centre (houses different datasets for expert stakeholders), Knowledge Centre (developed for common stakeholders), and Web-GIS based online mapping tool called CMIS Online which enables a user-friendly assessment of coastal resources. The framework can serve as a dynamic mapping application for coastal features, incorporating advanced GIS functionalities. This paper further describes the methodology for the development and implementation of CMIS as a pilot initiative along the coastline. The initiative can strengthen the institutional framework between associated government agencies, coastal planners, managers, and researchers. The study also encourages the use of open source coupled GIS techniques, which can enhance the transparency in the allocations and utilization of coastal resources among various end users, and thereby the developed framework can curtail over-exploitation of resources to some extent and can aid in the progression towards a more sustainable and resilient urban environment.

Keywords Coastal cities · Web-GIS · Open source · Mumbai · Resource management

Introduction

The coastal zone embodies one of the essential boundary zones on our planet, marking the dynamic interface between the lithosphere, the atmosphere, and the hydrosphere, three distinct but interlinked environments. These regions are encompassed with diverse habitats and ecosystems which provide many goods and services (Chen et al. 2019) to the natural as well as anthropogenic realms. The dynamics of the processes in the coastal zone is complicated because of the ever-changing line of the shore. This particularly has enormous significance due to its proximity to regions having the vast majority of the population and its deeds. The coastal zone is evidently a cultural and conceptual frontier showcasing a transition zone between the known and the comparatively unknown (Bartlett 2000), which are some of the most impacted, and these regions are vulnerable to many adverse eventualities (Adger et al. 2005). Presently over half the world's population (~ 55% in 2018) resides in urban agglomerations and it is expected to increase (68%) by 2050 (UN DESA 2018). The majority of the urban regions are located in the coastal zone or zones with distinct coastal influence (von Glasow et al. 2013). These regions have been a focal point regarding a wide array of stakeholder activities in recent years, especially in the case of large cities. The future challenges for the urbanized coastal region are vivid as the aspiration for resilient and sustainable development is tested by the growing

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economic inequality and environmental risks (Pelling and Blackburn 2014). The densely populated urban coastal zone (Neumann et al. 2015) and its vulnerability towards natural as well as anthropogenic hazards invoke a persistent requirement for an efficient and effective web-based management information system that can address the present and future requirements of various stakeholders. The stakeholders regularly require a validated information system, irrespective of their ultimate motives, that would aid them in managing their work and in turn, should help them to manage and develop the coastal zone in a more sustainable manner. Open-source Web-GIS based decision support systems can serve as a valuable tool for stakeholder activities and decision making in the urbanized coastal regions. GIS based web services are self-contained, self-described modular component of geospatial application which can be accessed through standard protocols and can be applied to various applications like geomarking, construction and coordination, e-governance, natural resources management, urban planning, and emergency response services (Gaikwad et al. 2014).

Web-GIS or web-based GIS is a term coined to define the use of GIS for spatial analysis, querying, and visualization of large-volume data served through the internet. Stakeholders have widely recognized Web-GIS as a fundamental tool for the storage and distribution of data to targeted audiences (Gong et al. 2017). Web-GIS based decision support systems are developed around the globe in recent times (Gomes et al. 2015; Kolios et al. 2017; Kunapo et al. 2018; Lv et al. 2018; Tang et al. 2017; Van Dongeren et al. 2018; Vasileiou et al. 2017). These kinds of decision support systems are an essential component for developing and underdeveloped countries because the majority of the global urban agglomerations are concentrated in the coastal zones of these countries. Similarly, Web-GIS based information systems in the area of coastal resource management are also developed by researchers to address regional issues. Jayakumar (2019) introduced an open-source based Web-GIS platform to manage mangrove forests (Andhra Pradesh, India) considering the past 30 years and concluded that the benefits of such systems in sustainable planning. Recently, Tian and Chang (2019) advocated the utility of Web-GIS based information system for sharing the information of ocean forecasting and proposed a similar platform to build a marine environment information system. Another case study presented the application of Web-GIS to facilitate integrated monitoring and management of coastal seiches (North Jiangsu shoal, China) to emphasize the benefits of such techniques for decision makers in an efficient way (Qin and Lin 2017). In the recent decade, researchers have investigated and proved the proficiency of Web-GIS based tools to resolve multiple conflicts of data sharing and collaboration in order to advance the quality for integrated management of coastal regions (Lathrop et al. 2014; Levine and Feinholz 2015; Barnett et al. 2016; Yang 2016). Many developed nations have identified and adopted GIS as a critical tool in planning, management, and development, but the socio-political scenarios prevailing in those countries often hinder the practical usage of GIS (Mennecke and West 2001; Mahmoody Vanolya et al. 2019).

Further, open-source GIS tools can play a significant role in developing countries too. Currently, open-source based GIS tools have been widely used, and it facilitates access to data and information which are relevant in developing countries (Olyazadeh et al. 2015). In addition to this, web mashup technology has a vital role in developing a further value-added application at the user end by integrating GIS data and services from various diverse sources (Karnatak et al. 2012). The web mashup technology integrates data or functionality from diverse sources to create new services and presents it as a new application or a new source of data. India is a rapidly developing country, and urbanization has expanded expeditiously in recent years, especially in the coastal regions. Currently, India has five megacities (cities having population more than 10 million), and three of them (Mumbai, Kolkata, and Chennai) are in the coastal zone (UN Habitat 2016) which are also prone to various natural hazards (De Sherbinin et al. 2007; Kumar and Kunte 2012; Dasgupta et al. 2013; Dhiman et al. 2019a, b). Among these megacities, Mumbai is designated as the financial capital of the country (Ramachandra et al. 2014) and has vibrant and immense anthropogenic activities. The primary objective of the current study is to bring forth a management information system for the Mumbai coastal region, which can be effectively used by decision-makers. Some primary considerations were assigned before the development of the system, such as the developed system should be easy to access, aesthetically pleasing, and the organization should be simple, yet all critical components must be in place. Thus, the paper introduces an open-source Web-GIS based decision support framework named Coastal Management Information System (CMIS), which has been developed to integrate data and knowledge coupled with GIS services for the Mumbai megacity.

The use of open-source Web GIS has made it possible to graphically represent all the essential aspects of the Mumbai coastal region. The GIS facilitates in bringing the whole urban coastal zone to the desktops of the users to effectively visualize the unique coastal features. The web-enabled framework can remove geographic and temporal limitations to an extent, which otherwise could have been an obstacle for the users to explore CMIS thoroughly. The present work also serves as a precursor to the development of a fully-fledged decision support framework for the entire Maharashtra coastline and eventually for the entire west coast of India. The paper is organized as follows: in section 2, we present the details of the study area, Existing Situation Analysis (ESA), datasets, software used as well as brief aspects and methodology regarding the development of the CMIS framework. Section 3 discusses the outcomes in addition to the primary/secondary functionalities and future prospects of the developed framework. Section 4 concludes the paper with final remarks.

Materials and methods

Study area

The coastal zone of Maharashtra state extends from latitude 15°43’N to 20°10’N and longitude between 72°39’E to 73°30′E along the west coast of India. Mumbai city as depicted in Fig. 1, situated in the state of Maharashtra, is a coastal mega-city, as well as the commercial and entertainment node of the country (VishnuRadhan et al. 2014). Mumbai, known as Bombay in the past, was a cluster of seven tiny islands until the end of the eighteenth century, which now forms a collected mass of islands, trapezoid in shape and occupies an area of 437 km^2. The Mumbai city has abundant natural resources such as lakes, wetlands, and mangroves, and the region is divided into two administrative blocks – Mumbai city and the Mumbai suburban. The intensified urbanization in the region is causing the destruction of mangrove forests and coastal ecosystem. These natural systems are very crucial for sustaining biodiversity and ambient ecosystem functioning (Dhiman et al. 2019a, b). Also, the high population density and uneven urban growth have escalated environmental and socio-economic problems (Yedla 2003; Dyson et al. 2005). The region is subjected to vigorous developmental activities in the recent past, leading to major issues related to water shortage, seasonal flooding, untreated sewage discharge into the adjacent creeks, and dumping of waste into the coastal waters

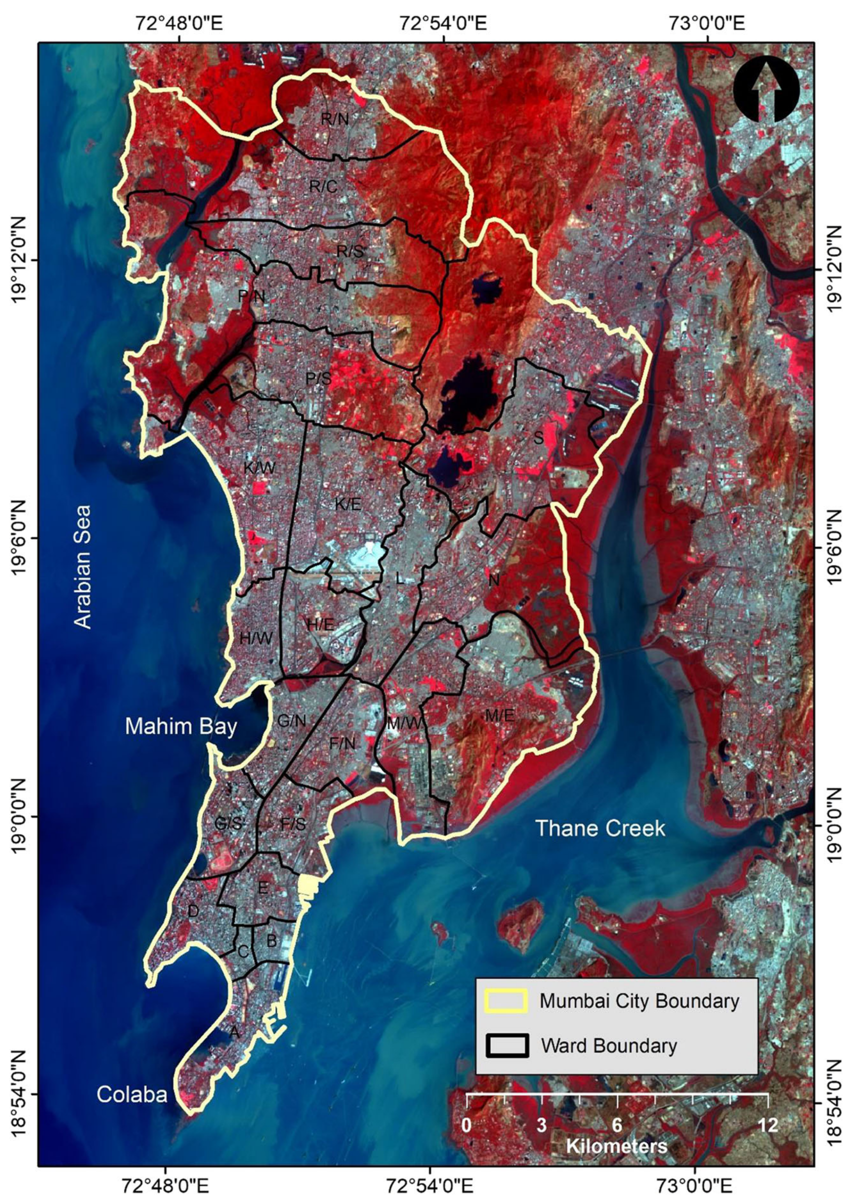

Fig. 1 Study area depicting the coastal environment and ward boundary of the Mumbai city

(VishnuRadhan et al. 2014). Severe coastal pollution affected the coastal ecosystem adversely, which altered the ambient ecosystem functions of the regions. The coastline urbanism in Mumbai is substantially different from the urbanization pattern observed in the city center (Chouhan et al. 2018). In spite of so many prominences and problems, surprisingly the Mumbai coastline lacks an open-source information system acting as a repository of data and knowledge regarding the coast, which can aid in the sustainable development of this highly stressed coastal region as well as the conservation of coastal ecosystem services.

Existing situation analysis (ESA)

Before the development of the CMIS, views and opinions were sought from coastal experts and decision-makers from all four coastal districts of the Maharashtra state during Existing Situation Analysis (ESA) and requirement analysis phase. The standard identified requirements were: a) the need of integrated system inclusive data and knowledge within an umbrella, b) prospective user's necessity for an interactive interface, a dynamic themed map containing the various coastal features as its layers available via the internet, c) need for a query-abled, themed, dynamic GIS mapping as an inevitable part of this system. Since this GIS-based framework had to be served over the World Wide Web, the concept of Web-GIS was also introduced. After the initial requirement analysis, CMIS was designed as a Web-GIS based system comprising of two other silos of data and knowledge, which was aimed at being a complete solution for the queries related to the Mumbai coastal region. Coast being the meeting place of land and water, is one of the most fragile, precious, and precarious natural resources. Sustainable development and protection of the coastline necessitate timely decisions and accurate management. This well-known fact was further emphasized when feedback was collected from experts and decision-makers. To aid in this process of decision making and management, a lot of entities contributed, most distinguished among them are the raw data, compiled reports, and an emerging technology that allows spatial and geographic features to be studied, analyzed and displayed using GIS. Thus as an integrated outcome, the CMIS is proposed to be developed for the coast of Mumbai city. Considering ESA as one of the most critical pre-development components, specific interactions were carried out with the prospective users of the system, and their requirements were prioritized the most while designing the CMIS framework.

Data and software

The data used in this framework was obtained from the Maharashtra Maritime Board (MMB), Mumbai, and Maharashtra Remote Sensing Centre (MRSAC), Nagpur. The dataset collected from MRSAC was pre-processed before its integration into the CMIS. A considerable amount of processing has been applied to the data received from the MRSAC to bring it into the best suitable format for the CMIS. The data available in the data centre page of CMIS will be available for download to the visitors of the site, care has been taken that it is supplied in a format that is easy to download, saved and explored. While most of the data have already been collected, processed and made available in the aforesaid format, the process is being continued for the rest of the data set whenever available. Table 1 provides a list of available data in the data and knowledge centre pages.

Preprocessed and validated datasets in ESRI shapefile format (.shp) is used in the CMIS online interface and enlisted as different layers in the Table of Content (ToC) section at the pmapper window. The datatype is a vector in forms of lines, points, and polygons for different feature classes as shown in Table 2. A suite of pre and post-processing state of the art software and programs were used, which include Mapserver, Apache Server, P.Mapper, ArcGIS, and NetBeans IDE.

Design methodology

The CMIS is designed on the basis of three-tier architecture to make all the layers and components independent. The major advantage of this architecture is the flexibility to run any of these tiers independently on different machines. The three-tier architecture houses i) presentation layer containing presentation logic, ii) business layer containing business logic, and iii) data layer containing data access logic. The presentation layer represents the client-side, whereas the business and data layer are located at the server-side and, all are connected bi-directionally with another database server, as shown in Fig. 2.

The input to this model follows a top-down approach, while the output follows a bottom-up technique. The user can send the request through the web browser, which is a component of the topmost layer or the presentation layer. The request is then passed to the middle layer, where the complete business logic of the application is stored. This layer analyzes the request and decides on which module must be invoked to serve this request, and the required data input. Based on the assessment, the data access layer is requested for the data required to process the request. On receiving the request, the data access layer reverts back with the query, and the business logic layer runs the algorithm for that particular module performing the required calculations and comes up with a solution for the query. The result obtained by the business logic layer is passed on to the presentation layer. The Presentation layer converts this result into an appropriate format so the end-users can utilize it according to their needs. The web browser (a component of the presentation layer) fulfills this task by employing two emerging technologies of

Table 1 Available data in Data Centre and Knowledge Centre for open use of stakeholders

Web page	Type of data	Year	Availability	Format
Data Centre	Bathymetry	2011–2018	Available	.xls; .pdf
	Beach topography	2017	Available	.pdf
	Tide Conditions	2010–2018	–	–
	Sediment Characteristics	2010–2018	Available	.pdf
	Geotechnical Features	2010–2018	–	–
	Computational Wave Fields	2010–2018	–	–
	Computational Tidal Fields	2010–2018	–	–
	Historical shorelines	2005–2018	Available	.shp
	Land Use Land Cover (LULC)	2018	Available	.tiff
Knowledge Centre	Coastal Villages of Maharashtra	2012, 2013	Available	.xsl; .txt
	Cleared Projects	2010 - 2018	–	.pdf
	Clearance Procedure	–	–	.pdf
	FDEP Monitoring Program	–	Available	.pdf
	Ongoing Projects	2010–2013	Available	.pdf

JavaScript and AJAX. The channel that is used for the three components for this model to communicate are detailed further explicitly using examples from the CMIS as follows; i) Presentation Layer - dynamically generated content is rendered by the browser (front - end), for example, the user selects a feature class, a particular creek and poses a query to find out the area covered by that creek, ii) Logic Layer - a dynamic content processing and generation level application server, ASP.NET platform (middleware) is used to perform the necessary actions to find the solution to the query, iii) Data Layer - a system comprising of both database and file-based system that stores vector and raster data as layers. These layers manage the data and provide access to them. For example, this layer returns the Creeks layer that is required for the Logic layer to calculate the area. The system runs without malfunctioning when there are successful connection and communication between the three components of this model. The speed and endurance of the system are taken care of by logically connecting the three layers and making them physically separated from each other. As the modern web browsers come with in-built plug-ins for JavaScript, the user can have access to high-quality services, on the fly, without having to download or install anything (Kalyanam et al. 2019). The CMIS functions using support from many servers, which includes the GIS server as well as the webserver and makes use of such servers for its functioning; the success of an information system depends on how effectively it can control back and forth routing of information demanded by users. This is where servers come into play in a networking environment and are used to exchange data and information effectively.

Table 2 Available data under different categories for associated users of Web-GIS based CMIS

Layers	Data type
Mumbai (City Boundary)	Polygon
HTL (High Tide Line)	Line
LTL (Low Tide Line)	Line
Roads	Line
Railways	Line
CRZ 100 m	Line
CRZ 500 m	Line
Mangroves	Polygon
Waterbodies	Polygon

Since the Open Geospatial Consortium (OGC) has the stringent specification for every GIS-based server that is used for rendering dynamically generated maps over the internet, care had been taken so that all the services provided by the CMIS are OGC compliant. The Open Source community is very active when it comes to geospatial technologies; they function under GNU Lesser General Public License (LGPL) and GNU General Public License (GPL), where the source codes of their projects are available for modification and redistribution by General Public (GNU General Public License, 2013). The open-source GIS product that has been adopted in the development of CMIS is MapGuide Open Source, licensed under LGPL, which is a web-based platform that facilitates quick development and deployment of web mapping applications and geospatial web services as shown in Fig. 3. It also features an interactive viewer that includes support for functions such as feature selection, attributes display, maptips and operations such as the buffer, selection by radii/ polygon and measure and supports all latest and popular geospatial file formats, databases and standards (both Windows/Linux compatible). It supports Apache and internet information services (IIS) web servers offering extensive PHP,. NET, Java, and JavaScript APIs for application development. Microsoft Windows has been selected as the major platform OS on

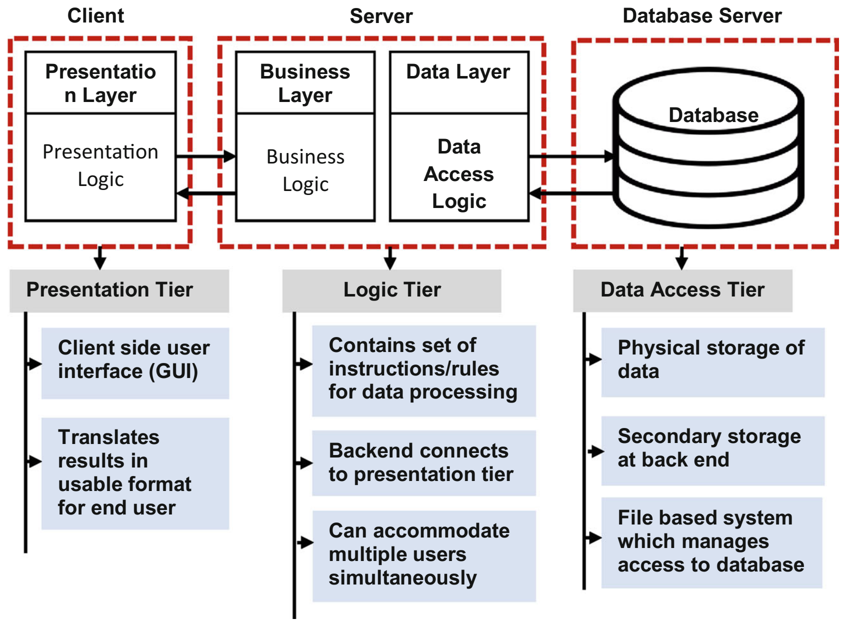

Fig. 2 Overview of the three-tier architecture model incorporate for developing functionalities and elements of the CMIS

which the CMIS is developed. Apache server is installed as the webserver, and the application development platform is PHP and Java. In a nutshell, MapGuide is an open-source application whose purpose is to display dynamic spatial maps over the internet and is basically a CGI program, which is a Common Gateway Interface of the standard set of rules for running scripts and programs on the webserver. It specifies what information is communicated between the Web Server and the client's web browser, known as CGI scripts, and is written using JavaScript. MapGuide CGI script sits passively on the webserver, and it uses information passed in the requested URL and the Mapfile to create an image of the requested map. The request may also return images for other mapping features like legends, scale bars, and reference maps. The values are then passed through the CGI variable replacement technology to the client browser.

The CMIS MapGuide application consists of a map file, geographic data, HTML pages, MapGuide CGI, and Web/HTTP

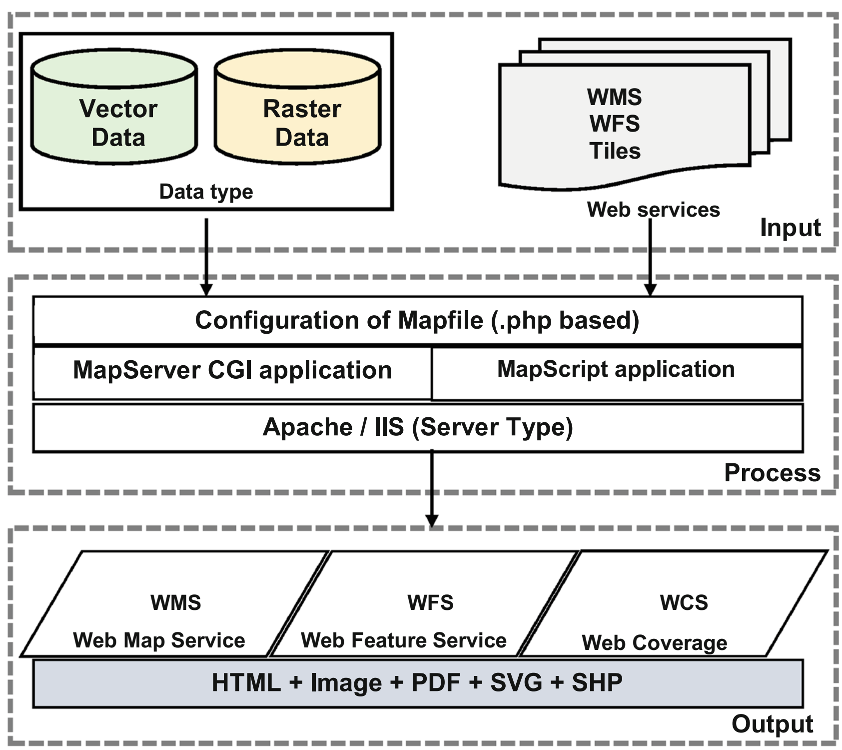

Fig. 3 Basic architecture of a server application handling dynamic GIS datasets and services

Server, and detailed features of these components are given in Table SI 1 of Supplementary Information (SI). The map file is a structured configuration file for the application. It contains all the styling information about the map to be displayed. It defines the area on the map, informs the application where the data is used by this module resides, and where to disseminate the output images. It also defines the map layers including the data sources, projections and symbology. The extension of this component must be .map, and thereafter only this extension is recognized by the server. A simple MapGuide application includes two HTML pages - a) an initialization file that uses a form with hidden variables to pose an initial query to the web server and MapGuide server. This form could be placed on another page or can be replaced by passing the initialization information as variables in a URL, b) a template file which controls – the appearance of maps and legends (output is generated by MapGuide server) in the browser.

The CMIS online supports vector data sources in shapefile format and raster data sources in tiff and Geotiff formats. It supports the PostGIS data sources for geographic objects to the PostgreSQL object-relational database as a backend spatial database.

Results and discussion

Outcomes

A dedicated homepage (Fig. 4) dubbed as the Coastal Management Information System (CMIS), with all required capability and features, has been developed. The CMIS comprises: a web interface with three primary silos and other links on the webpage like events, reports a problem, the gallery, CMIS logo on the top left corner, and contact us.

The Home link is the first webpage displayed on the request of the browser showing a brief description regarding the project and login as well as registration facility for stakeholders. It displays the GIS-based political map of India and the Mumbai coastline with a set of GIS-enabled layers. A particular detailed element based description of the CMIS is explained in Supplementary Information (SI) Fig. SI 1, which includes a map, list of layers, reference map, legend, scale bar, and a basic GIS toolbar.

The CMIS online supports all basic GIS functionalities (home, back, forward, zooming, panning, refresh the map, select, identify, measurement, layer transparency, custom scale) in a user-friendly manner. A detailed description and examples of major functions are shown in Fig. 5.

Primary functionalities

The home button can be used to return to the fixed zoom extent of India, where the study area is located at any instance of time during analysis. The zoom option can be used to zoom in or zoom out operations using the signs and the slider as per the user's choice (Fig. 5). Identify tool is an important tool designated to provide the detailed description of any clicked object on the screen and returns the attribute stored in the particular data type, in addition to giving an option to export the identified item in different file formats like .pdf, .xls, and .shp. (Fig. 5). The Web-GIS based application includes the spatial querying ability, which is unique to any GIS-enabled system. If the user selects any particular feature on the map, the metadata associated with that layer (for example, the area and perimeter of that featured class), the description provided for that featured class in the data set will be displayed in the selection pane. Tooltip shows the attributes of any selected layer while hovering the mouse over the point of interest and these attributes can be updated in the stored data for different purposes. Measurement is another essential tool that can be used to measure the distance, area, perimeter of any required location by the user. Transparency tool gives permission to set-up the custom transparency level for different selected layers which is helpful and convenient while working on multiple layers (Fig. 5). The query is yet another important part of the CMIS online window where the user can access many different customized queries, and these can be exported directly in the different file type formats similar to the identified tool, as shown in Fig. SI 2. This feature can be initiated for different waterbody types, vegetation types, specific locations, or any other coastal feature among all relevant layers. A layer has to be selected on which the query will work input and output fields have to be specified, which will tell the system on what basis this query shall work. While processing the query, it is imperative to set the parameters correctly and, the system is designed to handle both numerical and textual queries posed by the user.

The facility to carry out buffer analysis is a key feature for any GIS-based application; thus, it is essential to have this feature in order to properly and efficiently carry out the geospatial decision-making process. The buffer tool for the CMIS Online allows the user to create a buffer of desired thickness around a selected feature class, and the properties of the buffer are fully customizable by the users.

The typical application of buffers can be explained using the examples of various Coastal Regulated Zone (CRZ) criteria; for instance, the buffer of predefined width can be generated along CRZ 100 m lines depicting an area where construction of commercial buildings is not allowed. Another feature highlight of the CMIS is ready to print a GIS map with all detailed information of the scale, direction arrow, legend, and coordinate projections. Figure 6 depicts an example GIS map of water bodies and different classes of mangroves for a particular user-selected area.

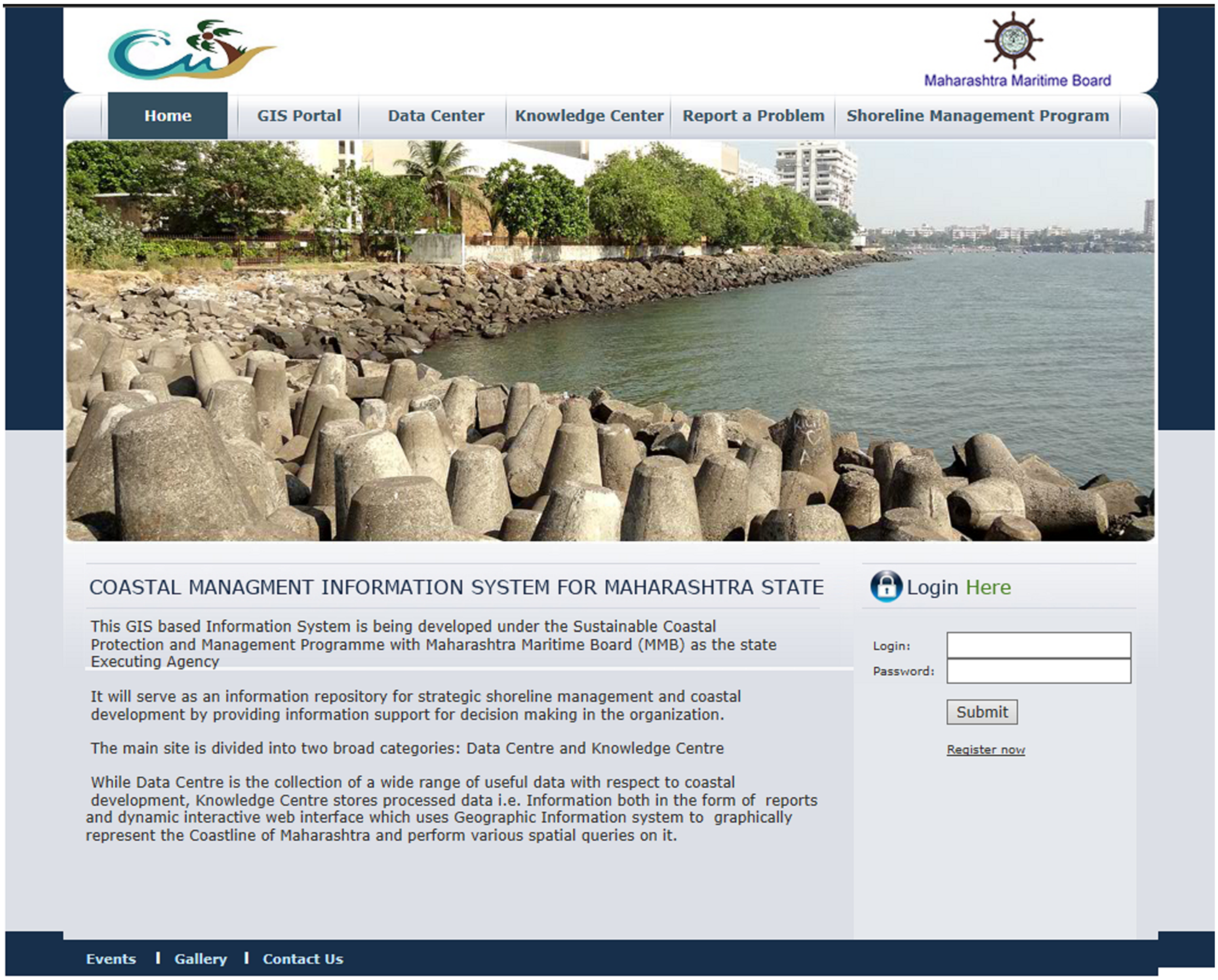

Fig. 4 The content description on the homepage of the CMIS showing different useful Tabs which can be accessed independently according to the choice of the services of any interested stakeholder

Other functionalities

The CMIS homepage has a data centre link (Fig. SI 3), which is a repository of various datasets related to coastal features available free of cost for all stakeholders in .docx, .xslx, and .pdf file formats. Currently, only the datasets pertaining to the Mumbai coastal region are available. The datasets relevant to other regions shown in SI will be incorporated eventually during the next phase of the CMIS development. The core data collected during field visits and validated by the MMB have been uploaded to the site and arranged in different categories such as location-specific and data types in order to improve the user interaction.

The Knowledge Centre (Fig. SI 4) is linked next to the Data Centre, which serves the purpose of storing the processed and analyzed data as downloadable reports as per user requirement. It includes the ready to use the information for both the beginners and experts in the user-selected coastal domain. The user can visualize and learn the reports about clearance procedure for proposed coastal projects, ongoing projects, and programs in the selected area, past pending and cleared projects to maintain the transparency of resource allocation and consumption. Other silent features are - historical database management of fisher folks and coastal villages, statistics of fishing, and census of these coastal communities. It also has some important links to other relevant sites of Geo-portals by the ISRO, Water Resources of India, and National Wetland Repository. Users can report a problem related to their query, data, or any other associated issues by using the direct link, which notifies the administrator of the server, and further, it shall be forwarded, depending upon the nature of the problem, for an opinion from concerned experts involved in the program.

Discussion and future prospects

A Web-GIS based management information system for the Mumbai coastal region was developed, which envisions

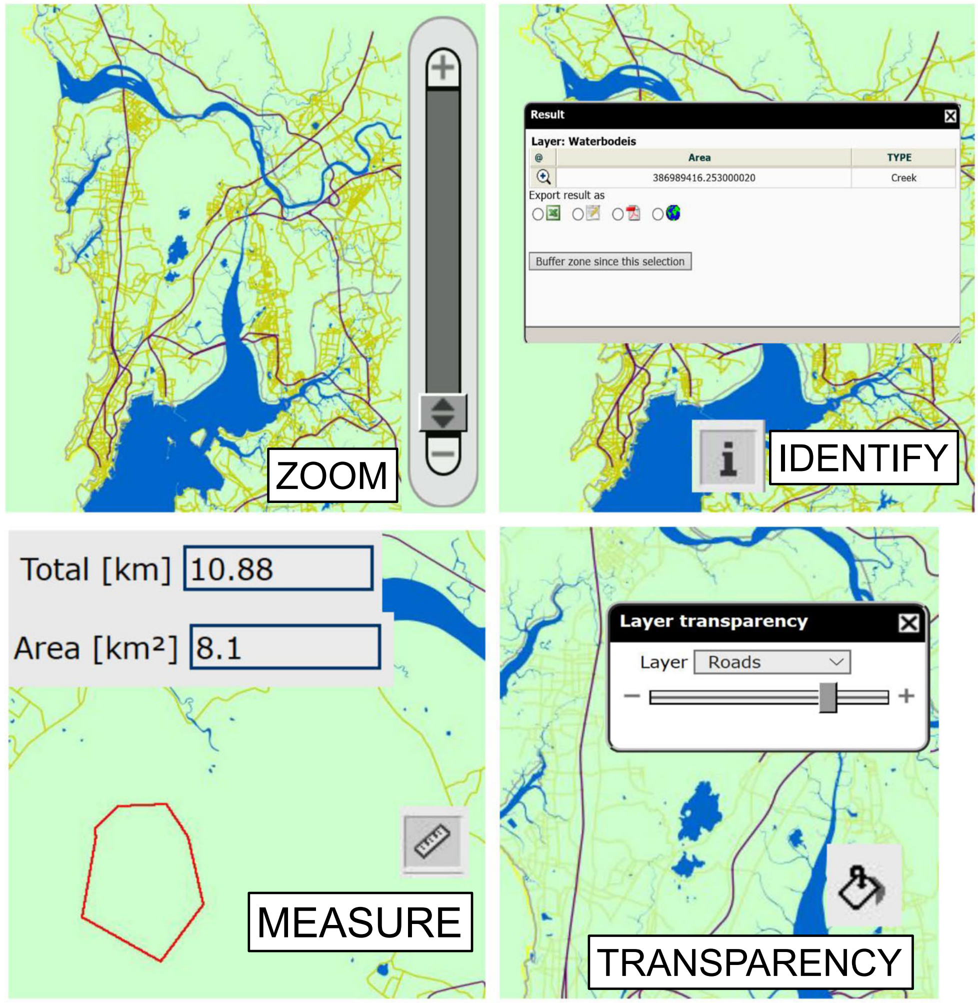

Fig. 5 Web-GIS based utilities and functionalities of CMIS for visualizing and assessing the coastal information based on available data

sustainable development with strategic planning and management of the coastal zone. The stakeholders and decision-makers sought a Web-GIS based Information System to manage the coast as well as the shoreline properly. ESA revealed that the prospective users wanted a dynamic Web-GIS based online mapping service supporting advanced spatial query processing features besides having the capabilities of showing latitude and longitude information, panning, and zooming the desired point locations. The Web-GIS was used to build the system in order to meet these requirements. The services provided by CMIS, starting from providing data support to making web services available are OGC compliant. The development of CMIS also borrows heavily from the open-source community, and the system also supports a large number of data formats major, among them being the Vector Data Sources, the Raster Data Sources, and FDO Sources. The most important components of the CMIS are the data centre, the knowledge centre, and the CMIS online. The CMIS online is the main attraction of the system, which is the Web-GIS based mapping service where the dynamic, Web-GIS enabled layers are used to represent various coastal features. These layers can be turned on/off, or overlaid on each other. Displaying attributes of selected feature classes, buffer analysis is some of the functions that it performs. "Report a problem" and "shoreline management program" are another two important aspects of the system. The web designing technologies such as CSS, Flash, and Fluid layout have gone into the development of the front end. An amalgamation of all the above-mentioned technologies and methods makes the CMIS lightweight, fast, accurate, and informative tool to aid in the integrated management and sustainable development of the coastal regions in the Mumbai megacity.

The CMIS system is based on Web-GIS technology, which has applications towards various fields of research and aims to address areas such as coastal resource management in a sustainable manner. The information it stores about the projects makes it commercially viable as well. The CMIS architecture can be divided into three models based on the number of functions committed by the browser and server, the thin browser/rich server, rich browser/ thin server, and the mixture model. The CMIS uses the mixed model, which ensures the maximum utilization of the system resources, of Web-GIS

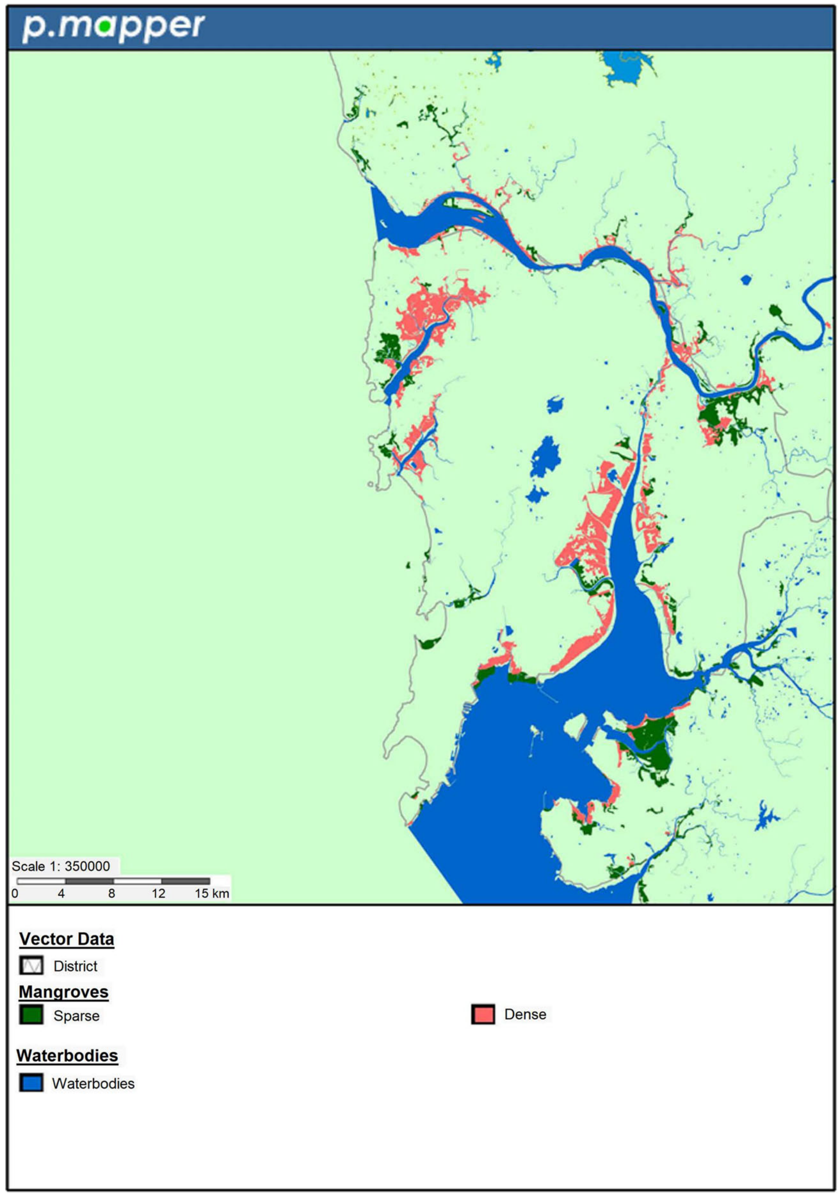

Fig. 6 An illustration representing the automatic sample of a ready to print GIS map in the CMIS which can be directly print and used without any expertise of GIS by any associated user of CMISs

architecture as it adopts the distributed processing strategy in the course so that the client and server can complete GIS tasks together.

The course of development of an information disseminating system such as the CMIS is a multidisciplinary approach and needs synchronization among many interrelated processes. Moreover, the development is a continuous process as the CMIS represents the dynamic shoreline as GIS layers, which can never be complete as the user's expectation and requirement from the system will change with the changing coastal features of the region. The relevance of the CMIS like systems is a direct function of its sustainability and upgradeability. In that respect, CMIS will continue to be developed and modified with enhanced modules and new applications. The data centre of CMIS stores coastal data collected during various field visits. Moreover, weather and climate also play an important role in the availability of data. Some particular types of data may be missing during some seasons (for example, during monsoon season) as seasons also play an essential role in terms of field access. While the structure has already been prepared, the storage capacity has to re-design to accommodate more data that will be generated in the course of time. Currently, there is a limitation regarding the number of queries that can be addressed in the CMIS system, which is yet another area that needs to be enhanced in the near future. The spatial queries addressed in the present version work on one layer at a time, and the system can be extended to work on multiple layers. Presently the system does not have to deal with a large number of layers; pre-caching or tiling of layers have not been performed. As the number of layers increases, the pre-cached or tilled layers will be absolutely necessary which will help in maintaining the speed of the application.

The field of Web-GIS is advancing at a fantastic pace, and the present design of the CMIS utilized the technologies which are currently available that best suit the present requirements in addressing various aspects and challenges encountered in the management of a heavily urbanized coastal region.

The current CMIS system has been tested successfully on a Local Area Network (LAN), and different functions were tested for its endurance. The system performed smoothly, without major glitches, for independent users as well as group users. The CMIS system is ready to scale-up on a World Wide Web and the same will be achieved in the near future according to the available infrastructure which we are currently collating. The targeted audience to utilize the capabilities of CMIS is focused ondecision-makers, coastal planners, environmentalists, policy-makers, Urban Local Bodies (ULBs) and expert stakeholders in the area of coastal resource management. This easy to handle system with a user-friendly interface is designed such that novice users can also achieve the full benefits similar to expert users.

Conclusions

The majority of the megacities today exist in the coastal zone, and the Mumbai city is a prominent one in terms of socio-demographic and urban aspects. The primary objective behind the development of the CMIS for the Mumbai coastal region is to equip the city with a tool that can drastically improve its capacity to endure in this era of rapid urban transitions and, also considering the fact that these transitions can pace back and forth rapidly in the wake of current and projected climate scenarios. The CMIS will help the stakeholders and decision-makers to re-route the city dynamics towards a more efficient and sustainable coastal protection and management. The CMIS is developed with an objective to make its users realize and go beyond the consensus that the coastal protection and management are fundamentally based on the available and accessible dataset for protecting the coastal sea and the shoreline. We believe that the CMIS has the potential to open the arena of urban coastal management issues in India to empirical testing and connotes the decision making for the community to explore the untapped opportunities of the dynamic shoreline and coastal waters. Since the CMIS is developed and works in an open-source platform, it can provide service to a diverse type of users without imparting any economic burden. The relevance of an open-source system, such as the CMIS, is a direct function of its sustainability and upgradeability. As such, an action plan pertaining to continuous development shall be adopted with two primary areas of focus, external program optimization and, features enhancement. Further, the spatial capabilities of the CMIS shall increase in the near future as the system will be developed further for the adjacent coastal region near the Mumbai coastal region incorporating more data. The near-future phase of the CMIS development shall incorporate the directions for the adaptive and preventive strategies to tackle the issues emanating from the unplanned past and current exploitation of this highly dynamic urban coastal zone.

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