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Review Article

GEOGRAPHICAL INFORMATION SYSTEMS FOR MARINE APPLICATIONS

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ABSTRACT
Geographical Information Systems (GIS) are special class of information systems which combine spatial and non-spatial information systems within a single system. It is a type of information system that collects, stores, retrieves, analyzes and displays geographically referenced and attribute data simultaneously. GIS is a decision tool that helps decision makers and facilitate decision making process. The usage of GIS for land problems began about 1960s, but application of it to sea problem was in the 1980s. Marine GIS gained a substantial significance in the 1990s with the emergence and popularity of Earth System Science.The aim of this study is to examine the usage of GIS in marine areas and to highlight the importance of GIS technology for marine applications. All of these concepts were examined in a theoretical framework in the study. So the method of the study is a literature review. With the literature review, the concept of GIS and its application in marine areas were tried to be explained. After reviewing literature it is concluded that marine GIS can give different perspectives to marine scientists for solving marine-related problems and facilitating decision making process.

Keywords: *Geographical Information Systems, Marine GIS, Marine spatial planning, GIS for coastline management, GIS for fishery.*

1. INTRODUCTION

Information systems (IS) are special systems designed to collect, store, analyze and present information in a systematic way. These systems improve information management of an organization by applying computer to data processing. So, IS can be defined as a set of interrelated components that support decision making in an organization by collecting, processing, storing and distributing information (Avison&Elliot, 2005; Laudon&Laudon, 2005). These systems are categorized as spatial and nonspatial information systems. In nonspatial information systems,such as student information system and library information system are nonspatial information systems in which data arenot linked to any coordinate information. In spatial information systems data are referenced to any position geographically with coordinate information named as spatial data (Aronoff, 1995; Lo&Yeung, 2002; Laurini&Thompson, 1992). As stated by Gilfoyle&Thorpe (2004), handling and analyzing spatial data have an important role because of the spatial aspects of many problems encountered in the organizations. Spatial data means geographic data which is obtained from measurement or observation of earth. But this data becomes information and can solve the problems only when it is asked who, what, when, where and how many questions. As a result of the need for combinatiorial usage of spatialand non-spatial (non-graphical or attribute) data with digital maps, computer-based systems known as Geographical Information Systems (GIS) emerged.

GIS relates spatial data to attribute data. Its main duty is to store spatial and non-spatial (attribute) data and dijital maps within the same database and to update, manipulate, analyze and display them simultaneously. As depicted by Shamsi (2005), GIS technology develops effective solutions in the management of natural resources by using the integrated power of both geography and information systems. GIS is very helpful for gathering, analyzing and visualizing spatial and non-spatialdata simultaneously. GIS can be used as a decision tool by facilitating decision making process in terrestrial and marine areas.This technology is used to capture, store and analyze terrestrial and marine-related data. Hardware, software, people and dataarecomponents that make up asuccessful GIS.

Hardware component of GIS is, computer and any other equipment (such as digitizers, scanners, printers and plotters, etc…) needed to store, organize, analyze and display spatial and non-spatial (attribute) data. (Heywood, Cornelius, & Carver, 2002).

For GIS to be successful it is important to use the most current version of the software. But as stated by Nasirin, Birks, & Jones (2003), GIS should not be thought of as a just software installed on a computer.People who will use GIS should know what to do with the data, how to benefit from the software package, which analyzes they will do and for what, and should be able to interpret the results of analyzes correctly.

In order to be successful in terrestrial and marine GIS, the selection of true GIS packages is very important. Software selection process must be considered in terms of ease of use, amounts and formats of data they can process. The selected GIS packages should have the ability to interchange data with other packages (Valavanis, 2005: 22).

People component of GIS consists of viewers, general users, and GIS specialists. Viewers are the people who want to browse a geographic database and access to information when they need. General users use GIS for managing businesses and making decisions. They have direct effect on the successful use of GIS in the organizations. GIS specialists are the people who actually perform GIS work. The designation of database and the supplying technical support to viewers and general users are among the main duties of GIS specialists. The system will not work with the absence of specialists who operate and support GIS. (Lo & Yeung, 2002).

As mentioned by (Gilfoyle & Thorpe, 2004; Lo & Yeung, 2002) GIS database can either be in a vector or in a raster format. Points, lines and polygons are representations of spatial data in vector formats, while pixels or voxels are representations of spatial data in a raster format. Points represent anything that can be described as an x, y coordinate such as port, dock and hatchery. Lines are the data that composed of combination of several point data, such as road, railway and stream. Polygons are data that start with a particular point and ends with the same point and are represented by a closed set of lines, such as lagoon, mangroves and lakes. Wind direction or wind force measurements for sediment type are examples of point data format, coastline and bathymetry are examples of line data format, statistical sampling areas or commercial catches are examples of polygon data format, sea surface temperature and sea surface salinity are examples of raster data format. GIS can manipulate these data by converting them to another format (conversion of images to grids), creating new data format and preparing data for analysis. Classification, proximity analysis, optimum path analysis, statistical analysis are some of the techniques that are included in spatial analysis tool of GIS (Valavanis, 2005: 14; Meaden & Do Chi, 1996).

Non-graphical data is the other type of data that must be mentioned in the context of GIS data. These data can either be compiled in the tabular form or hold the attibute information concerning to special graphical database. The database designed for fish landing at a specific port, which includes data about, dates, name and type of vessel, species of landed fishes,is an example of non-graphical GIS database (Meaden & Do Chi, 1996).

Data is very important factor in GIS applications and setting database management system is the heart of any GIS. Cost of data input is high in terms of purchasing digital data or setting up and maintaining data gathering system. So at an early stage of GIS establishment, costs can be very high. The legal situation regarding the means and degree of access to data sources may sometimes be poorly defined or unnecessarily restrictive (Nath et al., 2020: 11).

This study emphasizes both the importance of GIS and its application in marine areas. The research problem of the study is to present how GIS can be used to solve marine related problems? So with this study it is tried to show the importance of GIS for solving sea problem and how it can be used for solving marine area problems. The method of the study is a literature review. By doing literature review it was tried to show importance and several usages of GIS for marine areas. Because marine GIS is in its infancy stage, it is tried to draw attention to the importance of the subject by examining marine GIS applications that reveals the significance of the study.

2. GIS FOR MARINE APPLICATIONS

The usage of GIS for land problems began by the late 1960s, but application of it to sea problem was in the 1980s. Marine GIS gained importancein the 1990s with the emergence and popularity of Earth System Science. Other factors that expands the usage of marine GIS include increasingglobal ecological understanding and concerns,increased awareness of marine life.Marine researches began with the United Nations Convention onthe Law of the Sea in 1994, and the designation ofthe International Year of the Ocean in 1998. In the literature there are studies which showed the usage of GIS to determine high productive marine areas and potential fishery location areas. Marine productivity hotspots are crucial areas for fish aggregation for mating, spawning, and feeding. GIS and satellite data based model allows the spatiotemporal mapping of combined anomaly in below average temperature values and above average chlorophyll levels (Valavanis et al., 2004).

When the literature is reviewed it was seen that there are a lot of studies concerning GIS applications in marine areas ranging from oceanography to fisheries. In the literature studies about GIS and Oceanography can be categorized as Marine Geology, Flood Assessment, Coastal and Ocean Management, Coastal Zone Dynamics, Marine Oil Spills, Sea-Level Rise, Wetlands and Watersheds. In the literature some of the studies about the GIS and Fisheries are subdivided as Marine Fisheries, Aquaculture, Inland Fisheries. GIS can contribute to the Inland Fisheries area by mapping of spawning grounds, mapping migration corridors, mapping essential habitats, etc. (Valavanis, 2005).

In the literature there are a lot of studies that emphasıze versatile GIS applications in marine areas. GIS applications are very useful for monitoring, conservation and management of marine areas. Many authors studied spatial awareness in geographical environments. The understanding of various GIS data models and evaluation of spatial analysis in GIS are the basic steps for developing spatial thinking (Kaymaz&Yabanlı, 2017:189). Some of the uses of GIS in marine areas include maritime transport, fisheries, disposal of waste, conservation and managing coastal areas (Kaymaz&Yabanlı, 2017: 189, 195; Jayasankar, George, Ambrose, Manjeesh, 2013: 438).

The importance of GIS comes from its ability to combine different data types, to do spatial analyses and statistical queries with increased speed and accuracy. These feauture of GIS are very important in managing dynamic nature of marine habitats and coastal resources. But in order to manage this process marine data must be accurate and updated regularly. By combining different layers, doing statistical queries and performing buffering operations, such as determining fishing locations in water depths greater than 100 m.,or displaying marine areas having water temperature mean greater than 15 degrees Celcius with the water depth smaller than 100 meters can be performed with GIS. GIS allows decision makers to evaluate different management scenarios with increased speed and accuracy and then enables them to make more comprehensive decision. GIS is an important tool for analyzing time related changes in coastal areas (Paiman and Asmawi, 2017:160; Stanbury&Starr, 1999: 700; Meaden&Do Chi, 1996: 136).

2.1. GIS For Coastal Management

GIS can combine different data set from different resource and enable the coastal manager to see the picture of the problem as a whole. In this process coastal manager's ability to accept and understand complexity of coastal process is important in managing coastal area successfully. Managing coastal resources requires to integrate spatial and non-spatial data from different database. GIS can integrate these databases and allow managers to make decision quickly and accurately. By performing GIS practises coastal erosion vulnerability, sea-level rise and other threats can be modelled by coastal managers (Paiman and Asmawi, 2017:160).

Because coastlines are enduring quick development, dynamic nature of these areas requires strict management policies. To be effective in this coastal management process all decisions must be based on appropriate, reliable and timely data and manager of this process must have full access toall related database. GIS can contibute this process by managing large database, encouraging use of standards for coastal data definition, collection and storage of coastal data.GIS applications are very helpful for planning, managing and monitoring natural and human-sourced changes in coastline areas.The decisons tools of GIS such as simulation modelling and what if scenarios help keeping track ofthese changes regularly and making decision.Results of the analayzes are very important especially for GIS users whose works are related to the coastal areas, such as town planners, land managers etc. Measuring distances and areas, performing buffering operations around lines or determined areas are only some of the functions of GIS that can be used for coastal management and marine-related applications. Thus, a well-designed coastal area information system can serve as an important decision toolin the development of integrated coastal resource management strategies (Paiman and Asmawi, 2017:160,161).

Paiman and Asmawi, (2017:162) cited some GIS applications used in coastal management. GII (Geographic Information Infrastructure) for monitoring the Netherlands' coastal zone, COSMO (Coastal Zone Simulation Model) for risk management, SHO-MAN (the SHOreline MANagement tool) for coastline management are some of the applications mentioned in this study.

In order to maximize effectiveness of GIS in marine applications firstly data needs must be identified to manage coastal areas and marine resources. In marine applications different data sources can be obtained from different GIS data layers, satellite images, aerial photographs and database information Spatially and timely dynamic nature of coastal resources and marine haibats, combination of dissimilar data types is very important in decision making process. GIS can combine or overlaydifferent layers, manage spatial analysis and do querieswithin one layer or among objects in two or more layers (Stanbury&Starr, 1999: 700).

2.2. GIS For Fishery

One of the important application areas of GIS in marine is fishery. In the past the usage of GIS was not practical because of the difficulty of obtaining spatial data about organisms/habitats in underwater environments, When GIS is combined with other technologies (such as remote sensing), analytical tools and models, it allowed for spatial monitoring and analyzes. GIS can serve as an important decision tool in planning and management of fisheries because of the spatial component of this process. Spatial components include, movements and migrations of resources, the description of fishing spots, transportation networks, habitat loss and etc,.GIS is a technology that can elucidate the problems and produce solutions with the help of spatial components. Aquaculture studies used GIS for the past 15 years in the field of evaluation of suitability of coastal areas for farming activities. GIS is a helpful tool for studies seraching for water quality on sellfish aquaculture, various uses of estuarine waters and, etc (Nath, Chutia, sarmash, Bora, Chutia, Kuotsu, Dutta, Yashwanth, 2020: 7).

With the advances in radio telemetry, hydroacoustic telemetry, and side-scan sonar, biologists have been able to track fish species and create databases.These technologies can beintegrated with a GIS program to form a geographical representation. Some of the applications of Remote Sensing and GIS in fisheries are site selection for aquaculture or mariculture, modeling fish activity and movement, matching fish distributions with the environmental parameter such as, water temperatures, water depth, bottom sediment type and salinity, analyzing fisheries catches (where is the fish caught and how much is caught) and effort, setting regional and national fisheries database, mapping and monitoring seagrass, seaweed and coral reef, mapping of habitat and change detection.(Nath et al., 2020: 7).

3. AN OVERVIEW OF MARINE GIS

Some of the benefits of GIS can be summarized as: By creating digital maps through GIS, it is possible to update them, to change or merge them with other maps. diverse graphic representations are possible with the analyzes offered by GIS. The other benefits are, integraton of other large data sets, display of easily understandable spatially related data, regular flow of spatial data in a standardized form (Nath et al., 2020: 11) There are some points that need attention and to be careful when using GIS. Firstly, in order to use GIS, organizational change will be mandatory because GIS implementation will change the way organization works (Nath et al., 2020: 11).

As mentioned by Wright and Goodchild (1997), despite the static characteristic of terrestrial-based GIS problems, marine GIS problems have fuzzy boundary, dynamic nature and three dimensional characteristics. Marine area is a dynamic environment where almost eveything moves or changes due to physical processes such as current, upwelling. Marine GIS requires defining relations between wind and sea currents and displaying effects of these relations on oceanographic process and behaviour of marine organisms. Marine GIS has a wide range of applications such as coastal, oceanographic and fisheries GIS. A coastal fisheries GIS deals with,for example, how oceanographic processes, like upwelling, affect fish population and production. This is an example of overlapping of marine disciplines in marine GIS applications. Generating decision-aid tools is one of the main objective of marine GIS. In generating decision-aid tool process GIS technology is incorporated into other technologies, such as Global Positioning System (GPS), Remote Sensing (RS), modelling, image processing, spatial statistics and Internet. Involvement of marine scientists, such as oceanographers, marine biologists and GIS experts is required for marine GIS development. During this procedure, the first task of a marine GIS developer is to collobrate with other marine scientists for fixing and defining the spatial problem and the creating a list of spatiotemporal questions. The nature of these questions will greatly affect the whole design of the marine GIS tool because such tools contain specialised GIS tasks. Marine GIS tools can be categorized as cartography tools, data distribution tools, monitoring tools and decision support tools. These tools contain the main goals for a marine GIS development (Valavanis, 2005: 1-3).

Cartography tools provide visualization of spatiotemporal distribution of data set distribution, such as mapping of bathymetry, mapping of fisheries production, mapping of the distribution of sea surface temperature. Data distribution tools provide raw data in a GIS ready format, thereby enhance the use of the raw data, particularly of satellite data. Time series analyses of GIS datasets can be used for the monitoring of oceanographic phenomena like the start and the end of a cyclonic upwelling event. In order to know current state of the marine resources, seasonal or annual oceanographic phenomena monitoring tools are very important in marine GIS. Marine GIS decision support tools are precious for the development of marine resource management scenarios. They provide a detailed analytical results for species' population dynamics, their life cycles in relation to marine environment and their fisheries production status (Valavanis, 2005: 10).

The questions that marine GIS answer can be categorized as questions dealing with location and extent; distribution, pattern and shape; spatial association; spatial intereaction and spatial change Followings are some of the marine spatial questions that marine GIS can answer (Valavanis, 2005: 12,13):

- Where is the location of an upwelling?
- What is the topography of the upwelling area?
- Why upwelling does not ocur in all coastal areas?
- Why does upwelling happen in a particular area?
- What are the wind patterns of an upwelling area?
- Why do trawlers consistently fish in a particular area?
- What is the distribution of sea surface temperature, chlorophyll, and salinity before, during, and after an upwelling event?
- Is there a particular area where a specific marine species is consistently caught?
- How have productivity levels changed in a particular area?
- Why are particular species found in a particular area?

GIS can serve as a decision tool in finding answer to spatial questions by doing analyzes and then displaying and visualizing results of analyzes on a digital map. Generating true and up to date GIS database is very important before doing analyzes. Because correct answers to these analyzes depend on the creation of the correct GIS database through which questions like what characteristic of an object is, where and how it is located can be answered. Geographic data and attribute data are very important for doing analyzes in a GIS. The center of a GIS is the designing of true and up to date database. GIS is not simply a map making computer system. It also shows spatial relationships between map features.

Doing analyzes over several datasets with GIS provides valuable information for marine areas. GIS allows for representation of analyzed data in the forms of maps, graphs, lists and summary statistic. By marine GIS relationships between wind and sea currents and their effects on oceanographic processes, behaviours of marine organisms can be explained. Defining fish habitat and organizing living marine resources, tracing marine mammals, analyzing their hunting and migrant lines are marine problems that GIS can answer. For detecting changes in marine processes and visualization of these processes multidisciplinary data are used in GIS. GIS analyses give synoptic situation of marine environment that shows marine pollution, quality of seafoodand special ecosystems like mangroves and corals (Kaymaz&Yabanlı, 2017:191).

Marine problems have spatiotemporal characteristics. GIS allows for collecting and using different environmental parameters to understand their effects on marine environment. For example oceanographic GIS is used for doing analyzes about coastal zone management, marine habitat assesment, marine pollution, deep ocean mapping, sea level rise and visualing results on a digital map (Kaymaz&Yabanlı, 2017).

Consequently, thinking spatially and doing GIS analysis in the marine areaare very important for comprehending the dynamics of marine processes and their effects on the behaviour of species populations.Marine GIS requires multifaceted thinking. For example, the explanationof why a particular species exist in a particular areaat a certain times of their life cycles will require the data about their migration habits, wind and current patterns with GIS experts who integrate all the related data. From a GIS perspective, the main goal is to combine all the data necessary to develop a model of the marine environment to understand what and where objects are and how and why they are there. (Valavanis, 2005: 16).

In the process of building marine GIS, marine GIS developers have to cooperate with marine scientists, such as oceanographers, marine biologists, fisheries and etc., for defining spatiotemporal problems and finding solutions to these problems. In this process marine GIS requires forming spatiotemporal multidisciplinary database, manipulating different data formats (raster and vector) and setting system user interface. The integration of GIS methodolgies with visualization, statistics, spatial analysis, modelling and Remote Sensing is very important part of decision support process for studying the marine environmental problems and development of marine GIS (Valavanis, 2005: 24).

4. SAMPLES OF GIS APPLICATIONS IN MARINE AREAS

GIS applications in marine areas are in their early stages. Because there are some obstacles that hinder quick development of GIS in marine area, like massive marine data sets, the need for three-dimensional data processing, difficulty of getting ocean data, mapping or analyzing moving or changing sea environment, the need for marine scientists that specialize in marine GIS, etc. Despite these challenges, there are successful marine GIS applications in the literature. Habitat mapping, species distribution, fisheries oceanographic modeling, fisheries management are some of the areas that make use of GIS in fisheries.

Li and Saxena (1993), presented the results of the development of Marine Geographic Information System (MGIS) for the development of the Exclusive Economic Zone (EEZ) in the U.S. Pacific Islands region. Some of the applications performed in the study are spatial marine data processing, integration of GIS and mapping systems, simulation of marine operations. In the study MGIS has been used for selecting a potential deep-water research site off the Hawaii island and for generating three-dimensional database and using it for the navigation.

Lucas (1996), handled the issues and implications for coastal GIS, integration of ocean data within a coastal GIS for the Baltic Sea. In the study it is stated that the problems regarding the use of ocean data in coastal area are related to the spatial and temporal variability of coastal ocean data.

Meaden (2000), discussed GIS applications in fisheries management. The main focus of the study is to examine problems and challenges encountered in using GIS in marine fisheries. In addition the study discussed importance of GIS in fisheries management. Meaden mentioned the authors who studied fisheries and GIS, such as marine mapping, habitat mapping, marine productivity mapping, fisheries management, aquaculture location and activities from 1991 to 1997 period in the study.

Jayasankar et al., (2013) mentioned the case studies about GIS applications to fishery both internationally and in India. Some of the examples using GIS in India are thematic mapping of tuna and tuna like resources, monitoring change in the average sea surface temperature, etc.

Triana and Wahyudi (2019), examined GIS development for Marine Spatial Planning and they tried to predict challenges faced in this process in Indonesia. In the study it is stated that GIS is used to store, analyze and display collected data in the process of developing Marine Spatial Planning.

Nath et. al. (2020), highlighted the importance of GIS in fisheries and usage of GIS as a management tool in fisheries. The application of RS and GIS in fisheries in site selection for aquaculture, modeling fish activity and movement, matching fish distribution to environmental parameters, establishing regional and national fisheries database, identification of potential fishing zones were also discussed in the study.

5. CONCLUSION

Terrestrial-based GIS data has more static characteristic than that of marine GIS data. In this context marine data is fuzzier than terrestrial data in terms of locations and boundaries.

Once the aims are determined, then GIS user can list main types of required data and after that can determine additional optional data. For example, for coastal zone management, the GIS user will need data about existing land use, proposed land use changes, transport route, etc. Then the GIS user may want additional data about elevation and slope of the land, locations of harbours, etc. For monitoring fish yields basic data requirement can be listed as, boundaries of fishing zones, rate of catch per species, bathymetric data for particular area, etc. Then GIS user can make additions to the mentioned basic data.

Marine applications of GIS have been slow due to difficulties of mapping marine species distributions, constant change of marine environment, high cost of getting marine data, cooperation problems in data collection, difficulty of defining boundaries because of the fuzzy nature of marine resource distributions and the problems of storing huge amonts of data (Meaden and Do Chi, 1996).

The abilities of GIS in data integration, visualization, statistical analyses and queries help marine scientists to deal with uncertainities of deep (Wright & Goodchild, 1997). The very high costs of acquiring, integrating and interpretating marine data justify the use of marine GIS which provides all of these capabilities within a single system. Visualization of marine problem helps the decision makers to develop spatial thinking. The combined use of GIS and other disciplines, such as visualization, statistics, spatial analysis and Remote Sensing, is very important part of establishing decision support system for marine related problems and marine resource management.

As mentioned by Lucas (1996), in the case of the lack or deficiency of data about marine processes the role of GIS as a decision support tool will be limited. Accurate coastal ocean data must be made accessible and usable so that decison makers can integrate needed information into their task.

Versatile marine scientists such as fisheries and marine biologists, oceanographers, GIS specialists, analysts, etc. are necessary for building full-fledged marine GIS. The marine GIS should display marine data, support contouring, overlaying, incorporate links to GIS external software, support an interactive graphical user interface, enable data downloading and dissemination of the results through the Internet (Valavanis 2005).

Geographical interpretation of marine area using GIS is at the early stage but continue to develop. GIS helps marine scientists to develop comprehensive plans in the fields of fisheries, coastal areas and marine policy making.

Thanks to GIS for providing tools for making decision accurately and in time, creating, changing and updating digital maps easily, producing several what if scenarios, allowing for integration of large data sets, integration with other technologies such as remote sensing and satellite images.

GIS is not only a system of hardware and software. Successful GIS implementation requires having staffs who have high GIS knowledge, speciality, technical competence and skills and having organizations that have innovative environment. In addition, data needs of organizations must be identified. High cost of getting data and designing database, data manipulation and conversion of data to and from diffferent formats must be taken into account prior to establishing GIS.

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