FORMULATION OF GEO-SPATIAL SOLUTION FOR DISASTER MANAGEMENT

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ABSTRACT:

Mumbai city has become extremely vulnerable due to a large population living in huts especially in low-lying areas. Whenever city receives heavy rains; roads get waterlogged and the traffic is disrupted. Since the past 3 years, the monsoons in Mumbai have been creating havoc: flooded roads and railway tracks, clogged drainage system, and the huge traffic jams. Mumbai witnessed one of its biggest destruction on 26th July 2005. The recent Flood disasters showed that available Disaster Management Systems do not fully fulfil their requirements and potentials. Disaster Management poses significant challenges for data collection, data management, discovery, translation, integration, visualization and communication. It is often stated that the major problem in Disaster Management is not lack of technology or the existence of relevant information, but lack of 'information' about the information. Disaster Management depends on large volumes of accurate, relevant, on-time geo-information that various organizations systematically create and maintain. Spatial Information and Information Communication Technologies are the important elements in Disaster Management. Researchers have presented first prototype that is being developed for a pilot area at Mumbai, D Ward. The paper researches the demand for Mobile and Web Based Integrity in Disaster Management and suggests a systems approach to reduction of errors in Disaster Systems. It is with this purpose, the paper addresses the role of SDI (Spatial Data Infrastructure) as a framework for facilitating Disaster Management. The GIS enabled Mobile and Web based Geo – Spatial Software Solution for Disaster Management is designed and developed.

1. INTRODUCTION

1.1 Natural Disasters

An emergency is a deviation from planned or expected behaviour or course of events that endangers or adversely affects people, property, or the environment. Disaster is characterized by the scope of an emergency. An emergency becomes a disaster when it exceeds the capability of the local resources to manage it. Natural disasters include those unplanned events that occur as a result of natural processes such as earthquakes, tornadoes, tsunami, freezes, extreme heat or cold, floods, drought, or insect infestation…etc. In this paper the researcher has tried to discuss the precautionary measures and the Disaster Management enhanced technologies incoorporating effective real-time information sharing, transperancy, security, implemantation through wireless, networking schemas that can be used to take care of floods. A **flood** is an overflow of an expanse of water that submerges land. Floods are the major disaster affecting many countries in the world year after year. It is an inevitable natural phenomenon occurring from time to time, which not only damages the lives, natural resources and environment, but also causes the loss of economy and health.
Every year Mumbai is affected by floods during monsoons. Greater Mumbai is greatly diversified and practically has every type of flood risk. Mumbai witnessed one of its largest destruction in the form of heavy rainfall on 26th July 2005. It was a natural disaster which affected all: the rich and poor, the urban and rural, traders and artisans, government employees, corporate professionals, and the cultivators. Floods claimed almost 1,100 lives in the state, most of them coming from urban concentrations of Mumbai and Thane [1].

1.2 Area under Study

The Mumbai Metropolitan region has a total area of 4355 sq. km, consisting of 1273 sq. km urban area [2]. The Urban region has a population of 17.7 million, out of the total population of 18.9 million. Mumbai is divided into 13 wards. Mumbai D Ward is selected as study area [3]. The Ward covers an area of 6.63 square kilometres. The approximate population of the ward is 3, 99,931(as per 1991 census) with an additional day-time floating population of 1, 00,000. The ward is selected as it covers historical, religious and tourist's centers. The ward also covers slum affected by floods. The ward is also made up of low-lying areas that are affected by flooding. D ward has 23 buildings that are old and are identified as dilapidated and dangerous for occupation.

1.3 Disaster Management

Disaster Management is skilful handling of crisis, danger or an unexpected situation demanding instant action which can be handled under a controlled situation in case of a juncture. Disaster Management is a widely used approach at all levels of government to deal with the inevitability of natural hazards and their potential to cause damage in a given community. Disaster Management activities can be grouped into five phases: Planning, Mitigation, Preparedness, Response, Recovery (Short-term Recovery, Long-term Recovery)

1.4 Factors Affecting Disaster Management in Mumbai

One of the challenges considered for the effective and efficient implementation of Disaster Management is access to and usage of reliable, accurate and up-to-date spatial information for Disaster Management. Research Investigation revealed that the Disaster Management activities were carried out in isolation and no efforts were made to optimize the data or information for improved decision making. In the current study we have listed the factors affecting Disaster Management in Mumbai: lack of timely up-to-date information, lack of accurate Spatial Information describing the situation (available resource, access to roads, damaged areas, required resource and required responding operations), lack of sharing of information between involved parties, lack of synchronization between involved parties, highly dense populated areas. These factors resulted in Uncertainties at every stage decision, there by introducing Information errors. The Information errors resulted in the delay of emergency responders to make decisions, take actions and thus causing attrition of Property, Money and Lives.

1.5 Current Scenarios for Controlling

The current Crisis Management System used by Relief and Rehabilitation Department is the Arc View Software, developed by ESRI in the year 1998 [4]. The software was developed as a part of MERP (Maharashtra Earthquake Program) after the 1993 disastrous Latur Earthquake. The software is used only by state level Ministers and Government officials during the pre-monsoon preparedness meeting before the arrival of rains in Maharashtra. The software is implemented only at Control Room, Mantralaya.

1.6 Limitations of Arc View

The effective use of software suffers from the following drawbacks:
The software is a desktop solution which runs in isolation only at the control room. The links and objects are ill-defined. There is no search functions allowed to search in the database. The software is not net based and GPS enabled. The possibility to send information and results of analysis of these systems rapidly and efficiently to large number of users is missing. Thus currently there is no prognosis models for flood, dynamic level inquiries or warning systems integrated in this system. The software also has a limitation while handling heterogeneous data

1.7 Need for Mobile and Web Based Disaster Management Systems

There are essentially three parties that have spatial information needs in a Disaster Management arena. These include public sector authorities, such as emergency managers and government agencies, private citizens, and researchers. The disaster cycle can be divided into the temporal stages of before, during, and after a disaster. Using these two dimensions, a matrix can be defined where each cell represents a given party's spatial information requirements at each stage in the disaster cycle (Table 1). Each of the Disaster Management phases handles complex and diversified volumes of data and information which are also interdependent on one another. A significant challenge in Disaster Management is delivering the appropriate information to the proper party at the appropriate place and time in a useful form. "Useful form" in this context refers to the scale, accuracy, and detail of the delivered information. The information must be delivered in a timely manner in an appropriate form, where errors in the information may have serious consequences. The fact that the information must also be delivered in a timely manner puts unique demands on any system designed to deliver this information. It implies that there is a time window within which the information must be delivered to have value. The system needs to focus on acquisition and integrating of spatial information to meet the various needs of the parties listed in the Table 1 for the given time periods. There, hence, arises a need for an Integrated Communication and Information Network for Disaster Management that provides efficient & reliable exchange with real-time processing of relevant information. During a disaster the first things that goes off is the communication backbone because the existing infrastructure was destroyed or the event occurred in an area without infrastructure. It is important that the dynamic information should reach all the parties involved in the response and relief operations under difficult conditions.

Interested Parties	**Disaster Cycle**			
		Before	**During**	**After**
Public Sector(Emergency Responders, Government Agencies)		Risk Analysis, Disaster Simulation, Disaster Analysis, Disaster Planning		
Private Citizens			Evacuation Orders, Routing Information about the spatial extent of the disaster, Shelter Allocation	
Researcher				Process that leads to disaster, Route taken by evacuees, Effectiveness of Disaster Plan

Table 1. Spatial Information Needs

1.8 Objective of the Study

The main objective is to use real-time, strategically enhanced disaster management tool for effective and efficient implementation for Disaster Management and to help emergency responders to make decisions, take actions and to curtail the attrition. **The objective of the study is: to develop a conceptual web and mobile based Geo-Spatial data model for Flood Disaster Management in the form of Information and Control Systems.** This model will present the overall structure, concept and advantages of developing a Disaster Management System including the advantage of utilizing the Geo-Spatial data model. The main features of this data model are: Improved Efficiency, Accuracy & Productivity, Decision Support, building a Consistent and Reliable information base and managing resources.

2. GEO – SPATIAL DATA

2.1 Spatial and Geo-Spatial Data

Spatial data describes the locations of spatial features, which may be discrete or continuous. Geo-Spatial data represents real world objects (roads, land use, elevation) with digital data. To describe a road we refer to its location (i.e. where it is) and its characteristics (e.g., length, name, speed limit, and the direction). The location represents spatial data and the characteristics are attribute data. There are two methods used to store data in a GIS for both abstractions: Raster (Fig. 1) and Vector (Fig. 2).

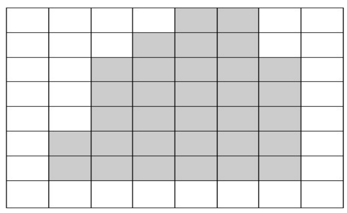

Figure.1 Raster Data Format

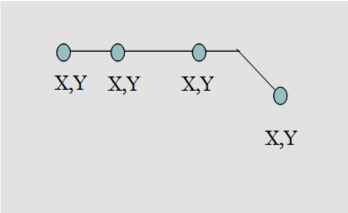

Figure. 2 Vector Data Format

2.2 Collection of Geo – Spatial Data

Geo-Spatial data can be obtained from Satellite images, field data i.e. survey data and global positioning system (GPS) data, a text file that contains x, y-coordinates and by scanning method that converts an analog map into a scanned file. The spatial data required for the current study was prepared by the researcher referring to the Landuse/Settelemt map of Mumbai D ward [5], the Mumbai Island City Disaster Management Plan [6] and literature and other maps on various themes of the area.

2.3 Mathematical Elements of Geo – Spatial Data

The Mumbai Island City Disaster Management Plan on 1: 25,000 scales has been transformed into soft copy using scanning technique. The map being on the scale of 1: 25,000 the minutes details missing, were plotted referring to the satellite map and other Land Use Map/Settlement Map of D Ward. The Real world entities from the map are abstracted into three basic shapes: Buildings, Emergency Units and Intersection Point of the roads are identified as nodes. The streets are identified as lines and the areas as polygon. The roads are a combination of multiple arcs. Each arc has a start node and an end node. Each node has been assigned a unique id and the coordinates for each node id is obtained using the graph theory.

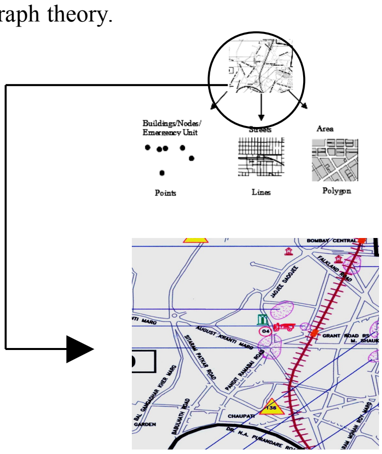

Figure. 3 Topological Features and Map of Study Area in Mumbai D Ward

The spatial relationships between features as points, lines and areas are then expressed using Topology (Fig. 3). Adjacency Matrix, Incidence Matrix, Coverage data structure is prepared using Topology. Adjacency Matrix is prepared to refer to the number of arcs joining each node. Incidence Matrix refers to the arc that is incident from or to a node. Using the information of Adjacency Matrix and Incidence Matrix the coverage data structure is prepared. The coverage model incorporates the topological relationships into the structure of feature data. The coverage data model is prepared for the Points and Lines in the study area from the digitized map and the satellite map. To make the digitized map usable it is converted into a projected coordinate system. Affine transformations are used to implement the following geometric transformations:

$$X = Ax + By + C,\ Y = Dx + Ey + F \qquad (1)$$

where x, y are the input coordinates (Fig 4, 5) and X, Y are the new User Projected Values respectively (Fig. 6).
The transformations coefficient A, B, C, D, E, and F are calculated using the following matrix equation:

$$\begin{pmatrix} n & \sum x & \sum y \\ \sum x & \sum x^2 & \sum xy \\ \sum y & \sum xy & \sum y^2 \end{pmatrix} \begin{pmatrix} \sum X & \sum Y \\ \sum xX & \sum xY \\ \sum yX & \sum yY \end{pmatrix} = \begin{pmatrix} C & F \\ A & D \\ B & E \end{pmatrix} \qquad (2)$$

where n is the number of control points. Substituting the values of n, $\sum x$, $\sum y$, $\sum x^2$, $\sum xy$, $\sum y^2$, $\sum X$, $\sum Y$, $\sum xX$, $\sum yY$, $\sum yX$, $\sum yY$ in the Equation (2) the values of transformation coefficient A, B, C, D, E, F are obtained. The values of A, B, C, D, E, F, x, y are substituted in Equation (1) and the new user coordinates X and Y are obtained (Fig. 6). They represent the actual coordinates for each node. The deviations between the computed X and Y coordinates values and the initial x, y values are calculated using root mean square error method.
The average RMS error can be computed by averaging errors from all control points:

$$\{[\sum_{i=1}^{n} (x_{act,i} - x_{est,i})^2 + \sum_{i=1}^{n} (y_{act,i} - y_{est,i})^2]^{1/2}\} / n \qquad (3)$$

where n is the number of control points, $x_{act,i}$ and $y_{act,i}$ are the x and y values of the actual location of control point i, and $x_{est,i}$ and $y_{est,i}$ are the x and y values of the estimated location of the control point i. The average RMS error in the present study is 2.379121. Since the average RMS error is < 6 the values of X, Y were acceptable.

2.4 Geo-Spatial Maps

Maps provide interfaces to Geo-Spatial system. Maps are viewed, queries are fired and analyzed. Maps are plotted to examine the results of queries and analysis.

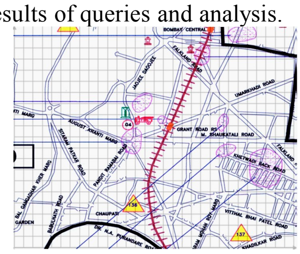

Figure. 4 Actual Coordinates

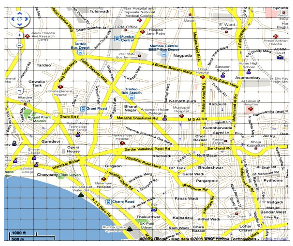

Figure. 5 Real Coordinates

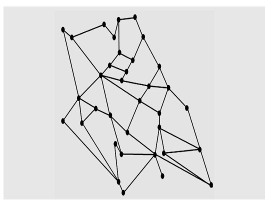

Figure. 6 User Projected Coordinates

Maps are also plotted for presentation and reports. In the present study the researcher has created General Reference Maps as well as Thematic Maps to represent spatial features: Flood Hazard Map of the Study Area (Fig. 7), Flood Risk Zone map of the Study Area (Fig. 8), Infrastructure Information of the Study Area, Shortest Path Analysis using applets

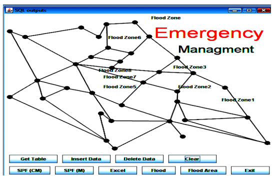

Figure. 7 User Interface

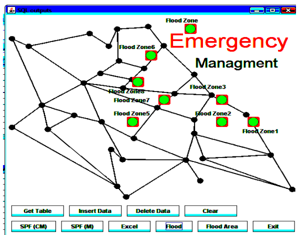

Figure. 8 Flood Zones in Study Area

3. MOBILE AND WEB BASED GIS ENABLED SOFTWARE

3.1 Need and Justification for New Software

To address disasters in a fast and highly coordinated manner, the optimal provision of information concerning the situation forms the basic needs. The current "Software Arc View" Disaster Management System is centralized at the control room with some fixed set of instructions. This results in poor resource management and hence causes inefficiency. Hence, there is a need of a new dynamic GIS enabled Geo-Spatial solution for Disaster Management.

3.2 Embedding Geo-spatial Solutions with Wireless Mobile Network and its Advantages

Geo-spatial information systems are valuable and powerful tools for collection, management and analysis of flood-relevant geo information. The Disaster Management Information System is developed using JAVA, PHP and MySQL which are platform independent.

3.2.1 S^{2}GIS: The Mumbai Metropolitan region, with its high population density, gently undulating region, with several low elevation patches requires such a system that will provide dynamic information regarding location of affected areas during rains, the next location of flooding areas, location of Disaster Management team and provide guidance to the Disaster Management team in identifying which route to take to reach the effected areas. With respect to the above mentioned environment, research study in Mumbai has been designed and conducted with an aim to develop a system based on Spatial Data Infrastructure through which access to and usage of data/information and consequently Disaster response/ Management can be facilitated. The important output of this research is: A conceptual SDI model to facilitate the development of an infrastructure for Disaster Management and a Disaster Management System for data sharing and data analysis using SDI model.S^{2}GIS is application developed using JAVA, J2EE, HTML, and PHP programming language. This Solution is developed to address the role of Spatial Data Infrastructure as a framework for Disaster Management. To date S^{2}GIS facilitates all the Disaster Management activities based on data/information sharing and analysis for decision-making, coordination, command and control has been developed.

3.2.2 Potential Areas for S^{2}GIS: We found the following main scenarios where we can apply the S^{2}GIS based Disaster Management Systems for floods:
Prevention and Information -
Awareness of potential risks through floods needs to be strengthened in order to minimize future impact. So danger areas need to be clearly identifiable for citizens.
Flood and Crisis Management -
In case of crisis, Disaster Management team and citizens not only need to receive information, but need also information and planning platform.
Flood Warning-
Flood Information System need to issue warning to the citizens indicating the environmental conditions

3.3 Facilitation of Disaster Management with S^{2}GIS

S^{2}GIS is an initiative intended to create an environment that will enable easy access, retrieve and disseminate spatial data and information in an easy way. It is designed to assess risks to human life and property, assist response during a disaster, discover and recover from the damage, manage ongoing hazardous conditions, plan and mitigate for future hazards, and impact policy and decision making. It will also help us understand the future geographic information challenges for this application area. S^{2}GIS is an appropriate information infrastructure framework for bringing the Disaster Management components together and facilitating decision making in Disaster Management

The main features of S^{2}GIS are:
1) Integration of Data from Multiple Sources
The System compiles data from multiple sources such as Satellite, GPS, Scanners, Text File thereby facilitating analyses of spatial data and dynamic decision making
2) A closer Look of the High Hazard Zone (Disaster Planning):
The regional hazard map is not capable of revealing the hazard scenario in adequate detail. A detailed large scale hazard mapping is suitable and effective in dealing with maximum risk zone. For detailed analysis and planning a high scale map of the study area is prepared by intersecting the land use/settlement maps with the inundation maps listing the chronic flood sites and the different things in the community that can be at risk. Geo-Spatial data can be easily successfully integrated in JAVA environment for retrieving near-real time flood level information. It can change the existing perspective of flood preparedness and mitigation substantially and render information for better decision making for saving lives of people.
3) Flood Mitigation:
Flood mitigation cannot be completely avoided, but damages from severe flooding can be reduced if effective flood prevention scheme is implemented. Using Overlay Analysis the developments within the primary impact zone are identified.
4) Flood Preparedness:
In the preparedness phase, governments, organizations, and individuals develop plans to save lives and minimize disaster damage. In the current study an attempt has been made provide detailed information about the emergency units in the D ward and the required emergency and paramedical units
5) Providing Information for Emergency Response:

Activities following an emergency or disaster are called as response activities. These activities are designed to provide emergency assistance for victims. In the current study an attempt has been made to facilitate the Emergency Response activities by providing the best route and closest facility required at the time of emergencies.

6) Finding Best Route:

Best Route means different alternate route in different situations. For example, while people are affected under disaster, they need to be rescued by any means. So the selection of the quickest route to the emergency site, hospital or shelter is very important at that moment. The network analysis was engaged to calculate the shortest way to reach in term of time and distance. The network analysis in the current study supports different objectives such as travelling quickly and travelling by the shortest route. The cost field can be in any units of distance or travel time such as minutes or hours. If we are finding a route that minimizes travel time, or meters we are finding a route that minimizes travel distance. In the current study the shortest path in terms of time in minutes as well as distance in meters is calculated using Dijkstra's Algorithm

7) Closest Facility:

Closest Facility refers to anything providing a certain types of service that is closets to a given location. The flood zone and settlement map are intersected to identify the closet facilities such as hospitals and shelter.

8) Quick Information Portal:

Response activities can also be facilitated if the emergency responder staffs get appropriate estimated information about the damage caused before arriving to the disaster location. In the current study an attempt has been made to provide this information to the emergency responders by executing queries to the database.

4. S^2GIS AT WORK

4.1 Requirements and Architecture

Geographical Information systems require the following four components to work with Geo-Spatial data: Computer System, GIS Software, People, Data, and Infrastructure. S^2GIS to be mapped on to the identified scenarios needs to be supported by some basic requirements and general system architecture. As there are no standard solutions regarding the integration of heterogeneous data and services, the system needs to remain open for further extension (functional, regional, technical). Component based architecture is necessary to realize the identified scenarios. A GIS based Disaster Management System for floods needs to be realized on the basis of a Geo-Spatial infrastructure. Based on that we identified the following top requirements with respect to Disaster Management Systems: maximum robustness/high scalability, handling of Geo-Spatial on each PC, Integration of external data and simulation models, support for heterogeneous terminals

4.2 Technology

For this research scanning technique is used for digitization of Mumbai Island City Disaster Management plan. Open Source map server of the Google is used to obtain the Satellite map in order to determine the real world coordinates. In the current prototype the flood information interactive vector maps are plotted using JAVA and PHP. The datasets for everyday business are created using MySQL Database contains attributes of the spatial objects required to facilitate Disaster Management. A web server is used to host the Disaster Management Application. Mobile phones, equivalent labtops, PDA's, palmtops and GPS devices are used for dynamic data collection and providing real-time information.

4.3 Software Customization

The model was customized to make it user friendly, interactive using JAVA, HTML and PHP. User friendly graphics and symbols have been used where ever necessary. The project windows contain View, Tables and Command Buttons. New data can be added in the tables. Dynamic queries can also be executed by the user. The methodology and the database have been customized for user friendly interface and easy implementation.

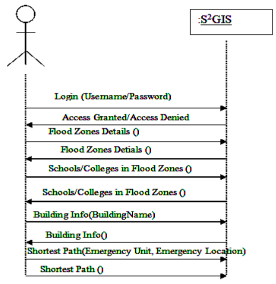

Figure. 9 System Overview

4.4 S2GIS Disaster Management- Mumbai D Ward

During the floods of 2005 a need of a system that would provide updates of the spatial extent of the disaster very rapidly to all the interested parties was felt. The Land Use map/Settlement map of D ward was analyzed to identify all the important things in the community. Using Overlay Technique the Flood map of the area was intersected with the Settlement map to identify the important things in the study area that could be at risk from flood. The spatial data is also linked with a tabular data storing its attribute to provide information required at the time of emergency. Data sets are created storing the information about all the schools and colleges in the study area, different buildings and information about each building in the study area. Attempt is also made to calculate the shortest path emergency responders located at Fire Brigade Station should to take to reach the emergency site.

5. CONCLUSIONS

Spatial Information and Information Communication Technologies are the important elements in Disaster Management which has been well-known worldwide. It is with this purpose, the paper first addressed the role of SDI (Spatial Data Infrastructure) as a framework for facilitating Disaster Management. Then the results of our ongoing research project in developing an SDI Model for Disaster Management in Mumbai are summarized. This includes the design and development of a S^2GIS Disaster Management System which facilitates sharing, accessing and use of data in Disaster Management. Through the combination of dynamic S^2GIS with Disaster Management a new quality within the range of the flood information systems is reached. With the use of S^2GIS it is possible to achieve improved efficiency, intensified integration with other IT systems. It has been proved that the design and implementation of a Web and mobile based SDI model as a framework and consideration of SDI development factors and issues can assist the Disaster Management agencies at all the levels of Disaster Management activities. The result of such quality decision-making in Disaster Management then can directly contribute to the sustainable development of the jurisdiction/community in terms of social, economical and environmental development. With the presented map based flood information systems we illuminate the potential of Geo-Spatial based Open Source Information Systems and improve the availability of flood prognosis information for both the population and rescue team.

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