Using Geographical Information System to Estimate Vulnerable Urban Settlements for Flood Hazard and Risk Assessment in City

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Abstract

The rate of urbanization in recent years is astounding. About 50 years ago, only three out of ten people in the world lived in cities. Most of these were in the development countries. Now about 50% of the world population lives in cities, and by 2020 it is expected that six out of ten people will live in cities. Most of the new growth is in the less developed and least developed countries. For the first time in world history, more people now live in cities than in villages (UN Population Division). This fact indicates that population growth tends to occur in urban areas. The growth of highly concentrated urban areas has crucial implication for the vulnerability of the cities and their residents. Disaster do not of course specifically target cities, but they will have much greater impact on human life and property when they will have much rather than the fairly disperse and less populated rural areas.

This paper seeks to demonstrate a method to more accurately estimated urban settlements vulnerable to hazard by using suitable indicators for identifying vulnerability to flooding, especially in densely developed cities, and to characterize at-risk populations based on measures social, physical, and environment vulnerability. We discuss two methods that employ Geographical Information science to access and quantify risk and vulnerability and Flood hazard analysis method to understand the likeliflood of flood occurences. The two methods will show the vulnerability of the city due to flood hazards.

This methods can serve as a model to helps other municipalities to estimate vulnerability to hazards, tailored to the specific conditions and characteristics of their locales. While this paper focused on the flood threat, the models can estimate vulnerability and exposure to other types of hazards such as earthquake, extreme weather events, and technological disasters.

1. Introduction

Flood are among the most damaging of natural hazards, and are likely to become more frequent, more prevalent and most serious in the future due to the effects of climate change and urbanization. The nature of occurrence of flood is governed by diverse factors, including rainfall characteristics, properties of drainage catchment and land water use and management in the catchment. Urbanization in flood hazard zones creates a challenge as urban areas accommodate higher concentration of people, building and infrastructure. Despite increasing flood risk awareness, human settlements continue to develop in flood prone areas due to the need for land, and poverty (Gupta 1994). These conditions reflect reality for urban poor who are faced with little option other than to illegally occupy public land or purchase affordable land in hazard zones.

Recognition of the increased vulnerability of people and infrastructure to the threat of flood loss in the city stimulated the need for robust assessment of risks in flood-exposed settlements, and the complexity of the problem called for the application and adaptation of contemporary Geo-Information Technologies (GIT).

A river flood hazard results from a water level that overtop the banks-natural or artificial-of a river and threatens human life and property. For a hydrologist, flood magnitude is best expressed in terms of instantaneous peak river flow(discharge) whilst the hazard potential will relate more to the maximum hight (stage) that the water reaches. The primary causes of floods mainly resulting from widespread climatological forces, and secondary flood-intesifying conditions that are more drainager basin-specific. It is also possible to relate the physical causes of floods to other environmental hazard.

Flood losses have greatly increased over the years due to land use change, urbanization of flood-prone areas, sub-standard construction, and high population density. Cities are more affected by flood than rural areas due to high population densities and concentration of economic activities. Urban floods are intensified by impermeable surface runoff concentration, and by building that obstruct water flow. Four types of urban flood: 1. Localized-occur s many times a year especially due to increased runoff and poor drainage conditions; 2. Small stream- water rises quickly with highflows that exceed drainage capacity if channels are not regularly maintained; 3. River- results from upstream land usechange and engineering works when dams and levees break, leading to sudden flooding downstream; 4. Seasonal- when rain and river water combine to elevate water level at certain time of the year. Urban areas in developing countries are at greater risk due to high population growth and rapid urbanization caused by rural to urban migration. Large numbers of urban immigrants find themselves in fragile economic circumstances, which lead to the creation/expansion of informal settlements in high risk zones (Bizimana and Schiling,2010).

Urbanization contribute to severe flooding. Paved areas and storm sewers increase the amount and rate of surface runoff of water. This is due the inhibiting infiltration of rain water into the ground and their rapid delivery of the resulting increase runoff to the channels, making river levels higher during storms. Such rapid increases in runoff or discharge to a river are called flashy discharge. Storm sewer are usually designed for a 100-year storm; however, large storm that drop a lot of rain in a short period of time may overwhelm sewer system and cause localized flooding. Rising river levels may block storm sewer outlets and add to localized flooding problems.

Quantification of economic impact, vulnerability and flood and other natural hazards is vital in determining potential economic impact, vulnerability and flood management policies. Increased risk as a result of climate change combine with rapid urbanization urge for further insight into the volume and distribution of economic losses. Since modern economies are characterized by widespread set of interdependent activities, the estimation of indirect hazard impact, e.g flood impact, become more urgent than ever. An illustration is the interuption of lifeline utilities and infrastructure, which could potentially lead to widespread economic and social repercussions due to the damage to critical links within their networks. The same can be said for business interruption of production facilities that provide vitalgoods and services. Insight on the higher-order effects caused by local disruptions is essential for estimating impact and adjusting policies to decrease vulnerability.

Various surveys have been conducted to determine the importance of geographical data by assessing the proportion of all data that are geographical. In local government bodies and in utility companiesthe proportion is often 80%; in mapping agencies it may very close to 100%. These suvey has also shown that the major users of geographical data –data costruction sector, public administration, agriculture, forestry and other resource management, telecommunication, electricity supply transportation spend 1,5 % to 2 % of their annual budgets. In aquiring geographical data . The major challenges to system developers and user today are the ease of use of the technology, the problem finding and accessing suitable data, and the lack of trained personnel able to exploit the technology’s potential to its full.

2. Conceptual Frame and Analytical Frame

2.1 Analytical Components of flood risk analysis

The key concept underpinning this research are flood hazard, flood exposure, flood vulnerability and flood risk. The flood hazard denotes the probability and severity of occurencesof a flood of a certain magnitude (Alkema, 2003). The flood exposure refers to the extent to which property, building, economic activities, infrastructure and population are located in relationship to a flood hazard. Flood vulnerability encompasses physical, social, economic and environmental factors which increase susceptibility to the flood hazard (UN/ISDR 2004a). Flood risk represents expected loss or damage to property, loss of human life, and interruption of economic activity. Flood risk depends on flood hazard, exposure and vulnerability. For example, if buildings are located in a flood plain, both hazard and exposure are present, but if the buildings are perfectly resistant to floods, vulnerability is absent, so there is no flood risk.

2.2 Flood Hazard Identification and Mapping

Flood hazard identification involves the process of describing the hazard in its local context and provides a description and historical background of potential environmental hazards that could impact the community.Flood Hazard represents the probability of occurence at a certain level of severity. Flood severity is characterized by water level, flood duration and flood frequency (Alkema 2003; Barroca et al. 2006). Other authors add to the definition warning time, the rate at which the water rises, accessibility to flooded areas, and level of development to characterize

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flood hazards (New South Wales 2005). limited spatial and temporal coverage due to the lack of ground receiving stations, similarly, the Disaster Management Programme of the United Nations Commissionfor Human Settlement has recommended consideration ofthe following indicators: flood rate, load sediments, volume of water. duration and area affected (UNCHS-Habitat 2001). As can be seen by the above, one approach to flood analysis is largely based on physical characteristics (depth, duration, velocity, frequency. extent, flood size, and load sediments), and another approach on response variables (warning time, readiness, rate of rise and access). This research emphasizes the physical characteristics with a focus on measurable indicators such as flood depth, frequency, and duration.

When a Flood hazard is identified, the next step may be flood mapping. This step identifies and displays the spatial variation and extent of the flood. To fulfill this step, one approach is based on historical records of flood characteristics where flood depth is the main indicator (Islam and Sado 2002).

The flood extent map defines how far a given water level will locally extend. Based on flood level, different methodologies have been developed to generate flood extent maps. MacKinnon (2004) derived flood extent from a digital elevation model (DEM) by separating pixel values into areas below and above the high flood level, thereby delineating areas that would or would not be Flood ed. To assess potential flood damage, flood depth and extent were modeled by giving pixels at water level values of zero to enable pixels below water level to have positive values depending on their "depth". Then, using the flood extent map, the flood depth raster map was clipped to display flood depth values solely within the extent of the flood (MacKinnon 2004). Tennakoon (2004) reclassitied the Flood depth pixel values into different Flood hazard zones. with 0.8 and I.2 m representing the upper limits of low and medium flood , respectively. The present research is based on MacKinnon‘s and Tennakoorfs approach.While spatial extent and flood depth are commonly used for Flood mapping, it is also quite useful to integrate flood duration and velocity (Tennakoon 2004) to help evaluate flood severity. However, duration has not been integrated into many flood hazard studies due to the data and expertise cost of its estimation (Tennakoon 2004), which requires hydrologic modeling. These constraints, as well as the lack of reliable hydrological records for the study area, preclude the use of flood duration data in this research. When there are no Flood records, remote sensing technology can be used to map flood ed areas if satellite images have been acquired during the flood 's peak). While estimating Flood depth from remote sensing images is very difficult, indirect methods based on the amount of energy reflected by water have been developed (Sanyal and Lu 2005). However, such estimates require advanced satellite image processing capability utilizing radar (e.g.Synthetic Aperture Radar). Although radar imagery can penetrate cloud cover, its use in developing countries is constrained by its high price and limited spatial and temporal coverage due to the lack of ground receiving stations.

2.3 Flood Exposure

Flood exposure is the extent to which properties, houses, economic activities and infrastructure are geographically situated in Flood -prone areas (Barroca et al. 2006; McEwen et al. 2002). Exposure relates the Flood plain, people's location and closeness to the area of inundation, and housing/property characteristics to one another. The relationship between flood exposure and vulnerability of exposed elements is directly proportional; as exposure increases, vulnerability increases. Accordingly, there is no vulnerability to flood ing where there is no Flood and there is no vulnerability if no elements are exposed. Flood exposure analysis identines Flood -prone areas and the elements within them that are exposed to flooding. The physical characteristics of the flood are ` examined and information about exposed elements (proximity to river, location in or closeness to flood plain) provided. In urban areas. elements at risk may include properties, buildings, infrastructure, population, environment, cultural assets and economic activities (Messner and Meyer 2006). To document exposure requires knowledge about the number of people, buildings, critical facilities and infrastruc ture (eg., roads, bridges), and land use types (eg., residential, commercial, industrial. agricultural) within Flood prone areas .

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2.4 Flood Vulnerability Assessment

There are three main approaches to assess flood vulnerability: physical, social context, and combined (or global). The physical approach focuses on human occupancy of Flood zones, degree of loss, flood characteristics, and flood impacts (Messner and Meyer 2006). This approach determines how exposed people, physical objects and activities may be affected (Davidson 1997). Physical vulnerability can be assessed through examining infrastructure, housing, economic activities, geographic location and population density. Exposed elements (e.g., residential houses, infrastructure,industrial or commercial activity, health services) have different degrees of vulnerability when located in the same flood -prone area (Barroca et al. 2006). Some mechanisms such as location of structures, structure types, their ability to resist flood damage, and tendency to flood can turn a mundane flood into disaster by increasing physical vulnerability to the flood (Blaikie et al. 1994). Social vulnerability approaches examine the social context of flood s as it relates to the coping response of communities (Messner and Meyer 2006). In this context, flood vulnerability analysis examines how well prepared and equipped a community is to avoid or cope with flood. Coping includes the adaptive capacity of a system or people to deal with floods or reduce flood risk

Another aspect relates to the knowledge of exposed people as is studied by examining awareness and perception. When aware of the flood risk, individuals or societies (are able to adapt. They may modify urban development plans or change building techniques (Barroca et al. 2006). Flood vulnerability can also be assessed by documenting the lack of ability or unwillingness of planning authorities to reduce the flood risk (Messner and Meyer 2006). The global approach combines the physical and social approaches by including physical, social, economic and environmental factors (UN/ISDR 200-4a). According to Barroca et al. (2006), this approach is gaining increasing significance in scientific research. This research sees Flood vulnerability as a combination of the characteristics and location of properties, buildings, housing, infrastructure, population, and economic activities in terms of their capacity to anticipate, cope with or resist floods. Identifying the strengths and weaknesses of the exposed elements and relevant stakeholders allows decision makers to effectively allocate limited resources to prevent or mitigate the effects of the floods (UN-Habitat and UNEP . 2001). '

2.5 Flood Risk Indicators

Following the above description of the main aspects in flood risk analysis, the analytical framework and the associated indicators for this urban flood research is presented in this paper. This framework considers three main components of flood risks and corresponding indicators. If data are locally available, they can help identify flood -prone areas, determine exposed elements. and analyze vulnerability to flood ing. Unfortunately, reliable, timely data are difficult to obtain in developing countries; in some cases, the information may be known but not adequately communicated to, or perceived by decision makers who seek to formulated flood risk reduction strategies. In this duty, GIT is utilized as of data most a are spatial in nature. Using GIS and remote sensing to identify and help vizualize flood risks can improve understanding and therefore help reudce the impact of flooding.

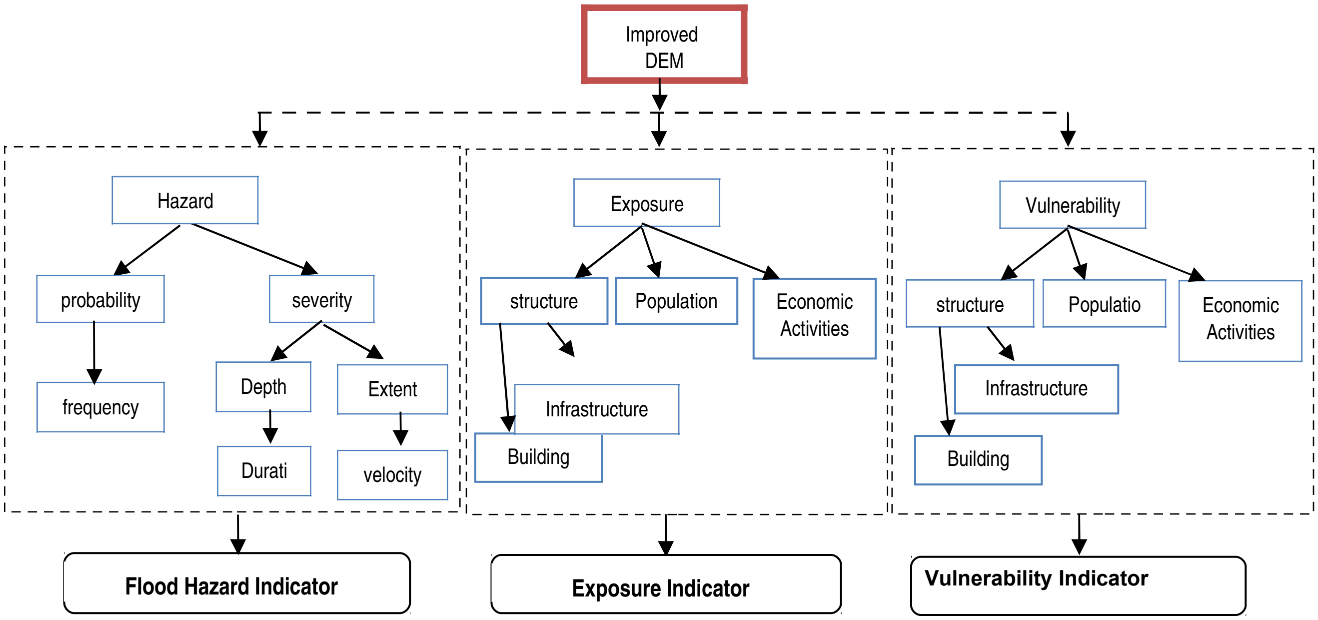

Fig.1 Flowchart of flood indicators

3. Analytical Methods

3.1 Data Collection and Data Analysis

This analysis will be guided by secondary data and primary data. Secondary spatial datasets consist of Quickbird multispectral satellite image of City with a resolution of 0,60 cm, existing spatial datasets (boundaries, roads network, contour line, drainage), meteorological data linked to the weather station. The recent version of population, social, economic statistical data of City.

Primary data consist of field observations, photography, interviews with urban planning authorities at sector, district and city levels and a household survey (including GPS location data of housing unit). The survey sample is selected within flood prone area in City. Sampling is based on proximity to the flood-prone area, experience with flood, and occupation by infrastructure, properties, housing or settlements. In collaboration with community leaders, flood ed areas are delineated using the quickbird sattelite image aided by local knowledge about flood extent in the study area. To generate building footprints and other critical land uses in the study area, the quickbird image is georeferenced and digitized on a computer screen using GIS software.

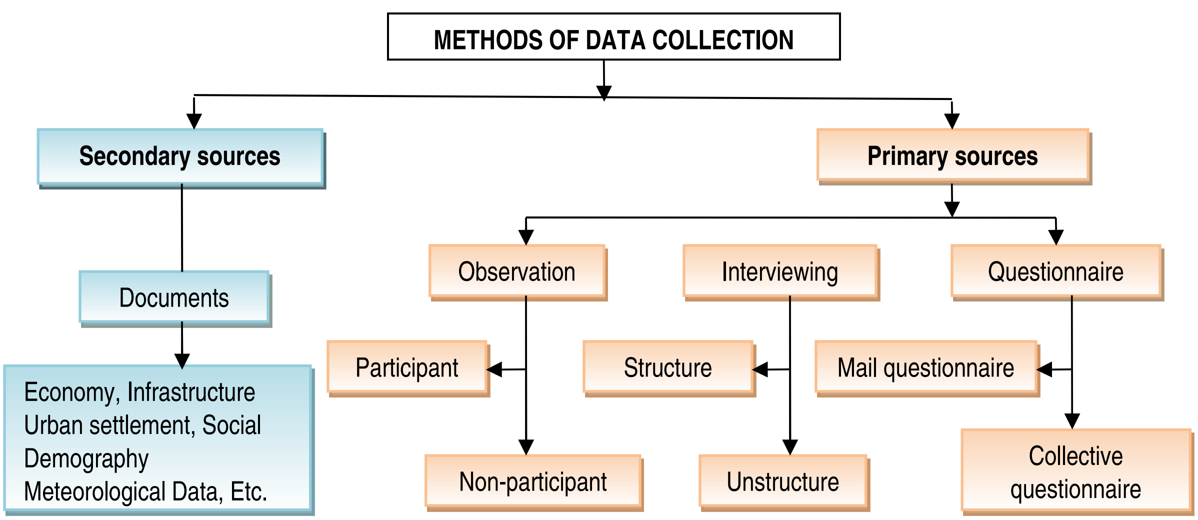

Fig. 2 Flowchart of data collection

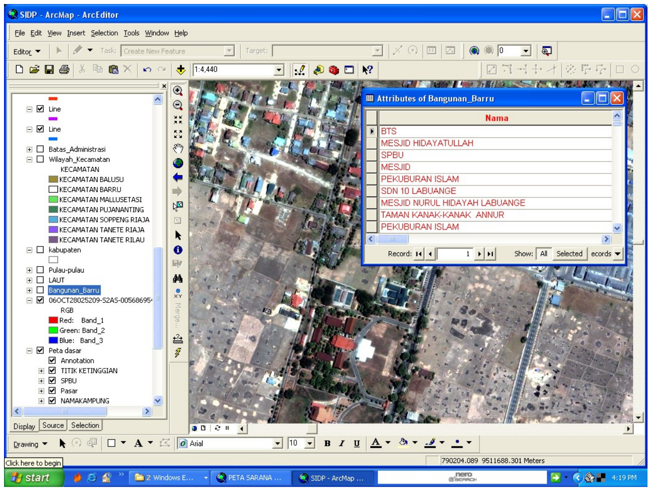

Fig.3 Vector data of Quickbird Satellite Imagery

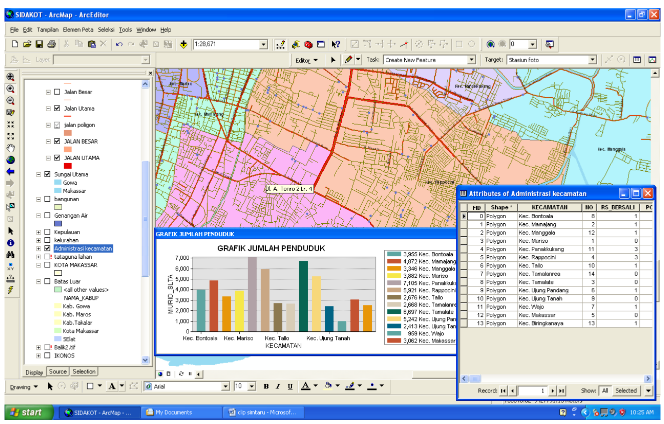

Fig.4 Statistical map of population, infrastructure, social and economy

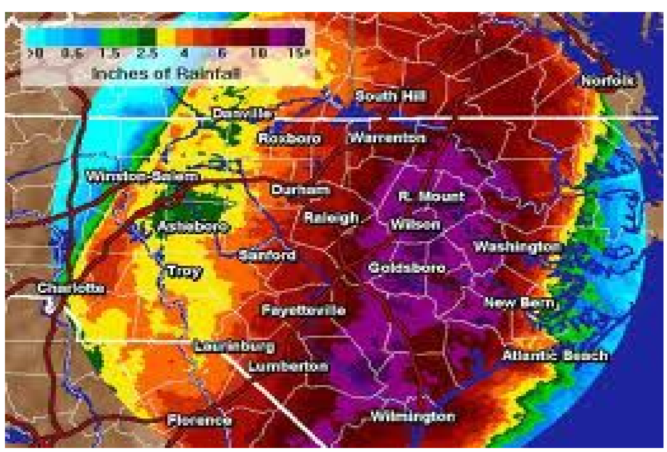

Fig.5 Sample of Rainfall data

3.2 Flood Hazard-Prone Analysis

The flood hazard consist of probability and severity. Flood severity assessed using flood depth and flood extent. The input data are contour lines, the Quicbird image and flood depth information from the household surveys. The flood hazard map is going to generate through the delineation of the flood plain extent using information from local experts at the district level, Digital Elevation Model (DEM) quality improvement, extraction of elevation information at the houses (point location of flood depth), subdivision of the study area in to two zones, flood depth interpolation and flood depth mapping base on average house elevation in each zone. The data uses for flood extent mapping are obtained from official interviews at the settlements in flood -prone area.

To identify the flood extent, the flood plain is delineate by local experts and digitize from the quickbird image. The flood depth from household surveys is estimated base on watermarks found on the houses with reference to the ground. To obtain data of flood depth, the observed flood depth at a house location is first aided to the corresponding elevation value from DEM; interpolation is then conduct to generate a flood depth surface. Figure below ilustrates the methodology used to generate flood map.

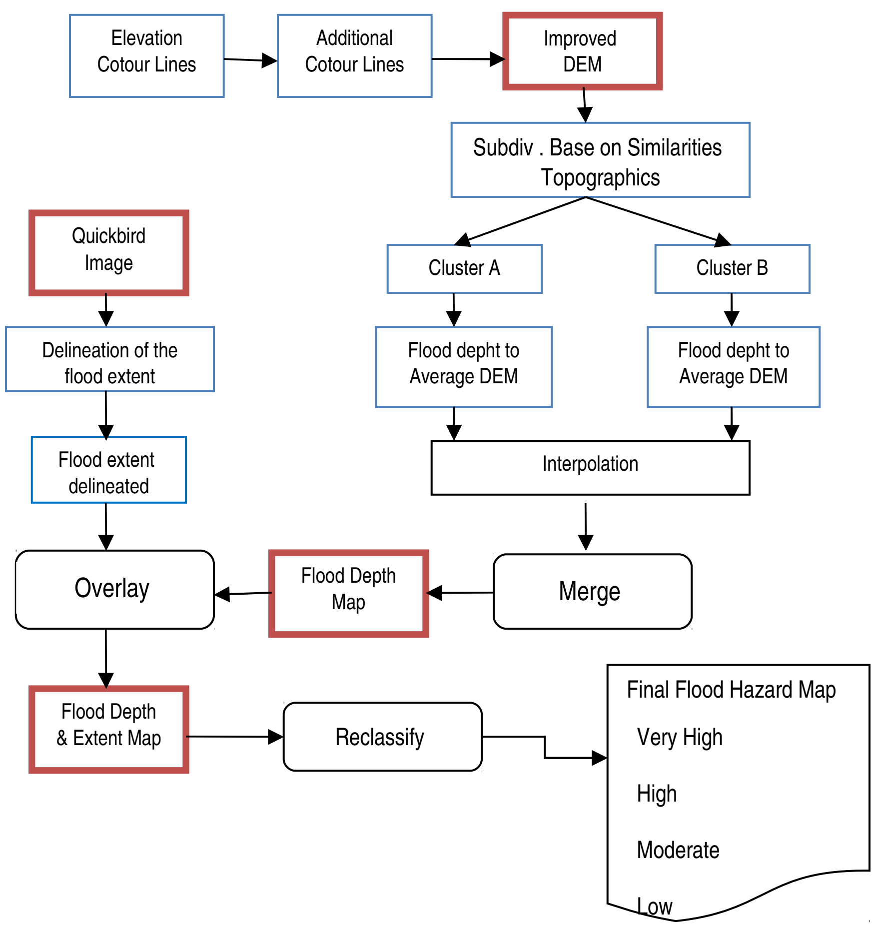

Fig.6 Flowchart process for flood hazard mapping

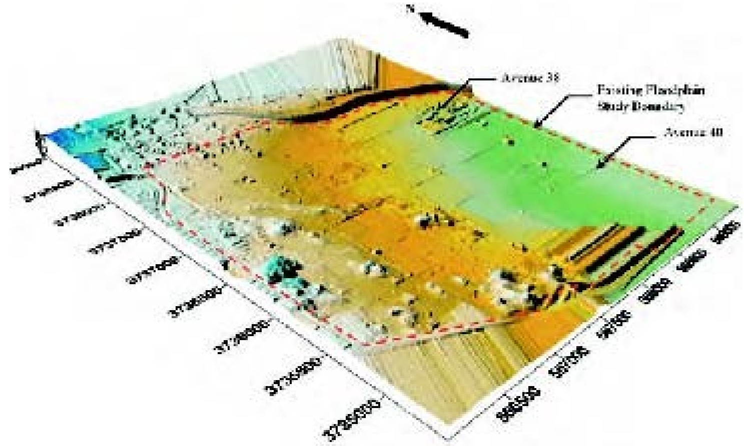

Fig.7 Digital Elevation Model (DEM) of city

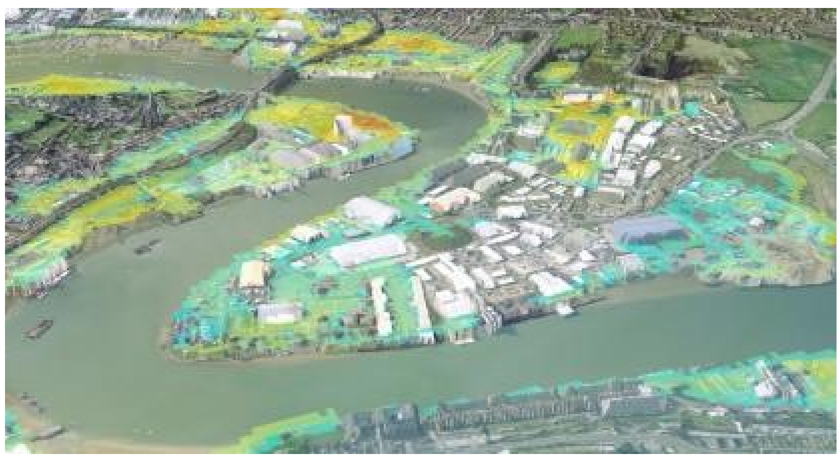

Fig.8 DEM of flood depth and extent map

3.3 Flood Risk Analysis

Information about settlement elements at risk (e.g., building, roads, bridges, water suply, population, economic activities) is overlaid on the flood zone. The analysis focus on those parts of the physical infrastructures considered important by local authorities at the district and sector levels. Bridges and water supply lines are visited and located using GPS during field observation, while road is digitized from the Quickbird image. Subsequently,population, houses, the roads, bridges, water supply lines, and buildings are overlaid on the flood hazard zone map for exposure analysis.

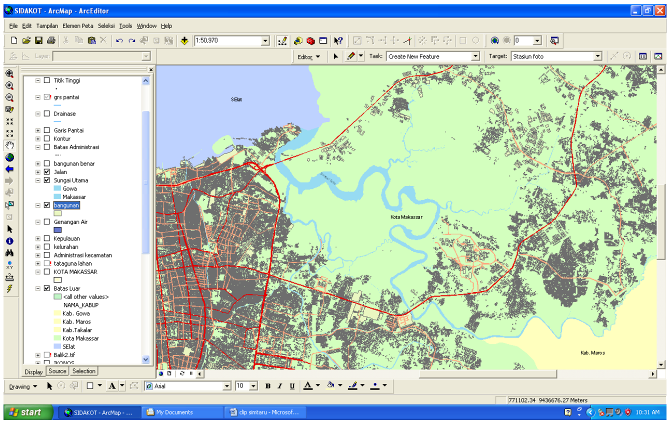

Fig.9. City Map with Building and Infrastructure

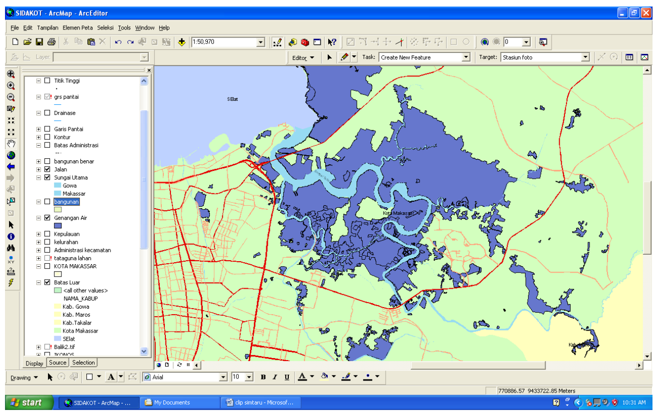

Fig. 10 Flood Map

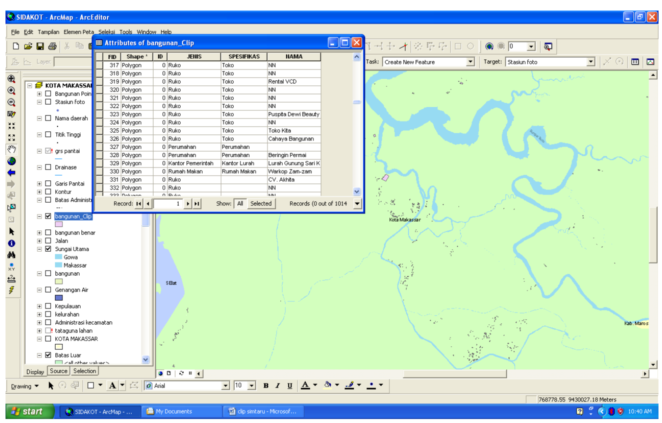

Fig.11 Flood Risk and vulnerability result

Fig.12 Flood Risk and vulnerability 3D model

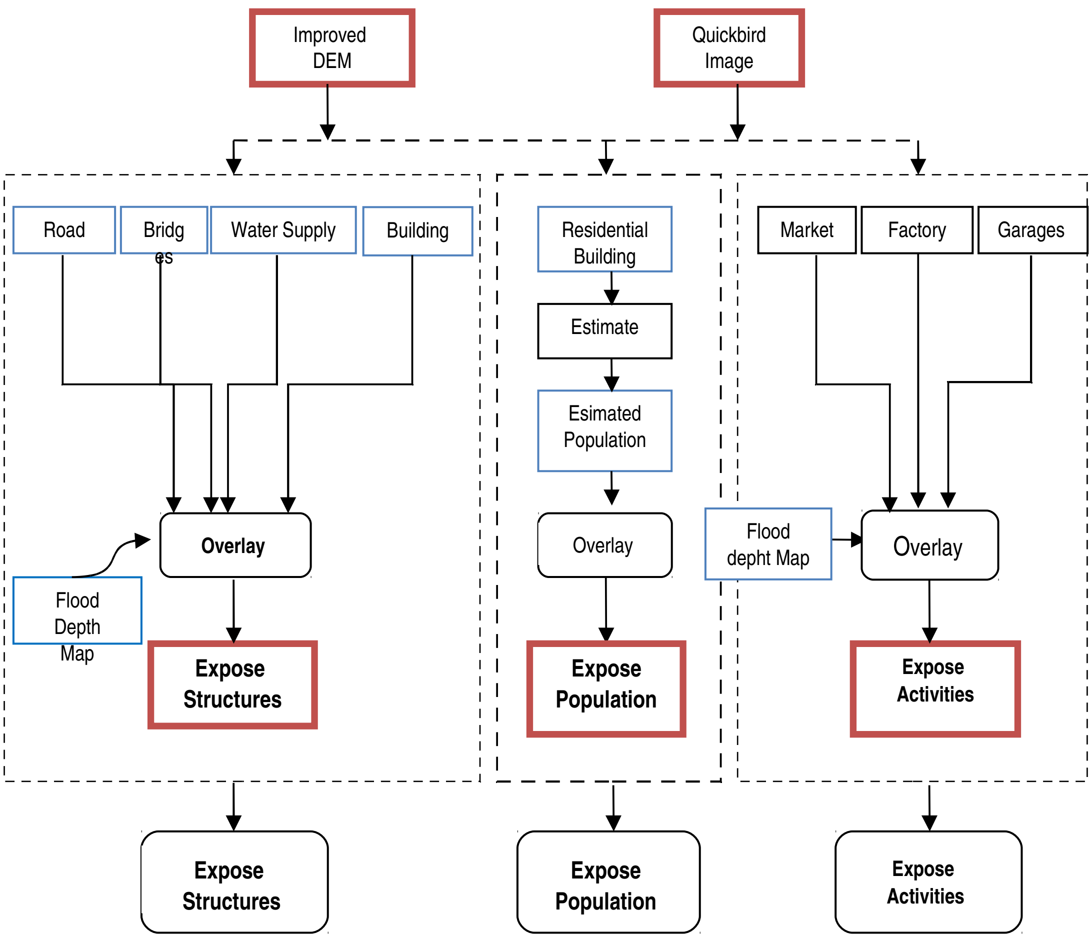

Fig. 13. Flowchart of City risk and vulnerability analysis

3.4 Data Quality Control

All data are processed (transformed, etc.) and analyzed several times. Ideally , therefore, each process should be subject to quality control. A few simple general rules will be done which may help to reduce the problems of inaccurasi :

- Employ verification routines to ensure quality
- Verify data as early as possible
- Verify data at several stages of their manipulation
- Know the nature of the data, be it geometry data or attribute data
- Be critical in all data uses
- Apply processing result carefully
- State inaccuracies associated with results and analyses

4. Conclusion

1. GIT can be used as a tool to locate household and calibrate the flood depth by interpolation and delineate the flood extent.

2. The usefulness of GIT for flood risk analysis is determined by the availability of base data (e.g. topographic information). Very high resolution satellite imagery combine with GPS field survey data can be utilized for delineating flood plain and analyzing flood risk for properties and infrastructure in a developing –world urban setting when other data are not readily available.

3. The Concept performed in this paper indicates a direct correlation between risk of flooding an adequate planning and control.

4. Ultimately, this paper highlights the needs to further explore the potential of GIT to assist urban planners and decision makers with formulating appropriate planning and policy strategies in order to limit flood losses.

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