Geographic Information System for Flood Management in Greater Colombo Area

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Abstract Nonstructural approach in flood management plays a major role in disaster management practice. This research paper focuses on flood management using GIS software which comes as a non-structural approach. Land use is essential ingredient in determining the flood plain area of the study area. Colombo as the highest populated city in Sri Lanka, there is a higher pressure on land for human settlement and related urban services. Increasing impervious area and reduction in retention areas due to rapid development has resulted in faster runoff. Thus, flooding has been one of the costliest disaster in terms of both property and human damage in this area. This research paper focuses on analyzing the changes in the land use in the area over the decade with the use of Arc GIS software. Hec-Hms software has been used for determining flood plain of the area flood risk map has been developed using the obtained results.

Keywords Catchment; DEM; Flood management; GIS; HEC-HMS

1. Introduction

There are two approaches in flood management practice such as structural approaches and nonstructural approaches. Structural approach can be defined as flood mitigation projects such as dams, detention ponds etc. Non-structural approach refers to flood forecasting, proper early warnings and conducting awareness programs among the flood affected community. Flood hazard mapping is considered as one of the priority tasks to be accomplished in disaster management practice since it is very effective in mitigating the impact of flooding compared to structural measures.

Flood management using GIS software which comes under non-structural approach has been initiated in this research. Application of GIS for mapping flood prone areas will make it easy to reduce the flood damages and risks involved. Such type of technologies can create accurate and current floodplain maps with improved efficiency, speed and public safety. GIS is ideally used for various floodplain management activities such as base mapping, topographic mapping, and post disaster verification of mapped floodplain extent and depths. GIS is useful in capturing and communicating a vast amount of information about the study area (Briviot et al., 2002).

The study area of the project, greater Colombo covers Colombo city which is the largest commercial city in the country and the area of four surrounding local authorities. Greater Colombo area has a total
extent of 104 km² and population of 1.2 million. This area has been vulnerable to flooding as most of
the area consists of low lying lands which is less than 6m above the sea level and some areas are
even less than 1m above the sea level. More paved areas and less open areas due to rapid
development has resulted in faster runoff. Citizens of this area have suffered from frequent floods
every year and their economic and social activities have often been interrupted. Therefore, there is a
necessity of such kind of flood management system.

In this case, Satellite images were used to obtain the land use patterns in greater Colombo area in
order to find the permeable and impermeable areas of the study area. Use of satellite images enables
to gather invisible information rather than traditional survey approach. Sub catchments of the study
area were obtained by analyzing the created DEM using hydrology tool (Sanyal et al., 2003). HEC-
HMS software has been used to identify the flood depth.

1.1. Objectives

Under this research it is required to fulfill few objectives. Main objective of this research is to analyse a
selected catchment and evaluate the risk of flood. In order to fulfill the main objective, there are few
sub objectives such as to create catchments for the study area using digital elevation model, compare
the land use patterns with the help of satellite images, and discuss the effect of land use patterns for
flooding.

2. Methodology

Following procedure was followed in this research to reach objectives. As the first step, literature
review was done to identify the methods which are available for preparing flood risk maps with the help
of Arc GIS software. Required procedure for the research could be determined through the literature
review.

5m DEM was created as by using elevation data which is received from the survey department. Then
the created DEM was used to obtain sub catchment with the help of Hydrology tool which comes
under spatial analyst tools in GIS software.

As an example, one sub catchment was selected to carry out analysing part in order to identify the
flood risk. Analyzing the land use patterns for the selected sub catchment were done by digitizing the
satellite images of study area(Samarasinghe et al., 2010). Effect of changing land use patterns and
percentage of impervious area in flooding has been analyzed by comparing 2000 land use map and
the 2010 land use map.

Finally, peak runoff and flood plain for the selected catchment were obtained by using hydrology
software (Chen et al., 2009). In this case, HEC-HMS software was used to analyse the catchment
using rainfall data. Variations of run-off flow due to changing the permeable area was modelled.

Flood plain was obtained through the HEC-HMS software and represented in the contour map in Arc
GIS. Similarly, the other catchments can also be analysed.
2.1. Data

Data Collection Source

Flood affecting areas were analysed by using 5m DEM which should have to be developed since the available 90m DEM was not accurate enough for the purpose. For this case, Elevation data were obtained from the Survey Department and developed the 5m DEM for the Colombo area.

Satellite images which were used to digitized the 2010 land use map. For this case, high resolution satellite images were used in order to identify the land use features. Those high resolution maps were provided through the supervisor by purchasing from Map mart. Google earth was used to verify the digitized map. 2000 land use map was created by converting created AutoCAD file to GIS file. That AutoCAD file was provided by Urban Development Authority, Colombo.

Collected Data

Elevation data required for creating 5m DEM were obtained from the Survey Department. Then, high resolution satellite images should have to be used for the purpose since it should consist of pixels smaller than 1m. Therefore 1: 150,000 scale, eleven satellite images which were taken in year 2010 were used for the purpose. Identified features were verified by using Google earth.

For the comparison of land use variations in the study area, obtained 2000 land use map was used. Land use in year 2000 was obtained through the Auto-CAD map. Addition to that, maximum limit of the impervious area was taken as 65% according to the Colombo municipal reports.

A design of rainfall hyetograph which was required to simulate the rainfall in the hydrology software was taken from the design reports of Metro Colombo Urban Development Project. 100mm/hr Rainfall with a 10 year return period was used for analysing.

Analysis

Analysis of the data was done by using ArcGIS tools and Hec-Hms software. As shown in the Figure 1, 5m DEM was created by giving elevation to 5m squares. A section from the initial DEM was taken to produce sub catchment by considering the easiness of analysis. Right side of the Figure shows the section of the DEM which was used for analysing.

As the first step, hydrology tools which comes under the spatial analysis tools in GIS were used to produce the subcatchments in the created digital elevation model. One of the sub catchments was selected to carry out further analysing steps.

Table 1: Elevation – Area data of the selected catchment

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>Area (1000 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.62</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>82.119</td>
</tr>
<tr>
<td>3</td>
<td>184.544</td>
</tr>
<tr>
<td>4</td>
<td>460.569</td>
</tr>
<tr>
<td>5</td>
<td>985.443</td>
</tr>
<tr>
<td>6</td>
<td>1875.293</td>
</tr>
<tr>
<td>7</td>
<td>2856.767</td>
</tr>
</tbody>
</table>
Sub catchment which belongs to Bambalapitiya and Kollupitiya area was delineated by using hydrology tools as shown in the Figure 2. After selecting the catchment, land use features were attached by clipping the total features in order to get total impervious area in the selected catchment and compare the land use patterns over a decade.

Characteristics of the selected catchment were used for calculating the runoff of the catchment by using HEC-HMS software. SCS curve method was used for the determination of flood peak flow. Area of the catchment was 3.58 km$^2$. SCS curve number was 86.5 by considering the conditions of the
selected area. SCS curve number and SCS unit hydrograph were taken as the loss method and transform method respectively.

Flood plain analysis was done in HEC-HMS software by assuming storage method as area elevation method. For that, area elevation data were obtained through the created DEM. Surface volume function in Arc GIS was used for the purpose and obtained the area elevation curve.

### Table 2: Land use variations over a decade

<table>
<thead>
<tr>
<th>Land use patterns</th>
<th>2000 %</th>
<th>2010 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>29.21%</td>
<td>40.44%</td>
</tr>
<tr>
<td>Roads</td>
<td>6.71%</td>
<td>8.26%</td>
</tr>
<tr>
<td>Water Bodies</td>
<td>3.29%</td>
<td>3.09%</td>
</tr>
<tr>
<td>Total impervious area</td>
<td>35.9%</td>
<td>48.7%</td>
</tr>
</tbody>
</table>

### Table 3: Peak discharges for different impervious areas

<table>
<thead>
<tr>
<th>Percentage of impervious area (%)</th>
<th>Direct runoff (m³/s)</th>
<th>Peak discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.92</td>
<td></td>
<td>60.9</td>
</tr>
<tr>
<td>48.7</td>
<td></td>
<td>62.8</td>
</tr>
<tr>
<td>65 (Maximum)</td>
<td></td>
<td>65.1</td>
</tr>
</tbody>
</table>

### 3. Results

According to the analysis of selected catchment, the land use variation and percentage over a decade can be shown in Table 2.

Percentages of impervious area which were obtained by digitizing were used for calculating the direct runoff of the catchment as shown in Table 3. Following Flood risk map (Figure 3) was obtained from analyzing the selected catchment in HEC-HMS software.
4. Discussion

According to the land use percentages obtained for the selected catchment, there is an increment in the area belongs to buildings and roads in year 2010 compared to year 2000. This can be totally due to urban expansion. When considering water bodies, the area of water bodies has been reduced due to the land fillings. Although there is no marshy lands in selected catchment, there is a significant reduction in marshy lands when considering the entire Colombo area. Satellite images which were taken in year 2000 and 2010 have to be used for digitizing since they were the most available images.

Percentage of impervious area was taken as the final outcome of digitizing the land use patterns. HEC-HMS software was used for determining the surface runoff and the flood plain elevation. Analyse of surface runoff was done by according to the SCS curve method since it has a limited data requirement and high practical applicability. SCS curve number was obtained by considering two elements such that soil type and antecedent soil moisture of the catchment.

In this case, Group C has been selected for the type of soil since the selected catchment is contained of soils high in clay. Type 3 has been selected as the antecedent moisture condition by considering the most critical condition which occurs at the high moisture content.

According to the results obtained from the surface runoff of the selected catchment, surface runoff has been increased when increasing the percentage of impervious area. This implies that flood risk has been increased with increment of land use for buildings and roads. Elevation of the peak flood was obtained by considering the maximum limit of impervious area (65%) since it is the most conservative approach.
There can be deviations between flood elevation obtained from the model and the actual situations. Since few assumptions have been made during the modeling such as SCS curve number, number of outlets, created DEM etc.

After identifying those areas as flood risk areas, we can manage land use to minimize flood damage to people and their properties also. And also drainage system can be modified such that minimize the flood risk.

5. Conclusion

Identification of flood risk areas plays an important role in avoiding or minimizing the hazards. Among the factors affecting floods, land use variation is very important since it can be controlled. Digitizing the satellite images method was used to represent the land use patterns since it can identify number of land uses at a time and difficult to use manual techniques where having a huge variation in land use patterns.

GIS had been used at all these stages to support and speedup the data processing and analysis. GIS has the ability to perform and display different types of professional analysis including to “create, manipulate, analysis and display” all types of geographically or spatially referenced data. HEC-HMS software has the ability to represent the peak flood flow and the flood plain with the minimum number of data.

Analysis is done for only one catchment in greater Colombo area due to the time limitations. But it can also be done for overall research area by analysing each catchment and compiling them.

References


