Optimization of Drainage Network to Minimize Urban Floods Using Remote Sensing and GIS Techniques

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Abstract: The frequency of the occurrence of disasters is increasing day by day. Urban flooding has become one of severe problems faced by Sri Lanka seasonally leading for various social and environmental interruptions. With the increasing of the occurrence it has become a necessity to find a proper solution to overcome the problem. This study mainly focuses to optimize the drainage network in Panadura urban council area, Sri Lanka to minimize the urban flood hazard susceptibility using Remote Sensing (RS) and Geographical Information System (GIS) techniques.

Light Detection And Ranging (LiDAR) Digital Elevation Model (DEM) was utilized to delineate requisite drainage and mini water catchments using Environmental Systems Research Institute (ESRI) Arc Hydro Model. Prior to LiDAR DEM processing an accuracy assessment was performed with respect to the ground truth elevation measured by Total Station and GPS surveys. Current available drainage system in the area was assessed in two ways as alignment and capacity for large water volumes in heavy rainfalls with respect to the delineated natural drainage system. By performing the comparison successfully, highly flood vulnerable locations in the current drainage system were identified. Finally adjustments to the current drainage network and new drainage paths were proposed.

Keywords: Digital Elevation Model (DEM), GPS (Global Positioning System), Total Station, Arc Hydro Model

1. Introduction

Urban flooding has become a severe problem in Colombo, Kalutara, Gampaha, Kegalle, Matara districts within the country for few years. During last two years the problem has gone up to a more vulnerable level due to frequent flash floods causing several social interruptions such as traffic congestions, delays of trains, closure of schools, electricity interruptions, disruption of several services and temporary loss of income (DMC Report, 2010). Considering these facts of urban flooding, it is required to propose a long term solution for the problem through detail studies.

Panadura Urban Council in Kalutara district has been chosen for the case study. This is a highly built up and industrial area with a population of 33735 approximately. Panadura city has been facing the problem over five years and sever events were recorded in May of 2009 and April, May and November 2010.The causes identified by many authorities for flash flooding are poor drainage maintenance (structural damage), lack of drainage paths, improper drainage construction along

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the Galle road, water flow blocked by garbage due to illegal dumping, filling of wetlands and unauthorized constructions.

According to the literature, a number of physical studies based on topographic surveying have been conducted to propose a solution for this severe problem. But most of them were failed during the implementing phase although they utilized both high cost and time. Therefore as a highly applicable approach, this study was carried out to propose an appropriate solution to minimize urban flooding in Panadura area. The major difference comparing to previous studies is the decision making according to the GIS analysis. As Remote Sensing data, processed Digital Elevation Model (DEM) created by LiDAR images was used.

2. Study Area

The extent of the study area covers about 5.85 km^2 of Panadura Urban Council in Kalutara district, Sri Lanka.

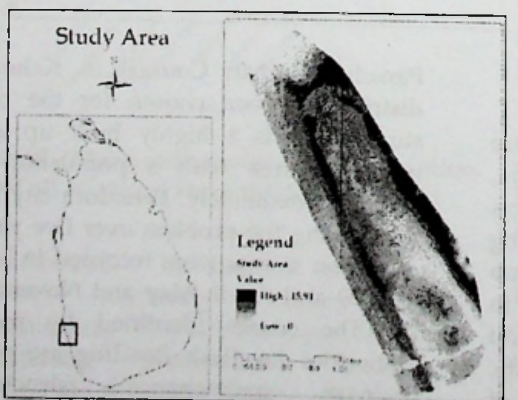

Figure 1- Study Area of Panadura UC

Topographically it is flat low elevated area belongs to coastal plain where elevation varies from 0 m to 15.91m. It is within latitude of 6° 40′46"- 6° 43′11"and a longitude of 79° 53′57"- 79° 55′40".

3. Data Used

- LiDAR DEM (5m - resolution) as the main Remote sensing data (Source - Disaster Management Center, Sri Lanka)
- GIS Layers- Road Network, Drainage Network digitized from Google Earth
- Field data - Elevation data using Total station survey and Coordinates of flood points, culvert points and water block points using GPS survey.

4. Methodology

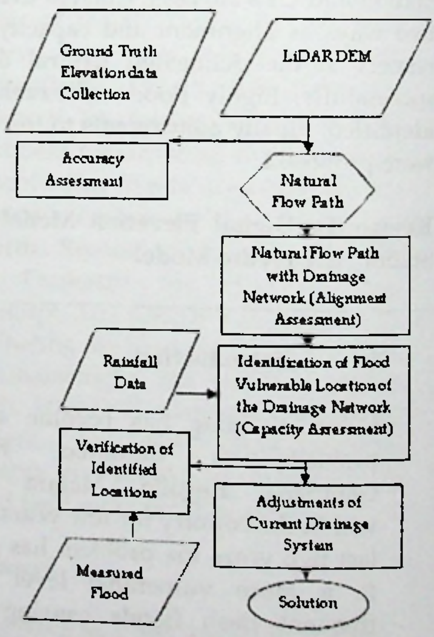

Figure 2- Methodology for proposing solutions

Methodology consists of four phases as accuracy assessment, hydrological processing, data analysing, verification and design.

Accuracy Assessment of DEM

To assess the accuracy, variance of elevation differences was calculated for each total station point with respect to the extracted elevation values of LiDAR DEM.

Hydrological Processing

Arc GIS can be used to accommodate more reliable approach of spatial variations in hydrological parameters than using manual procedures. Therefore LiDAR DEM was processed using ESRI Arc Hydro Tool to delineate the stream network (natural flow path). flow direction, sinks and flow accumulation were generated prior to the stream network delineation assuming that water can flow in from many cells but out through only one cell.

Data Analysing

This was performed by assessing two aspects as Alignment and Capacity of drainage network.

- Alignment assessment

  Alignment was assessed by overlaying the delineated natural flow path with the current available drainage network.

- Capacity assessment

  Capacity assessment was performed by comparing Q_1 and Q_2 discharge values (Maduranga. et al. 2009).

Where Q_1,

$$\text{Introducing Natural Discarge}(m^3s^{-1}) = \text{Flow Accumulation} * \text{Area of Pixel} * \frac{\text{Daily Rainfall}}{\text{hours} * 60 * 60}$$

and Q_2,

$$\text{Capable Discharge of Drainage}(m^3s^{-1}) = \text{Cross Sectional Area} * \text{Flow Velocity}$$

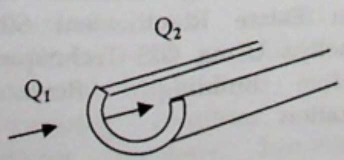

Figure 3 – Input and output discharges of drainage

If Q1>Q2, Drainage point is considered as an incapable one and if Q1≤Q2 it is considered as a capable one.

This calculation was performed for both maximum (resulted from 18 years) and average rainfall value in flood seasons.

Verification

Identified incapable drainage points using calculations were compared with ground truth flood locations for further verification of methodology.

Design

The design for a new drainage was developed based on the amount of surface runoff it has to cater. Surface runoff was calculated using highest rainfall (450 mm/day) resulted for the area and assuming all rain become runoff and no loss of water because of interception, evaporation, transpiration or loss to ground water.

New proposed drainage was divided into segments with respect to the area calculated using maximum flow velocity (0.5 m/s) in flood seasons

5. Results and Discussion

Accuracy Assessment of DEM

The resulted accuracy of LiDAR DEM was 0.3377 m. Since accuracy is in the centimetre level source DEM was accepted as an accurate one.

Alignment assessment

Alignment of current drainage network was assessed by overlaying that with delineated natural flow path. The overlaid two layers are represented below (Figure 4). According to the result of the assessment, more deviations were encountered in the top most region of the drainage system than the lower region.

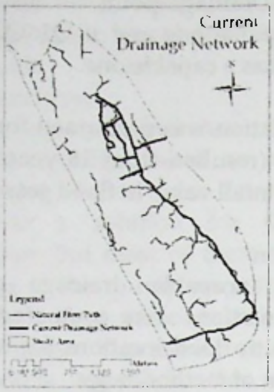

Figure 4 – Alignment of current drainage network

Capacity assessment

Table 1 – Calculation of flow rate

Point ID	Discharge at Culvert (m³)	Water Accumulation (m³)		
		Max. Rainfall	Ave. Rainfall	Average rainfall-flooding
C5	0.6567	5.212	0.1144	2.1177
C6	0.7620	7.994	0.1755	3.2484
C7	0.6567	8.524	0.1871	3.4637
C8	1.1675	11.495	0.2523	4.6710
C9	1.5240	12.205	0.2680	4.9608
C1D	0.7620	2.294	0.0504	0.9323
DE1	0.4572	1.037	0.0228	0.4212
WB1	0.0000	2.757	0.0605	1.1203
WH	2.2860	1.549	0.0340	0.6294

The table represents the results for natural flow accumulation and the discharge which is capable by current drainage network.

Drainage Design

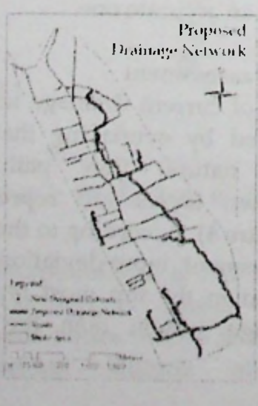

Figure 5 –Proposed Drainage Network

Based on the delineated natural flow path a new design was developed. Further, settlements and road network of the area were considered during the design phase.

6. Conclusion

The major problem in the drainage network available in Panadura area is the incapability to handle water volumes generated from natural accumulation not only in heavier rainfall but even in average rainfall in flood season. Therefore increasing of drainage volumes is a vital factor. As an alternative for increasing the volume, water blockage in the drainage should also be removed by cleaning the plant cover and wastes. The other identified problem is the improper alignment with the natural flow path in most parts of the network. As the final solution, to overcome all these problems a new drainage which will satisfy all aspects was designed.

7. Acknowledgement

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