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Beyond Capacity: Drainage Issues and Flooding in a Tri-Municipal Catchment of Kathmandu

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Abstract
The Kathmandu Valley's rapid and uncontrolled expansion has hampered its overall progress. The increased demand brought on by urbanization and population growth is too much for the drainage system to cope. The three municipal divisions of the Kathmandu district that make up the study area are Budhanilkantha Municipality, Tokha Municipality, and Kathmandu Metropolitan City. 520 sub-catchments were created from the two-hundred and seventy-one hectare (271.31 Ha) Catchment depending on the sewage network and elevation. This study's primary goal was to show how the drainage system is insufficient to adequately discharge rainwater to the next natural river, leading to overflowing manhole nodes and full pipes and connections. The manhole nodes displayed on map are categorized according to the hours they are flooded, and the pipe links are shown according to the hours they are full. The study shows that the current drainage system is insufficient for draining the available rainfall water, which results in floods in nearby locations. Many manhole nodes and pipe links are found to be flooded for more than 2 hours. The maximum ponded depth of water is found to be 1.176 m with 2.47 million liters of flood volume. Upgrading of the existing drainage system is essential to accomodate the available rain volume. Measures to increase infiltration capacity of the catchment helps in reduction of water volume in drainage network. Different green infrastructure techniques like LID techniques can be used to decrease surface runoff and control flooding in urban areas.

Keywords
Urban Flooding, Kathmandu Flood, Drainage Issue, SWMM.

1. Introduction

The Kathmandu Valley's fast and haphazard urbanization has had a detrimental effect on its overall growth. Kathmandu and other different metropolitan regions in Nepal have always had serious drainage management challenges. One of the world's cities with the greatest population density is Kathmandu. This has led to the concretization of the city and its adjacent towns, clogged and packed streets, and encroachment of rivulets.

According to an analysis of land use maps of the Kathmandu Valley from 1989 to 2016, there was a 412 percent increase in built-up areas [1], which might have increased storm-water runoff by more than 200 percent. Experts believe concrete built-up and black-topped roads prevent water from penetrating the earth and boosting runoff, which shortens the duration of concentration as well as causes drainage overflow and urban floods[2]. The drainage infrastructure cannot handle the additional demand brought on by urbanization and population expansion.

Rapid urbanization and poorly constructed or engineered sewers are thought to be the primary drivers of the increased frequency of urban flood disasters, in addition to extreme weather [3]. The key factors contributing to Kathmandu's intensified flood risk are: rainfall, people encroaching on the river corridor, alteration of land use, inadequate drainage capacity, and disturbing the river's natural path.

Although flooding has been a major problem in different places of Kathmandu for a long time, study incorporating the analysis of flood and initiation for the mitigation and preparedness is lagging behind. Storm Water Management Model (SWMM) and other models are found to be effective in analyzing urban flood in different places of Pokhara. However, there has not been much advancement related to analysis of urban flood and design of drainage network in Kathmandu. Due to easy access, simple data input parameters, and simple processing procedures, SWMM would be a better model for Nepal than other pricey and complex models [4].In addition to being able to model complicated storm drains, SWMM offers an integrated environment for modifying study area input data, performing hydrologic, hydraulic, and water quality simulations, and visualizing the results in a number of formats. SWMM simulates infiltration and runoff from the sub catchment with the option for several infiltration models, using a number of nonlinear reservoirs, a dynamic wave equation, and land surface components [5].

2. Study Area

The study area in this research covers 3 municipal divisons of kathmandu district, which are Kathmandu Metropolitan City, Tokha municipality and Budhanilkantha Municipality. With 2.9 million people living in its urban center and 845,767 residents in 105,649 homes in 2021 [6], Kathmandu is both the capital and the most populated city in Nepal. The majority of the catchment area falls under Tokha municipality. According to the 2021 Nepal census, there are 133,755 people living in Tokha overall with the population density of 7,816/km² consisting 66,532 men and 66,532 women to make up the whole population. In Budhanilkantha, according to the 2021

Nepal census, there were 26,678 houses and 179,688 people living in the city, with a population density of 5,200/km². Although not as much urbanized as Kathmandu metropolitan city, Tokha and Budhanilkantha are also major urbanization hub.

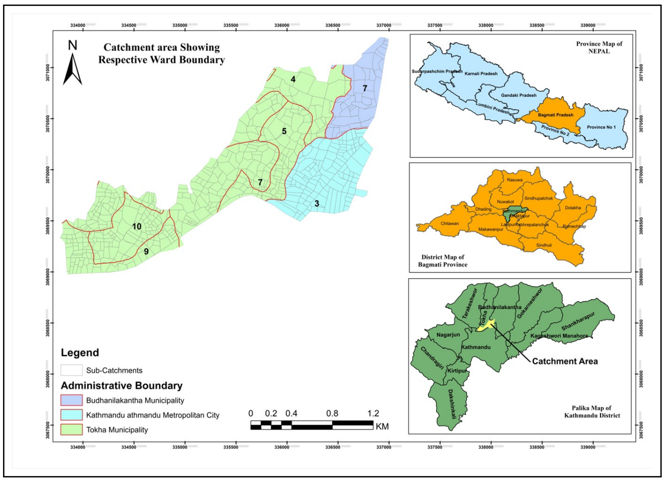

Figure 1: Study Area Map

3. Methodology

The total catchment of 271.31 Ha was delineated based on the sewer zone map of Kathmandu [7] prepared by Kathmandu Upatyaka Khanepani Limited (KUKL) Project Implementation Directorate (PID). It depicts the extent of area that contribute for the surface runoff and drainage flow in the study area. The catchment was further divided into sub-catchments based on the elevation and Drainage network.The sewer network elements and their properties were mapped according to the data from KUKL Project Implementation Directorate (PID) as provided on the webpage. Precipitation data required for the study were collected from the Department of Hydrology and Meteorology.

3.1 Data Collection

3.1.1 Drainage Details and Maps

KUKL PID (Project Implementation Directorate) gave information on an existing website produced for detail information on the location, nature, type, size, slope, and other properties of various drainage elements for the drainage map and specifics about the drainage system. The webpage http://sams.softavi.com, provided an interface that was used to gather information about sewer elements and their properties.

3.1.2 Precipitation Data Analysis

For the analysis, Annual maximum rainfall data for 30 years was collected from Department of Hydrology and Meteorology (DHM) for rainfall stations at Budhanilkantha and Panipokhari. Short duration rainfall data was not available at DHM and daily accumulation data was used to develop 1hr rainfall intensity. Short duration rainfall was calculated by the empirical formula developed by Indian Metrological Department (IMD).

$$P_t = P_{24} \times (t/24)^{1/3}$$

where,
P_t is required rainfall depth in mm
P_{24} is maximum daily rainfall in mm
t is time duration for which, rainfall is required in hour

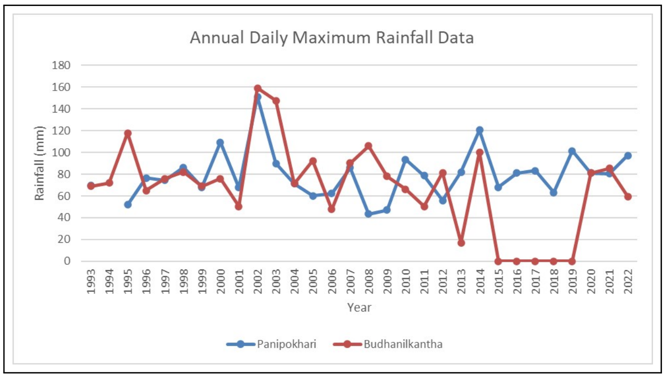

Figure 2: Rainfall Pattern

3.1.3 Land Use Map

For determination of impervious area in the catchment area, LULC map of 2019, obtained from ICIMOD was used [8]. The overall catchment consists of 3 types of land use type which are: Forest, Built-up and Cropland. Among these 3 types, Build-up area covers 85.897 % of the total catchment, Cropland covers 13.316 % of the area and Forest covers 0.787 % area of the total catchment area. The catchment doesn't consist of water bodies due to selection of catchment by avoiding presence of natural drainage so as to analyze the effect of drainage network without the direct influence of natural channels and rivers.

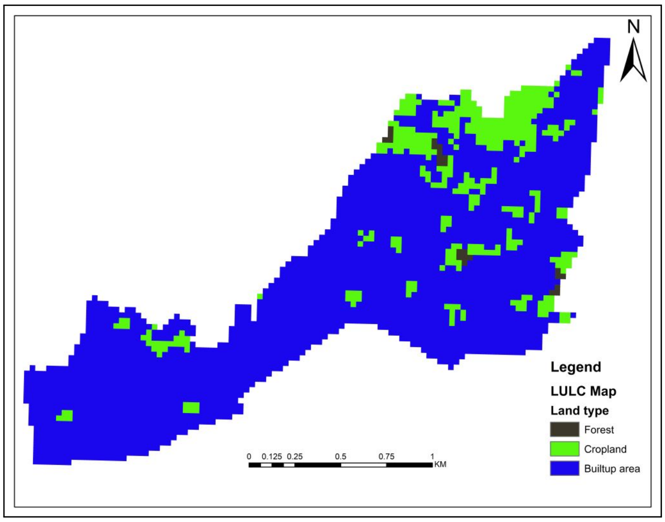

Figure 3: Land Use Map (2019) for study area.

3.2 Model Preparation

3.2.1 Determination of Sub-Catchments

The study area was fixed and the total catchment was outlined in Qgis with the help of sewer zone map and drainage network layout from Sewer Asset Management System website. The Catchment of 271.31 Ha was divided into 520 sub-catchments based on the elevation and sewer network.

3.2.2 Assignment of Nodes, Conduits and Outfalls

Nodes are manholes and Links are the sewer pipes Connecting manholes. The data collected from KUKL PID is used to assign nodes, conduits and outfalls to their respective coordinate with their input parameters. The data were clipped and saved for desired extend in the form of shape file. The shape files were first imported in Storm and Sanitary Analysis (SSA), which is an add-on or extension to Autodesk Civil 3D. Then the data were exported to the format which is readable by SWMM. The input parameters for different elements were defined from the shape file and those elements with missing data were removed without disconnecting the network.

3.2.3 Assignment of Rain gauge

Rainfall Stations at Budhanilkantha and Panipokhari contribute to the catchment area and their area of coverage was determined by Thiessen polygon method. The sub-catchments are assigned respective rainfall valuebased on the station area they lie on.

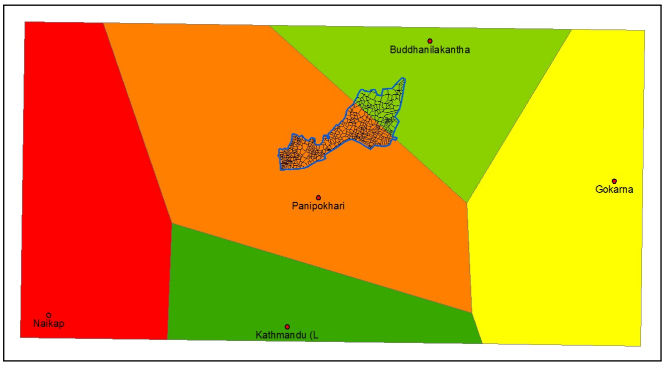

Figure 4: Thiessen polygon

3.3 Analyzing The Model

The model was prepared and analysed to check the sufficiency of drainage network to accomodate the available rainfall. The model was Simulated in SWMM with Dynamic Wave Routing Model using Horton Model for infiltration and Hazen-Williams as Force Main Equation.

4. Result and Discussion

4.1 Analyzing the Network Plan

The plan is shown for various part of the catchment with overview map showing area of view.

These maps categorize nodes on the basis of hours they are flooded and links are displayed on the basis of hours they are full. As seen in the figures, many manhole nodes and pipe links are flooded for more than 2 hours which are represented by red color. From Figure 7, it can be seen that the impact of flooding at manholes is less in comparison to other areas. Whereas, Areas presented in Figure 5 & 6 are mostly flooded and for more than an hour.

These maps represent that the existing drainage network is not sufficient in discharging the available rainfall water causing flooding in neighbouring areas. The high built-up area with impervious concrete covers cause decrease in infiltration and increase in surface runoff causing the water to flow directly to the drainage system and exceeds the drainage capacity and causes flooding. The pipes when full, causes flooding in the manhole and when the flooding exceeds the manhole capacity, water is released from the manhole to the surrounding area causing flooding in the vicinity.

The water depth ponded above the manhole nodes are presented in Table 1. The table is presented for 20 nodes with maximum ponded depth of water. From the table, it can be seen that, the maximum depth of water ponded above manhole is 1.176 m with 2.47 million liters of flood volume which is flooded for 3.2 hours. Some Nodes flooded for more than 5 hours with depth greater than 0.4 m depth of ponded water as shown in the table. The flooded nodes create havoc and affects the surrounding areas.

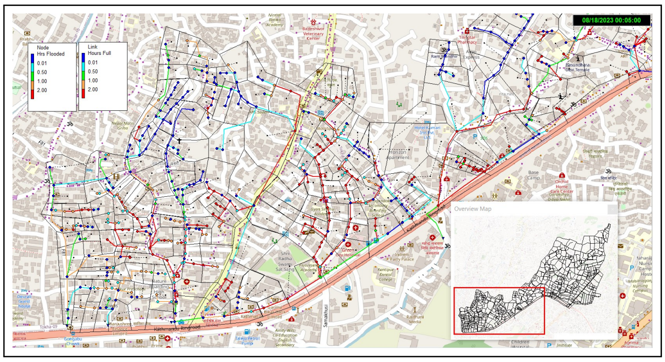

Figure 5: Plan with Nodes hours flooded and link hours full(1)

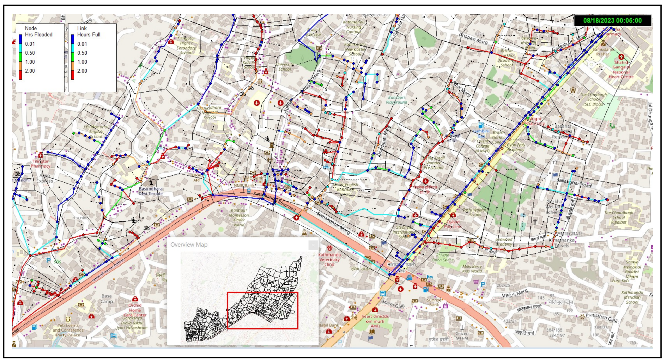

Figure 6: Plan with Nodes hours flooded and link hours full(2)

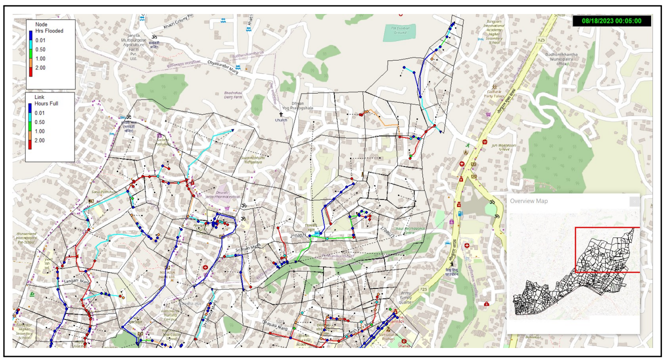

Figure 7: Plan with Nodes hours flooded and link hours full(3)

Table 1: Ponded Depth of water for top 20 Nodes

S.N.	Node	Hrs Flooded	Flood rate CMS	Flood Volume (10^6 ltr)	Ponded depth(m)
1	13772	3.2	0.881	2.472	1.176
2	13892	2.78	0.527	1.558	0.771
3	12797	2.99	0.44	1.499	0.743
4	11946	3.89	0.224	1.311	0.651
5	12443	1.85	0.556	1.3	0.643
6	12666	5.68	0.393	1.268	0.633
7	13784	2.06	0.42	1.243	0.604
8	11727	5.61	0.248	1.212	0.601
9	11100	5.63	0.226	1.128	0.562
10	12668	2.51	0.377	1.05	0.517
11	11874	5.64	0.235	1.001	0.498
12	11873	5.09	0.186	0.993	0.49
13	11728	5.62	0.115	0.98	0.489
14	15867	1.24	0.436	1.008	0.477
15	11708	5.63	0.186	0.953	0.475
16	11886	2.92	0.327	0.95	0.473
17	12366	4.03	0.306	0.934	0.465
18	13574	4.54	0.415	0.944	0.465
19	15873	3.45	0.356	0.964	0.465
20	11702	5.63	0.147	0.873	0.434

5. Conclusion And Recommendation

The main aim of this study was to demonstrate the insufficiency of drainage network to effectively discharge the rain water to the subsequent natural river, resulting in pipes and links being full and overflowing of the manhole nodes. The flooded water from the manhole is ponded around the manhole for hours causing flooding at different locations. The figures and tables represented show that the impact of flooding exists for hours causing trouble to public and private places.

This study highlights the drainage issues seen across the catchment and flooding problem caused due to lack of sufficient drainage capacity to effectively discharge the rain water into nearby natural river system. Proper study and analysis should be done before planning and implementing urban designs and construction of drainage should be checked. Hence, the drainage system is to be updated or infiltration capacity must be increased to decrease the volume of water entering the drainage system. For decreasing the surface runoff, different green infrastructure approaches can be used. LID techniques like green roofs and permeable pavements can function well in urbanizing cities when the core area is developing haphazardly and other LID applications like rain barrels and bio-retention cells are not appropriate [5].

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