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Modeling of Urban Storm Water Drainage using HYKAS for Lamachaur, Pokhara, Nepal

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Abstract

Earlier in Nepal, the agricultural cultivable land consumed the rainfall by itself. Therefore, the necessity of proper drainage system was not considered during those days. But nowadays, the surface runoff amount is high due to urbanization such that the existing improper drainage system becomes insufficient to discharge the total surface runoff and it leads to overflow problems. The roads turning into streams can be easily observed in Pokhara valley and many other urban areas of Nepal especially during rainy seasons. Therefore, the inadequate conveyance of storm water is the associated problem in many cities of Nepal. Lamachaur area (Ward 16 and 19 of Pokhara Metropolitan City) is also facing storm water drainage problem due to rapid urbanization, its topographical nature and developmental activities like other major cities of Nepal. In the present study, the existing situation of drainage system was evaluated for the Lamachaur area. Furthermore, planning and design of modified drainage system for the area was performed. For this, various thematic maps were generated by modeling with HYKAS based on both steady and unsteady flow methods and newly designed drainage was suggested for the recent drainage system to prevent overflow on streets in the area. HYKAS is widely used planning, analysis and design of storm water drainage system. The catchment area (164.70 ha) was divided into 123 numbers of sub-catchments. With the existing conditions, the outfall was observed to be at Tallo Deep, Madhyam Path and KI Singh Pool. In the steady flow calculation, load factors for the drainage system with various rainfall intensities were observed. The drainage size of the existing system (400mmX600mm and 900mmX1000mm on both sides of the road) was found to be insufficient to carry the runoff. For unsteady flow analysis, Saint Venant equation was used for hydrodynamic computation of selected as well as entire network system. The time series of heavy rainfall event that was occurred in 9th September 2018 was used for unsteady flow analysis. It was found that the main region of flow from Gharmi Village to Tallo Deep was having the problem of overflow for the rainfall intensity. The region from Tallo Deep to KI Singh Pool was found to have less problem of overflow. Dimension of the drainage system has been proposed after unsteady flow analysis. The proposed modified drainage system will help in proper draining out of storm water from the study area. This will solve the existing problems associated with overflow as the hydraulic analysis has been considered. The methodology used in this study can also be adopted for other areas of Pokhara and major cities of Nepal facing storm water drainage problem.

Keywords

Flood, Overflow, HYKAS, Drainage, Storm Water Drainage Design

1. Introduction

Storm can be defined as the violent disturbance of atmosphere with strong wind and usually rain, thunder or snow and the storm water has the origin during heavy precipitation events. The overflow problem is due to the surface runoff generated after losses from precipitation. A storm water drainage system consists of nodes, links that carry the storm water up to the outlet. Earlier, there were no problems of overflow and the drainage system was not required. But nowadays, due to migration haphazardly to days and also due to urbanization that runoff increases which finally load the road side drains. In addition to these, the catchment that responds rapidly to rainfall, leads to the rapid creation of large impervious areas, producing significant problems such as regular flooding, inadequate drainage facilities, erosion, sedimentation and deterioration of water quality in receiving water bodies overflow problems, property and life loss too. Inadequate conveyance of storm water can be easily observed and the roads turning into streams especially during rainy season are the associated problems. Urban flooding in particular is not an unknown situation in major cities of Nepal. The after flooding situation in Bhaktapur, Nepal is shown in Figure 1 as an example.

Figure 1: Flooding situation in Bhaktapur, Nepal after heavy rainfall on July 12, 2018

During the rainy season and with the rainfall of heavy intensity, the Lamachaur area of Pokhara also has the problems like overflow in the road side drains which often leads to the accidents, property loss as well as life loss. The overflow problems in Lamachaur, Pokhara can be observed in Figure 2. The runoff due to maximum rainfall occurring in the catchment needs to be taken into consideration in storm water drainage design and the runoff should be properly disposed thus preventing the overflow and other related problems.

Figure 2: Overflow during heavy rainfall in Lamachaur area on July 24, 2018

Hydrological studies are important and necessary for water and environmental resource management. The most basic challenges of hydrology are the prediction and quantification of surface runoff from a catchment. Generally, pathways of flow that dominate during storm events determine the resulting surface water during and after the event [1]. The problems of overflow like that of Bhaktapur valley of Nepal on July 2018 during rainy season are due to poor or no study on hydrological analysis. Hence, a comprehensive hydrological study must be carried out for the proper management of storm water [2]. Demands from society on the predictive capabilities of such study and analysis of hydrological parameters are becoming higher and higher, leading to the need of enhancing existing research theories and even on developing new methods [3]. There must be adequate requirements of the research and development in the storm water drainage design in such catchment. Numerical simulation has been widely used for design purpose in many areas of environmental engineering (e.g., snow fence design). Though modeling concept for storm water management is new in Nepal, developed countries successfully practicing it using different models (e.g., SWMM). Storm water drainage system should be adequate and is very essential in the modern infrastructure because it affects the roadway serviceability and usable life[4]. HYKAS is an advanced model used for steady and unsteady flow calculation in storm water drainage system which is widely used in Europe originated in Germany incorporating its guidelines. The model calculation is primarily based on Storm Water Management Model (SWMM) of US-EPA. In the case of re-calculation of an existing drainage network or calculation of any special hydraulic structures, it is recommended to calculate using an unsteady hydrodynamic calculation method. Not only that, even for the flooding analysis and sudden water level variation due to the pressure flow or other factors, it is necessary to calculate using unsteady condition. Based on the user set boundary conditions and the hydrological conditions, analysis will be subjected accordingly. The model is widely used for planning, analysis and design related to drainage systems in urban areas. This software is capable to simulate the precipitation movement from the ground surface through channel or pipe network. Single event and a long continuous period of event can be done simulating by using HYKAS. HYKAS fulfills most of the requirements of a modern hydraulic calculation program and enables the user to dimension and verify sewer networks. The drainage networks can be analyzed separately as well as in combined form. Various heavy rainfall events can be analyzed for overflow in the network. The user can choose the network load and examine the effects of individual rain events and long-term continuous simulation. This makes it as a powerful tool for modeling the storm water drainage system among other available models. The programs GraPS (graphic system for sewer and water supply networks) and HYKAS enable the user for drainage system calculation[5] . It is a robust software package for analyzing the effective urban flood water control and management for the study area.The HYKAS is a useful software for runoff computation based on soil type properties. Thus, HYKAS can be easily applied in the similar properties of land like Lamachaur, Pokhara. The main objective of the study is to design and analysis of urban storm water drainage system using the HYKAS model. The specific objectives of the study are as follows:

- Analyze the existing storm water drainage system using HYKAS.
- Design and analyze a new storm water drainage system using HYKAS to propose for mitigating the overflow problem on the roads of Lamachaur area.

2. Methodology

The study and analysis of the hydrological data (e.g., rainfall, runoff etc.) of the Lamachaur catchment is essential for the purpose of designing effective storm water drainage system in the study area. The daily rainfall data was collected from meteorological station, Kaski and tipping bucket rainfall data was collected from Pashchimanchal Campus, Lamachaur. The rainfall data was analyzed for the input to the model. The existing drainage elements were setup with the outfall at Tallo Deep, Madhyam Path and KI Singh Pool. The sub-catchments were delineated according to the runoff conditions. Hence, the generation of overland surface runoff can be made. The drainage network was determined according to the existing field conditions. With the existing network conditions, the hydraulic load capacity of drainage network system was generated. The velocity and discharge from simulation were compared with the velocity and discharge obtained from direct field measurements using current meter. The thematic maps were generated for the existing drainage conditions and the rainfall runoff model was generated using HYKAS. The new storm water drainage system was designed after the unsteady flow analysis. The simulation results for existing and planned drainage network were analyzed. With the proper location of drainage components, the planned drainage network was defined which could solve the existing overflow problems associated with the network.

2.1 Study Area

The Lamachaur area is chosen for the study. The study area extends from 28º16’15” latitude 83º58’13” longitude and 28º14’44” latitude 83º59’20” longitude. The Lamachaur catchment includes the area of Bhunpure, Amala Bisauni, Jimire, Khatriko Dahar, Sahardahar and Bhaktipath of Pokhara Metropolitan City Ward No. 19 as well as area of Pashchimanchal Campus, Tallo Deep to Lamachaur Road and Lamachaur Machhapuchre Village Road of Pokhara Metropolitan City Ward No 16. The Lamachaur area that was under study is shown in Figure 3.The catchment of the study area has been chosen small based on the outlet located on this area and has been treated separately.

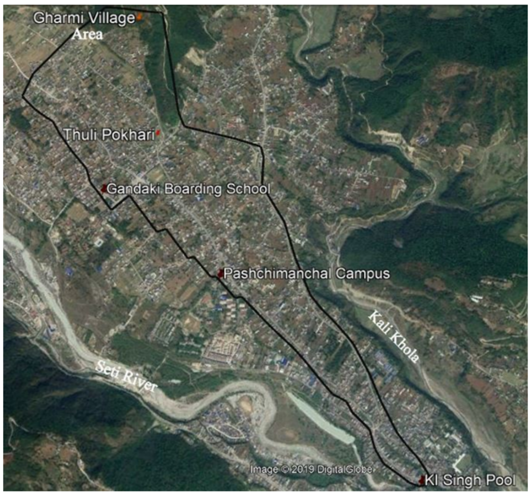

Figure 3: Study area of Lamachaur Catchment (Source: Google Earth 2019)

2.2 Analysis of Rainfall data

Based on the hydrological data obtained from meteorological station, the daily rainfall data was compared with the data obtained from tipping bucket for the period of June 1, 2018 to July 10, 2018 only. It is because the rainfall data from the tipping bucket was available over that period only as it was installed after the study was initiated with the realization of unsteady flow analysis for the appropriate drainage design. The data from both the stations are nearly comparable with their peak values matching as shown in Figure 4.

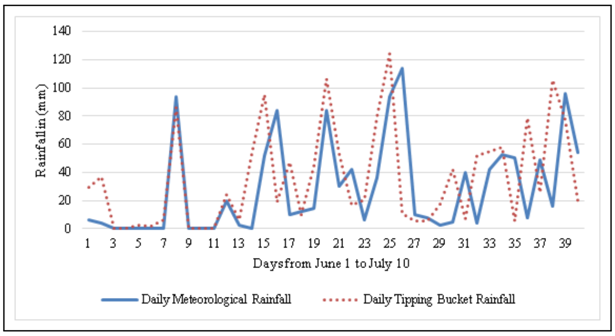

Figure 4: Comparison of daily rainfall data obtained from meteorological station with tipping bucket rainfall data

The rainfall event where there is continuous rainfall and which has high intensity has been used. For the analysis, the rainfall intensity data of 9th September 2018 has been used. The overflow has been observed for this rainfall event. The reason of using this rainfall event is that the discharge was measured for the conduit at that rainfall event. Velocity was measured at the field for this rainfall event.

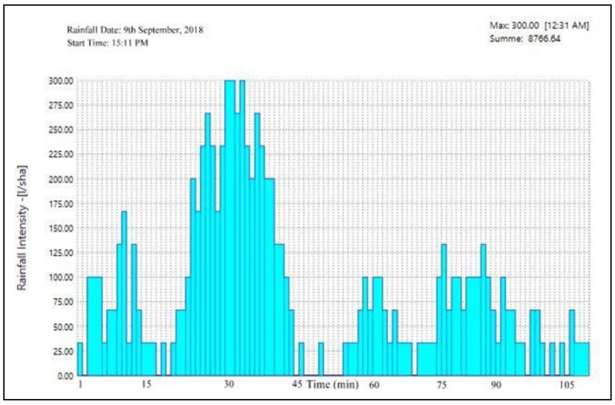

Figure 5: Rainfall intensity distribution during rainfall event of September 9, 2018

2.3 Delineation of sub-catchments

The catchment area (164.70 ha) was divided into 123 numbers of sub-catchments and each sub-catchments were divided into three significant parts, namely connected impervious areas, the supplementary areas and the pervious area. In addition, there is the fourth catchment surface but it does not contribute to runoff (e.g., Thuli Pokhari pond). Therefore this area excluded from the catchment area in modeling as shown in Figure 6.

Figure 6: Delineation of drainage network

The visual observation of the catchment was performed for defining the soil type. The soil type for the entire catchment was found to be sandy loam. The calculation of surface runoff was conducted using Grenzwertmethode (Horton) method. This method was chosen as the design was performed for the consideration of urban areas. The maximum runoff generated from each sub-catchments can be observed in Figure 7.

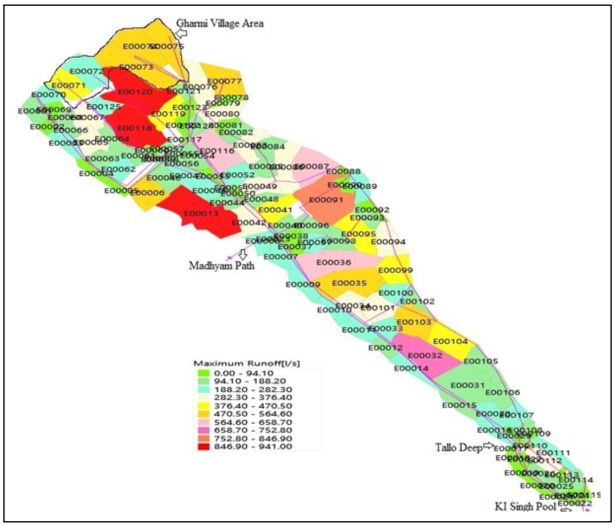

Figure 7: Maximum runoff for each sub-catchments

It was found that maximum runoff more than 846.9

lps was generated from the sub-catchments E00120, E00118 and E00113 those are located nearby Lamachaur Chowk. As we move downstram, the maximum runoff amount is comparatively decreasing and it is because the area is more residential and thus larger imperviousness.

2.4 Generation of overland surface runoff

2.5 Drainage network calculation

The drainage network was modeled with the existing drainage conditions. The complete drainage network of Lamachaur catchment is shown in Figure 8. The outlets are located at three locations of the study area (Madhyam Path, Tallo Deep and KI Singh Pool). Calculation of the existing drainage was conducted using steady analysis approach. The calculation was performed using Time coefficient method. With the entry of existing drainage size and the completion of drainage network, the model was set to run based on input of rainfall intensity.

Figure 8: Drainage network with free outfall at three locations of Lamachaur catchment

3. Results and Discussions

The number of sub-catchments were separated assigning the conduits for each and the area of paved portion, the roof area as well as the land use zoning was assigned for each sub-catchments. With the input of existing drainage properties, the calculation was performed using HYKAS for steady state analysis as well as unsteady state analysis. The conduit with maximum discharge flowing over the entire network is shown in Figure 9.

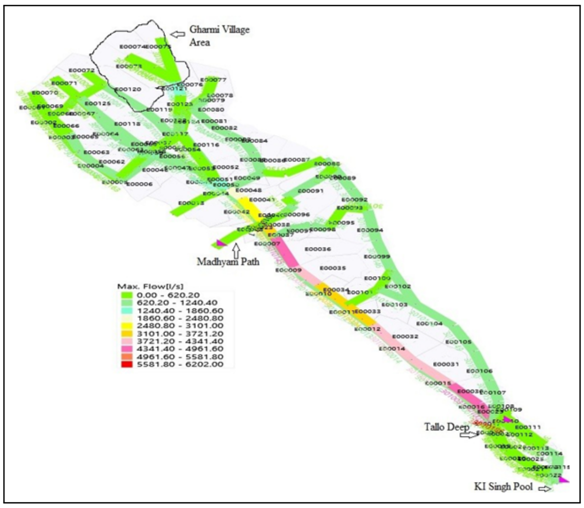

Figure 9: Maximum discharge in the entire network system

It is observed that the conduit maximum flow from Madhyam Path to Tallo Deep is comparatively larger. This is the area where a motorbike and also a man were flowed with water inside the drain during the rainy season of 2016.

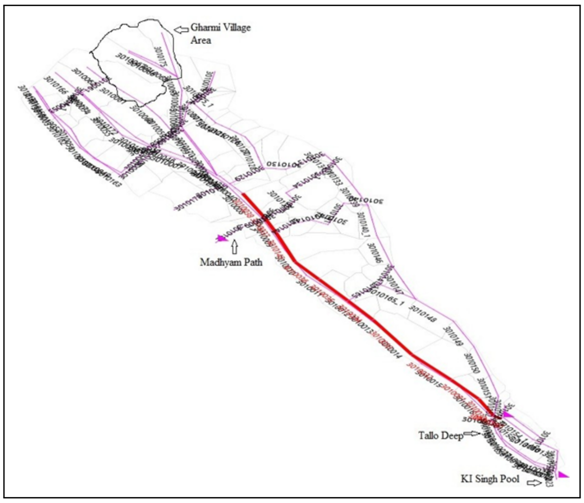

Figure 10: Location of maximum discharge greater than 2.5m^3/sec for rainfall event of September 9, 2018

This area of conduit flow with maximum value greater than 2.5 m^3/sec is shown in Figure 10. As one observed in Figure 10, the maximum discharge originates from upstream area of Madhyam Path where the networks both from Lamachaur Chowk area and Gharmi Village area connected.

3.1 Comparison of discharge and velocity

Two conduits (3010036 and 3010013) where the overflow was observed at the field were selected for the purpose of comparing measured discharge and velocity with the HYKAS results. Comparison of discharge has been conducted by changing the runoff coefficient to adopt the measured discharge in selected conduits. For the rainfall event, from the dynamic analysis of calculation result from HYKAS, the existing drainage condition was analyzed and the discharge in the conduit 3010036 was found to be 4.13 m^3/sec as shown in Figure 11.

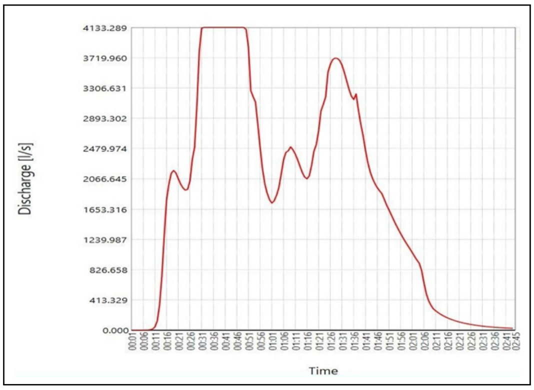

Figure 11: Time history of simulated discharge for conduit no. 3010036

Similarly 0.935m^3/sec of discharge was observed in Figure 12 for the conduit 3010013.

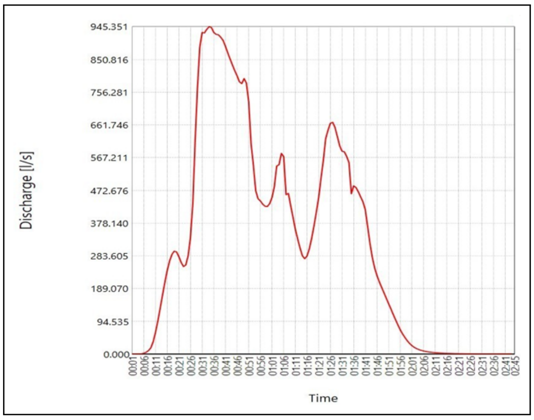

Figure 12: Time history of simulated discharge for conduit no. 3010013

Also, for the rainfall event, from the dynamic analysis of calculation results from HYKAS, the existing drainage condition was analyzed and the velocity in the conduits was found to be 4.584 m/s and 3.94 m/s respectively as shown in Figure 13 and Figure 14.

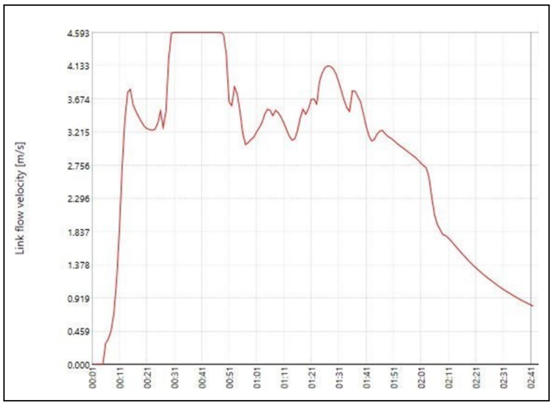

Figure 13: Time history of maximum velocity for conduit no. 3010036 (time in x-axis)

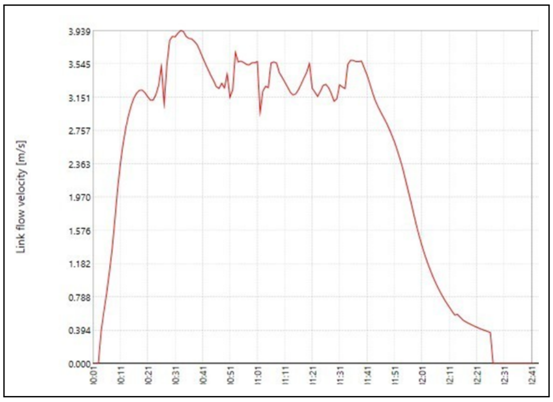

Figure 14: Time history of maximum velocity for conduit no. 3010013 (time in x-axis)

The discharge and velocity were calculated based on the field measurements for the same conduits 3010036 and 3010013 using current meter. For this, the revolution was noted for the fixed period of time and with the constant of current meter, the velocity was calculated and then discharge considering the area of existing drain. Constants a=0.5718 and b=0.0885, provided by the manufacturer were used in the velocity formula V=aN+b, where N is the number of revolutions per second.

Table 1: Calculation of velocity and discharge using current meter for conduit no. 3010036

Width m	**Depth** m	**Rev.**	**Time** sec	**Vel.** m/s	**Area** m2	**Flow** m3/s
0.9	1.0	172	20	5.01	0.90	4.51
0.9	1.0	143	20	4.18	0.90	3.76
0.9	1.0	137	20	4.01	0.90	3.61
			Avg.	**4.39**		**3.96**

Calculation of velocity and discharge based on field measurements are shown in Table 1 and Table 2 for conduits 3010036 and 3010013 respectively. The discharge on conduit 3010036 is 3.956m^3/sec and for conduit 3010013 is 0.927m^3/sec. Similarly, the maximum velocity on conduit 3010036 is 4.39 m/s and for conduit 3010013 is 3.86 m/s. From the comparison of HYKAS results of discharge and velocity with those based on field measurement found to me more or less matching and hence the HYKAS results are comparable with field measurements.

Table 2: Calculation of velocity and discharge using current meter for conduit no. 3010013

Width m	Depth m	Rev.	Time sec	Vel. m/s	Area m2	Flow m3/s
0.4	0.6	80	10	4.67	0.24	1.12
0.4	0.6	43	10	2.55	0.24	0.61
0.4	0.6	75	10	4.38	0.24	1.05
			Avg.	**3.86**		**0.93**

3.2 Observation of maximum rate of overflow

The maximum rate of overflow on the sub-catchment can be viewed for the rainfall event. For the analysis, whole network system has been used. The rainfall intensity of 1.33 mm/min for hour duration of 323 l/s-ha has been used to determine to load in the existing drainage network system as shown in Figure 15.

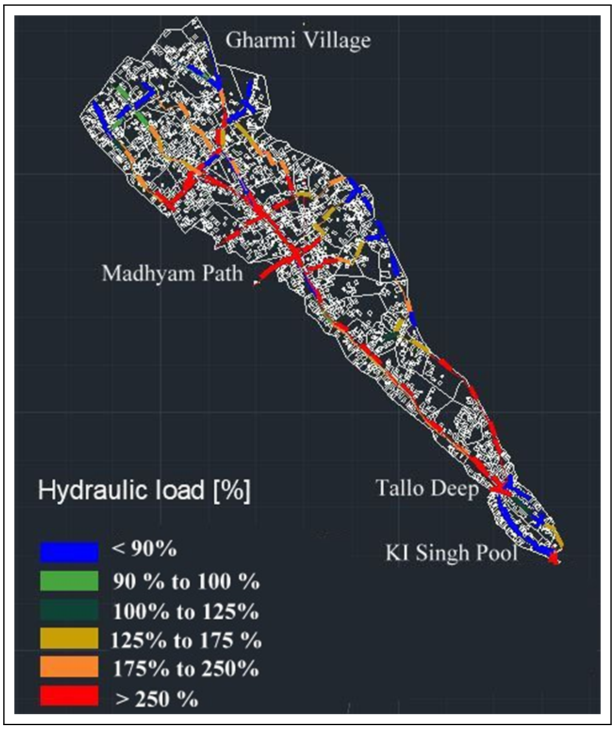

Figure 15: Hydraulic load capacity of entire network system for average rainfall intensity of 323 l/s-ha

Conduits having less percentage than 90 represents safe area. For example, the most North part of the catchment (Gharmi Village area and Lamachaur area located upstream of Lamachaur Chowk) found not to have overflow problems. However, the existing drains along the main road from Lamachaur Chowk up to Tallo Deep found to be insufficient to carry the storm water as we observed the load factor is more than 100 percent. Furthermore, the entire area located downstream of Tallo Deep found more or less safe to flow the storm water with the rainfall event up to 1.33 mm/min.

3.3 Generation of rainfall runoff model

Three sub-catchments (E00118, E00032 and E00030) with different maximum runoff (see Figure 7) for the rainfall event of September 9, 2018 were selected for the generation of rainfall runoff model. Figure 16 shows the time series analysis generated for the date where it can be observed that the peak discharge for the sub-catchment E00118 that is located near the Tallo Deep is much less compared to other two sub-catchments. More interestingly, though the maximum runoff of E300032 is less than that for E00030 (see Figure 7) and the sub-catchment E300032 is located just upstream of Tallo Deep, the peak discharge from unsteady flow analysis for these two sub-catchments differ slightly. This is the reason why unsteady flow analysis is important to evaluate a drainage system.

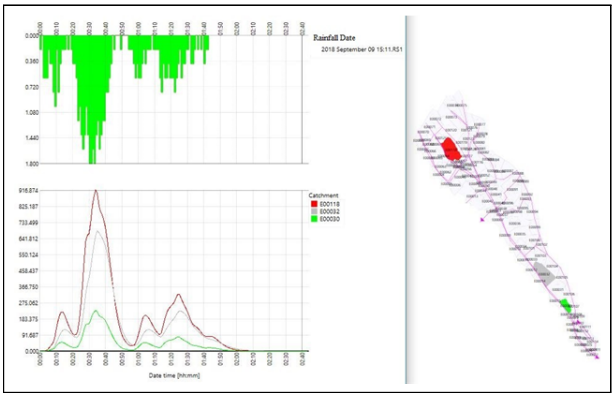

Figure 16: Rainfall runoff model for the rainfall event

3.4 Analysis of simulation results for rainfall event of September 9, 2018

The effects of rainfall event during September 9, 2018 on the existing drainage system were analyzed first for different time from rainfall started time until the peak rainfall time. Figure 17 illustrates the overflow situation along the longitudinal sections up to Tallo Deep with existing drainage at the time of maximum rainfall happened on September 9, 2018. Thin strip in the figure denotes no overflow problem for the longitudinal sections where as the thick one shows problem of overflow in the associated longitudinal sections. The strip for the sections upstream of Lamachaur Chowk (North part of Gharmi Village and Lamachaur) is very thin and it is hard to see. This means there is no overflow in that area even for the existing drainage system and it is because the area is where the runoff originates. However for rest of the longitudinal sections shown in Figure 17 (from Lamachaur Chowk to Tallo Deep) there is problem of overflow as the strip is thick along the longitudinal sections.

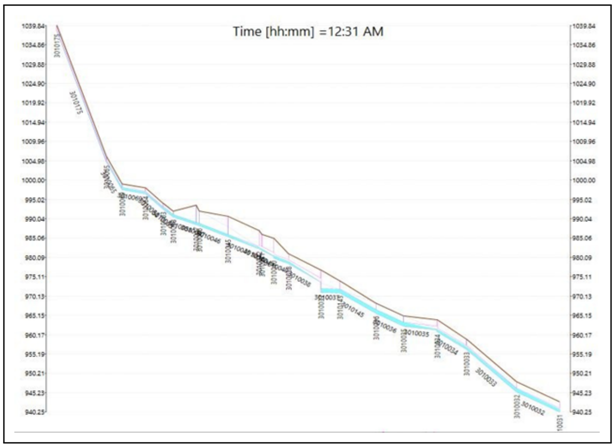

Figure 17: Analysis of simulation of rainfall event for existing network

The proposed drainage network has been planned with provision of manholes at 50m interval. The manhole has been provided with circular shape but different size. Figure 18 is the simulation results with the time of maximum rainfall happened on September 9, 2018 for planned drainage network. One can easily observed that the strip thickness along the longitudinal sections is much lesser compared to that for the existing drainage network. It can be concluded that the planned drainage network is sufficient to safely discharge the storm water through the conduits itself such that there is no problem of overflow anymore. The appropriate conduit size for the catchment has also been obtained from the unsteady analysis. For the outlet of Tallo Deep, the equivalent conduit diameter required is 3.4m, whereas for outlets of Madhyam Path and KI Singh Pool, conduit diameter of 1.8m and 1.0m respectively will be sufficient.

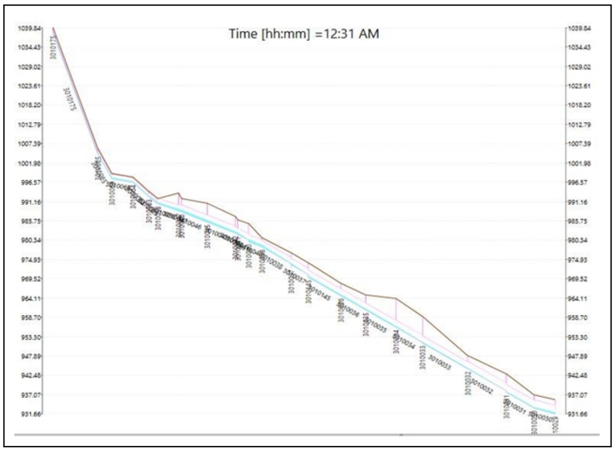

Figure 18: Analysis of simulation of rainfall event for planned network

4. Conclusions

Lamachaur area of Pokhara, Nepal is facing storm water drainage problem due to increasing population, developmental activities and rapid urbanization. The challenges associated with urban flooding in the area have been causing a major problem to the society like loss of property, accidents and many more. For the drainage network modeling, rainfall data and soil data were used as primary data. For the hydrological study, daily rainfall data from 2002 to 2018 obtained from meteorological station and the available tipping bucket rain gauge data of 2018 were used. Soil type has been taken as loamy sand from visual inspection. The study was performed to design and analyze urban storm water drainage system using the HYKAS. This model used for the calculation of hydraulic properties of urban drainage network based on both steady and unsteady flow approach. The steady flow calculation was conducted using Time Coefficient Method with the rainfall intensity according to Reinhold r (15, 1) from HYKAS manual. With steady flow condition, the existing drainage system was analyzed. It is concluded that the main region of flow of runoff from Gharmi village up to the Tallo Deep have the problem of overflow with the given conditions. It is found that the existing drainage system with drain size of 600mmx400mm and even 1000mmx900mm are insufficient to safely carry the storm water without overflow. However, the region from Tallo Deep to KI Singh pool is found be relatively safe and with no problem of overflow. New drainage network was planned with manholes to solve the overflow problems and unsteady flow analysis was performed. The planned drainage network found to be able to solve the existing overflow problem along the main road from Lamachaur to Tallo Deep. In conclusion, the problems of overflow during rainy season can only be addressed if the storm water drainage is designed by studying the hydrological data of the catchment. The daily rainfall data cannot be used for drainage design because the rainfall of high intensity only occurs for short period of time. Both the steady state and unsteady state analysis is essential for the evaluation of drainage system. The drainage should be able to carry rainfall of the high intensity without overflow safely considering rainfall series of the event. Hence, the modeling of drainage system needs to be performed considering calculation from steady state as well as analysis from unsteady state condition. HYKAS found to be potential software for storm water management in urban areas of Nepal for all these reasons.

5. Data Availability

Daily rainfall data, tipping bucket rainfall data and the HYKAS model used during the study were provided by the Department of Meteorological Station, S4W-Nepal and Parajuli Software Pvt. Ltd. respectively. Direct requests for these materials may be made to the provider as indicated in the Acknowledgements. Field measurements data (velocity of water flow and size of existing drains) used during the study are available from the corresponding author by request.

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