Research Inventy: International Journal of Engineering And Science
Vol.10, Issue 8 (August 2020), PP 01-12
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Sustainable Urban Storm Water Drainage Design using SWMM: a Case Study of Lamachaur, Pokhara, Nepal

Keshav Basnet[1], Sanjay Khadka[2] and Kishor Kumar Shrestha[3]

[1] Msc Coordinator for Infrastructure Engineering and Management Program and Assistant Professor for Department of Civil and Geomatics Engineering, Paschimanchal Campus, Institute of Engineering, Tribhuvan University, N 28.2538926 , E 83.9764104, Nepal.

[2]MS student, Infrastructure Engineering and Management Program, Department of Civil and Geomatics Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, Nepal.

[3]Associate Professor, Department of Civil and Geomatics Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, N 28.2538926 , E 83.9764104, Nepal.

Abstract: *Unplanned growth of urban areas is affecting the natural drainage surface. The roads turning into streams can be easily observed in Lamachaur, Pokhara and many other urban areas of Nepal especially during rainy seasons. This study was mainly focused to find the best solution to overcome the overflow problem of Lamachaur area and to recommend design alternatives that would work effectively throughout the design period. The tipping bucket rainfall data was obtained from Pashchimanchal Campus located in the study area and rainfall data with ten year return period was obtained from intensity duration frequency (IDF) curve generated for a meteorological station located in Pokhara airport. The complete storm network was drawn as line diagram in Storm Water Management Model (SWMM). The input parameters for conduits, nodes, junctions, rain gauge, sub-catchments and outfalls were entered. The catchment was modeled in the SWMM. The longitudinal profile of existing drain was obtained. The existing drain network was observed to be insufficient during peak runoff. Moreover, six cross drainages at different locations were designed to reduce runoff for effective and economic design. The land use land cover (LULC) map of the concerned area was prepared in the Arc GIS environment with the help of self-digitization of area using SAS imagery as base map and shape file was created. The LULC map for the year 2050 was predicted analyzing trend from 2000 to 2020 on every five years with Transition Probability Matrix. The modeling of drain was performed for ten-year flood return period considering predicted corresponding LULC. The Dimensions of drain were calculated by Hit and Trial method analyzing longitudinal drain profile to be safe. With the procedure adopted to calibrate the events, a set of parameters that led to the best fit between the observed and the simulated hydrograms were obtained for each event. Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2) and RMSE observation standard deviation ratio (RSR) for peak runoff values using SWMM model and Rational method was found satisfactory. Capacity of existing drains along with validation with discharge obtained from Rational method was performed. The analysis of storm water and drainage system supports in proper modeling of urban drainage system consequently assisting to solve concerned issues, with benefits to urban planners and related institutions in urban planning and infrastructure management. In summary, SWMM was observed to be a potential tool that can be used for storm water management in vulnerable areas of Pokhara and other major cities of Nepal where overflow is a major problem.*

Keywords: *Flooding, Stormwater management, Road side drain, Overflow, Rational method.*

Date of Submission: 24-07-2020 Date of Acceptance: 05-08-2020

I. INTRODUCTION

Water is a prime requirement for the existence of life though uncontrollable amounts of water can adversely affect the survival of living beings. Earlier, most of the area was agricultural cultivable land used the rainfall to itself; the drainage system was not required. Due to present trend of haphazard migration along with rapid and unplanned urbanization; natural drainage gets affected which finally raise the load to road side drains. The impervious area is in increasing phase due to the construction of buildings, pavements and concrete structure. On the other hand Pokhara city of Nepal receives heavy instantaneous rainfall which mostly is beyond the holding capacity of constructed cross drainage and drains (Basnet and Neupane, 2018). The overflow of water from existing drain during peak rainfall, the roads turning into streams can be observed in Lamachaur, Pokhara. Due to the overflow problems, probability of road accidents increase difficulty to pedestrians and vehicles while travelling which affect the trade as well as tourism sector in nearby areas. During heavy rainfall, water overflows from drains and the entire street and roads get flooded. The overflow problems in Lamachaur area can be observed in Figure 1. This creates difficulties in transportation and has chances of inviting accidents. Sometimes, overflow enters public houses, shops too. The excess storm water has been creating flood with deposition of wastes and debris in road and creating shoulder erosion. Furthermore, there is a high chance that the lifespan of road may get deteriorated. Thus, it becomes necessary to effectively and efficiently manage storm water. The main goal of this study was to find the solution to overcome the overflow problem in Lamachaur area and design alternatives that would work appropriately throughout the design period. Furthermore the sustainable storm water drainage designed in the area by analyzing different models of storm water management would be recommended to local and provincial government authorities for implementation.

The study and corresponding analysis were considered to provide possible way out determines the solution of the overflow problem in the study area and design alternatives that would work appropriately throughout the design period. Pokhara city receives the high amount of rainfall as it lies just 25 miles away from Lumle which receives highest amount of rainfall in Nepal which is greater than 5600 mm/year (Kansakar et. al, 2004). Lamachaur area, lying to the northwestern of the main city just at the base of high hills has an unpredictable rainfall pattern. Thus, storm water management stands a high challenge in the study area. It is quite crucial to manage the overflow from drains in the areas (Basnet and Neupane, 2018). Analysis of storm water and drainage system assists in proper modeling of urban drainage system consequently benefitting urban planners, Metropolitan authority, Provincial Government and concerned institutions in urban planning and infrastructure management.

The Rational Method is a simple technique for estimating a design discharge from a small watershed (Basnet et. al, 2018). It was developed by Kuichling (1889) for small drainage basins in urban areas. The Natural Resources Conservations Services (NRCS) runoff equation was developed to estimate total storm run-off from total storm rainfall. That is, the relationship excludes time as a variable. The rainfall intensity is ignored. An early version of the relationship was described by Mockus (1949). With the intent of using the Rational method for hydraulic structures involving volume control, the modified rational method was developed by Poertner (1974). As described in the Storm Water Management Rules, the New Jersey Department of Environmental Protection (NJDEP) has specified that one of two general run-off computation methods be used to compute runoff rates and volumes. These are the NRCS methodology, which consists of several components, and the Rational method (and the associated Modified Rational method), which are generally limited to drainage area (Manual, 2004).

Based on the technical classification; Nepal Road Standard, NRS (2013) has made a provision for which the return period for various classes of road for calculating drainage discharge should be accounted. However, it has not properly mentioned the methodology forestimation of such design discharge from catchment (DOR, 2013). Different watershed modeling techniques can be used to determine the design discharge in Nepal. In developed countries like USA, well developed drainage design guideline and modeling practice is very common. In India, the modeling practice is started in educational institutions like Indian Institute of Technology (IIT), National Institute of Technology (NIT). Adequacy of existing drain was checked at NIT, Warangal, India. In the context of Nepal, the modeling practices have been started in engineering institutions including Institute of Engineering (Basnet and Neupane, 2018).

SWMM is freely available software whereas HYKAS software is payable. SWMM is latest model than HYKAS. Since SWMM has easy steps, anyone could learn easily from you tube and design the size of drain. In the context of Nepal, SWMM would be more suitable model due to easy access; easy data input parameters and easy processing steps rather than other payable and complicated models.

Though developed counties like USA, China and India used SWMM for modeling of stormwater drain, SWMM was not used before in Nepal. However there was one study lately conducted in Lakeside, Pokhara (Khadka and Basnet, 2019). During the analysis at Lamachaur by Basnet and Neupane (2018) and at Lakeside by Khadka and Basnet (2019), the drainage networks were designed just to prevent overflow at present situations considering rainfall data of single year with current LULC, while in this study, the drainage network was designed using SWMM considering ten year return period rainfall data with design period of thirty years by predicting LULC of 2050. Although the suggested drain size by Basnet and Neupane (2018) could hold the peak flow in the study area, accumulation of water from whole catchment to single drain leads to high velocity and therefore the discharge. Cross drainages option in this study therefore play significance role in reducing velocity at drain network with safe discharge passage to outlets.

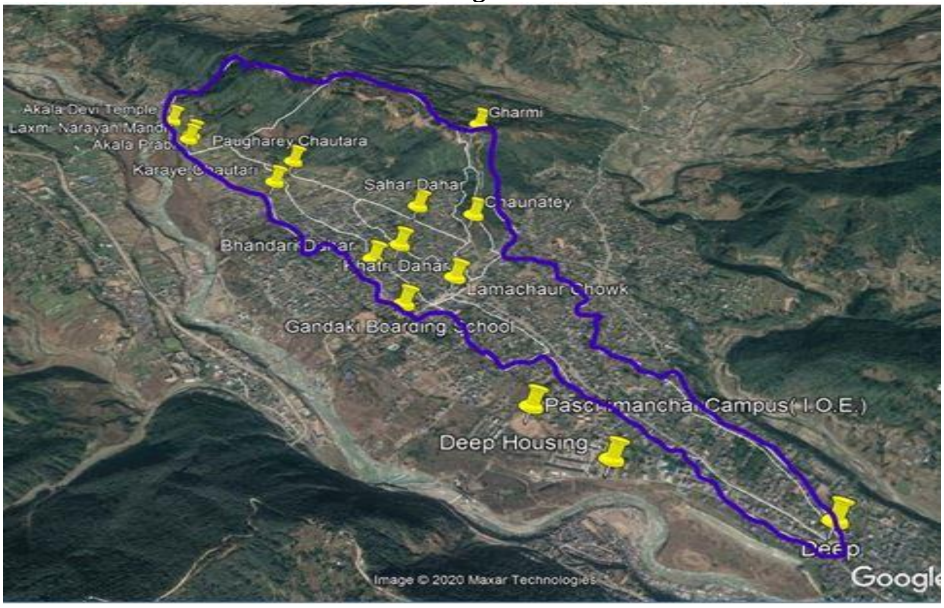
Figure 1 Overflow problem in a road of Lamachaur, Pokhara, Nepal (Basnet and Neupane, 2018)

II. METHODOLOGY

Firstly, the area to be studied was identified. The study area extended from 28°16’09” latitude 83°57’46” longitude and 28°14’54” latitude 83°59’10” longitude. The Lamachaur catchment includes northern part of Gandaki Boarding School to Gharmi Danda extending up to Batulechaur, Madhyampath and southern part few hundred meters below Pashchimanchal campus gate and some parts of Tallo Deep. The catchment area was obtained as 287.92 Hectares using Google Earth. The entire study area has been represented inside blue zone which showed the total catchment area and the drainage occupying the storm water from that area as shown in Figure 2.

The map of study area was loaded into the SWMM as a backdrop image. The loaded image was geo-referenced for obtaining the exact coordinates in SWMM. The area was divided into number of catchments based upon the elevation. Similarly, sub- catchments, conduits, junctions, rain gage point, etc. were defined and input properties for all these parameters using map obtained from Arc-GIS were assigned. The input for imperviousness percentage for sub-catchments was calculated after analyzing LULC on GIS. The dimensions of drains were inserted from field observations. The sub- catchments were linked to their corresponding nodes and links. The time series rainfall data was provided which contributes to the parameters of run-off from sub-catchments to the defined outlets through the corresponding links. Simulation of catchment response using SWMM was performed for existing drainage networks. The existing drainage network was found to be insufficient to hold the peak runoff during heavy rainfall. For sustainable and economic design of drainage, cross drainage were planned and designed on different suitable location i.e. at ‘Uppallo Akala’, ‘Tallo Akala’, ‘Karaye Chautara’ ‘Lamachaur Chowk’, Pashchimanchal Campus and ‘Deep’. After analyzing Land use Land Change Trend analysis, prediction data for 2050 was obtained and drainage was modeled based upon predicted imperviousness percentage of land. Furthermore, SWMM simulation was performed with consideration of cross drainage. Corresponding dimension of drain sections were calculated to hold peak runoff during heavy rainfall based on predicted imperviousness percentage of land. For obtaining runoff, water level profile in conduits, and critical location of surcharging were considered subsequently with use of Rational Method to relate and validate the results.

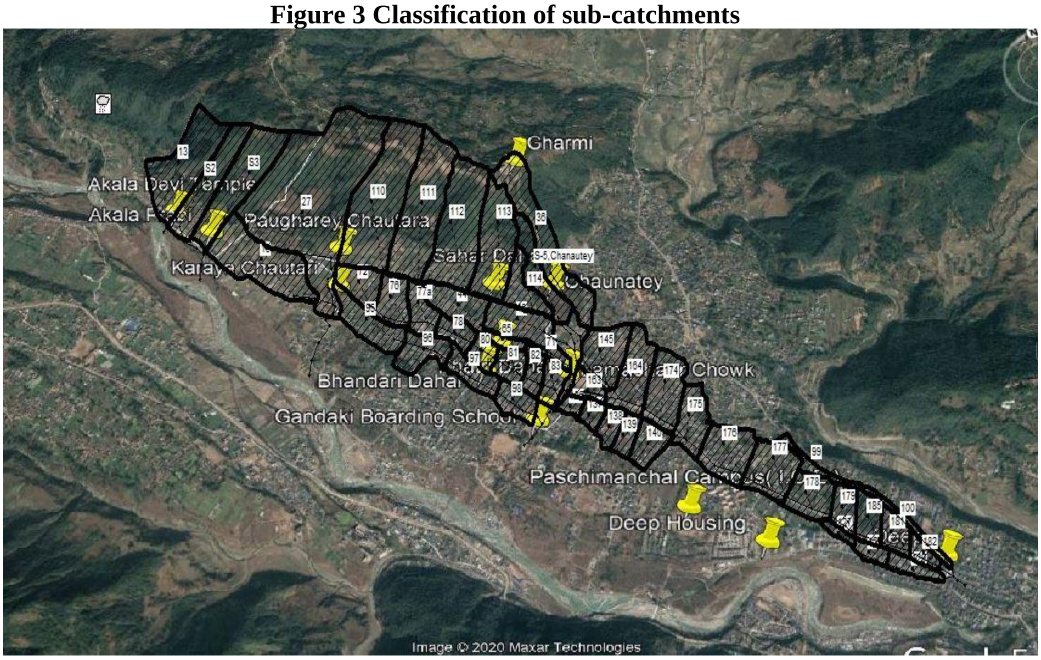
Figure 2 Catchment area for the study site located at Lamachaur, Pokhara, Nepal overlapped in the map from Google Earth



2.1 **Catchment of Sub-catchments Area**

The elevation of the catchment was 1072.00 m at the top and 934.00 m at bottom levels of the catchment. The length between top level and bottom level of the catchment was 20.00 kilometers. The whole catchment was divided into sub-catchments based on elevation and existing drainage networks as shown in Figure 3. The percentage slope, percentage impervious, N- impervious and N- pervious were assumed on the basis of SWMM guidelines provided on SWMM Manual (1982).

Figure 3 Classification of sub-catchments



2.2 **Assigning Nodes, Conduits and Outfalls**

After defining sub-catchments areas, the input parameters for conduits, node and junctions were entered. The input parameters for junctions were: elevation and maximum depth, for conduits were: drainage network a dimension, Manning's roughness coefficient and for outfalls were; invert elevation and maximum depth of drains. The elevation Values were obtained from Google Earth Pro. The dimensions of drain sections were obtained from field measurement. Manning's roughness coefficient was assumed from SWMM Manual suitable to the location (1982). The run-off from the corresponding sub- catchments were distributed to the respective nodes and finally to the outlet through conduits as shown in Figure 4. In this study, the drainage system with drains at the single side of the road was considered. On the basis of field observation, drainage networks, nodes, conduits and outlets were modeled on SWMM that is shown in Figure 5 for a modeled drain.

Figure 4 Nodes and conduits from sub-catchments connecting to outlets on existing drainage system

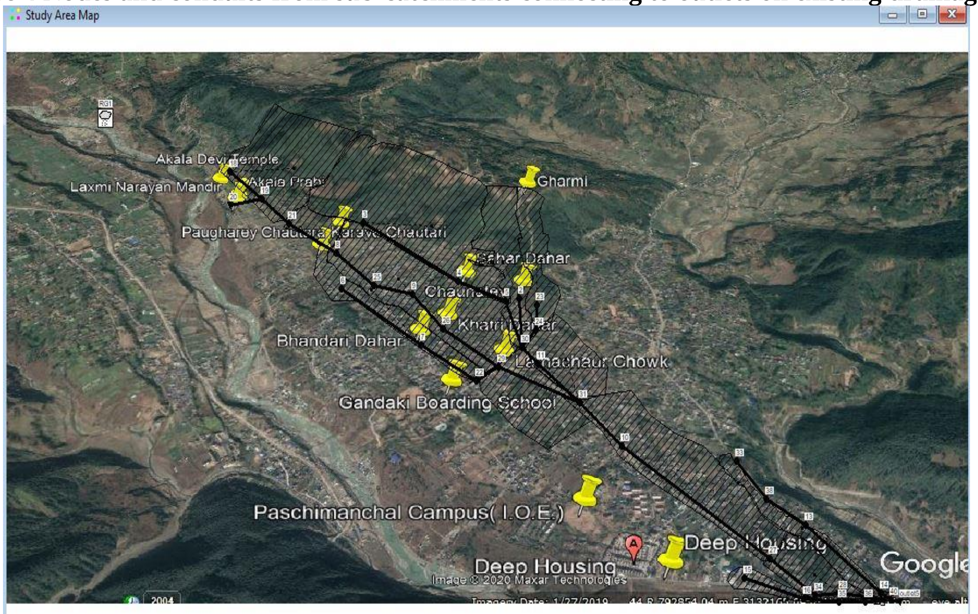
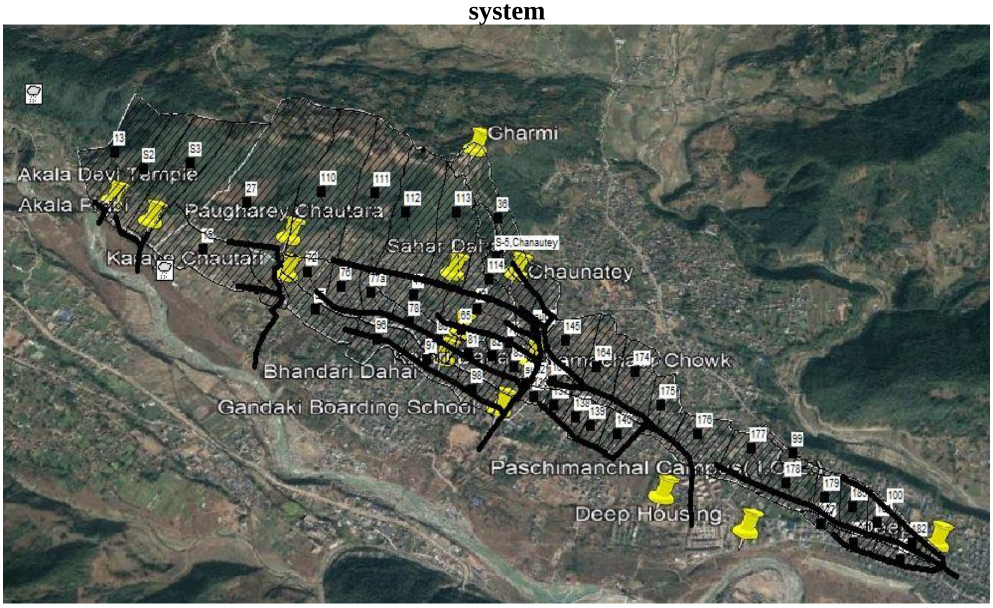


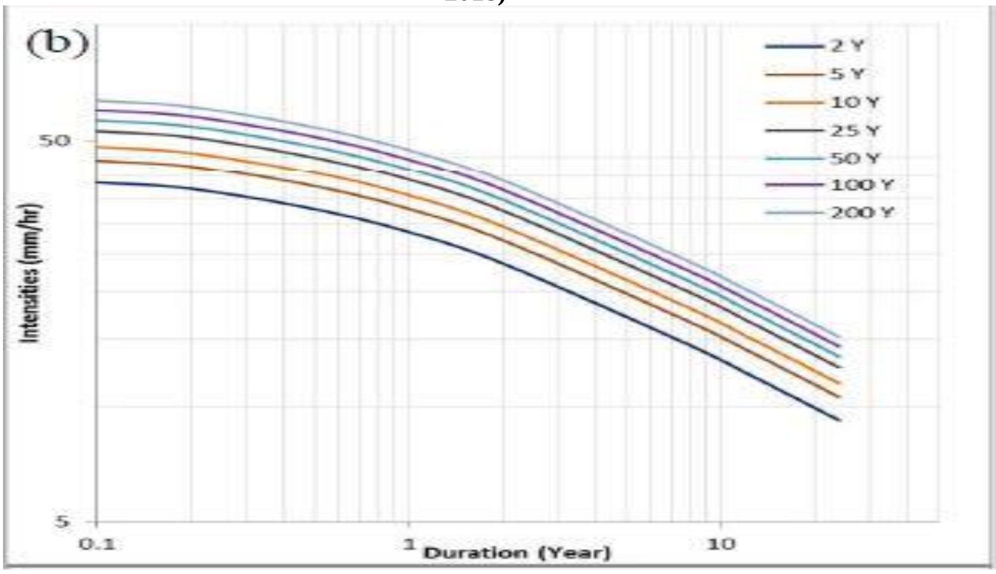
Figure 5 Nodes and conduits from sub-catchments connecting to outlets on modeled proposed drainage system



2.3 Time Series Rainfall Data

The Time series rainfall data at interval of five minutes for one hour of most rainy day was entered. The rainfall value for ten-year return period of one-hour duration on five-minute interval was calculated from IDF curve generated for Pokhara Airport Region as shown in Figure 6 (Devkota et. al, 2018) and the tipping bucket rainfall data was obtained from Pashchimanchal Campus. This was assigned to rain gage and connected to the sub-catchments that contribute to the runoff. Maximum rainfall value of 16.58 mm was obtained at 45-minute interval. The tipping bucket data was used for modeling the existing drain while ten-year return rainfall data was used for designing drain.

Figure 6 Intensity duration frequency (IDF) curve generated for Pokhara Airport (source: Devkota et. al, 2018)



2.4 Run-off in Sub catchment

From the precipitation data entered, the runoff from the catchment was computed which varied from each other due to varying land features and other properties. As most of the land area was covered with buildings and paved surface, the runoff coefficient value needed to be almost high. The natural drainage is in decreasing order due to continuous growth in concrete construction works. The impervious surface is in increasing order.

2.5 Prediction Map Analysis

The Land use Land cover map of Lamachaur area was studied from 2000 to 2020. The changing trend was analyzed on every ten year interval and LULC map for 2050 was predicted. The LULC map of the area was prepared in the Arc GIS environment with the help of self-digitization of area using SAS imagery as base map and shape file was created. The land use land cover was classified to forest, agricultural land, barren land and built up areas. Different sub-catchments with varying catchment patterns were used as input for sub catchment in SWMM. The land use land cover map for different year was calculated using GIS. The land use land cover for the years 2000, 2010 and 2020 were calculated for the Lamachaur area as shown in Figure 7, Figure 8, and Figure 9 respectively.

Obviously, the land use is dynamic and continuously changing from one type of land use to another. Here, the changing pattern of land use and land cover through classified image of time interval ten years was analyzed. The built-up area was observed to be increasing with lowering trend of agricultural, thin forest and dense forest as well (Figure 10). The availability of agriculture land for conversion to built up area was significantly convenient since people use agriculture land for settlement purpose. But, after 2030 it can be considered to shrink agriculture land for settlement purpose compelling the dwellers to use the forest areas. Hence, after 2030 the trend of conversion of agriculture land to built-up area may to conversion of forest land to built up area. Furthermore, huge settlement and completion of development activities like construction of road networks may be considered to decrease significantly.

Figure 7 Land use land cover map of Catchment for the year 2000 A.D.

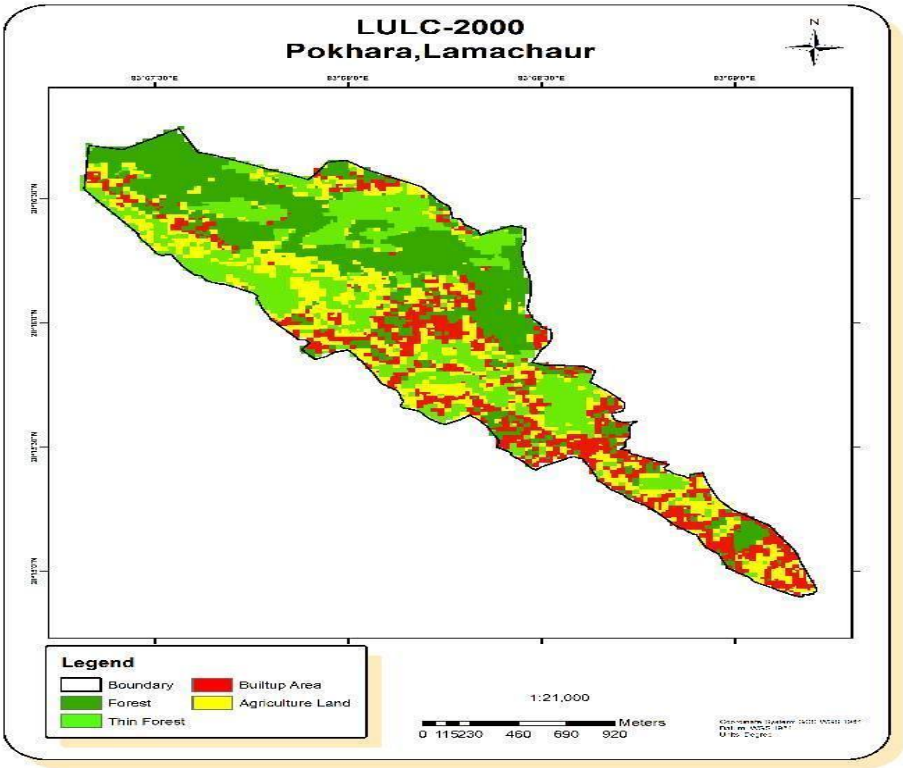


Figure 8 Land use land cover map of Catchment for the year 2010 A.D.

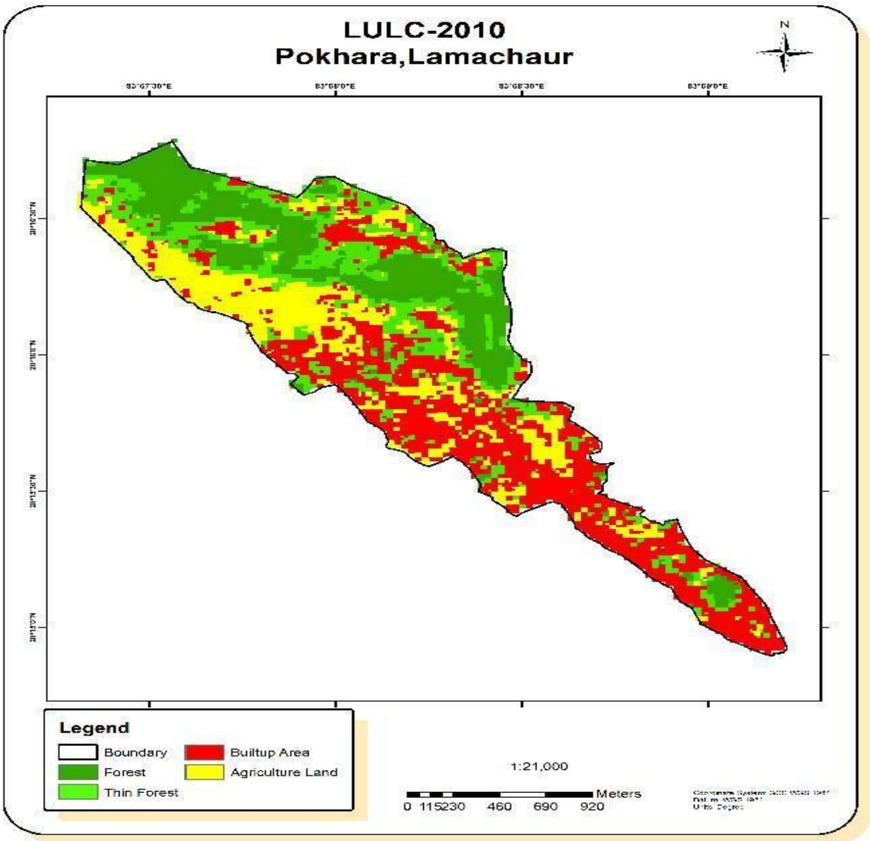


Figure 9 Land use land cover map of Catchment for the year 2020 A.D.

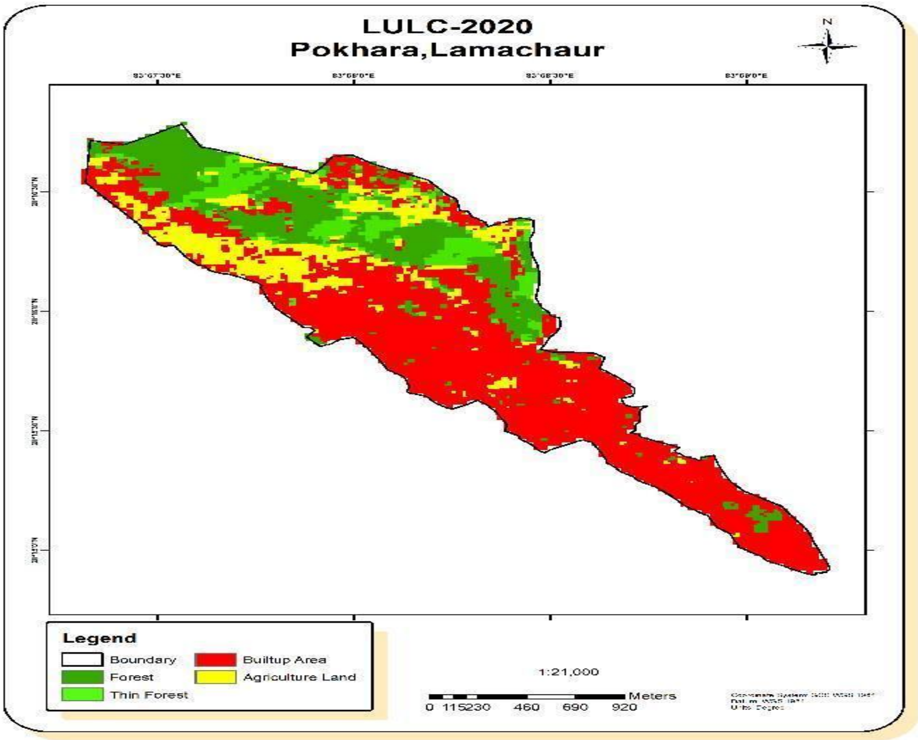
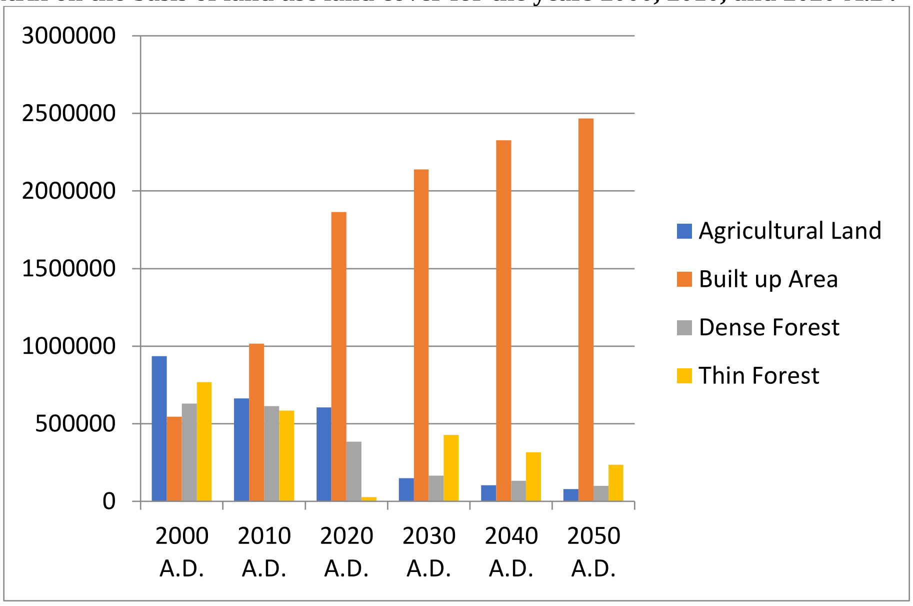


Figure 10 Predicted land use land cover for the years 2030, 2040, and 2050 using Transition Probability Matrix on the basis of land use land cover for the years 2000, 2010, and 2020 A.D.



III. RESULTS AND DISCUSSIONS

3.1. Analyzing Longitudinal Profile

With the entered parameters, the longitudinal profile of drain was obtained after SWMM simulation and presented in Figure 11 and Figure 12 for the existing drainage system and the proposed drainage system respectively where sky blue color indicates the flow level during rainfall. As one observed in Figure 11, the existing drainage was found to be insufficient to hold peak run-off during peak rainfall events. This is not the case for the modeled proposed drain as observed in Figure 12.

Figure 11 Longitudinal water elevation profile at 55 minutes interval at J-14 to J-18 for existing drainage system

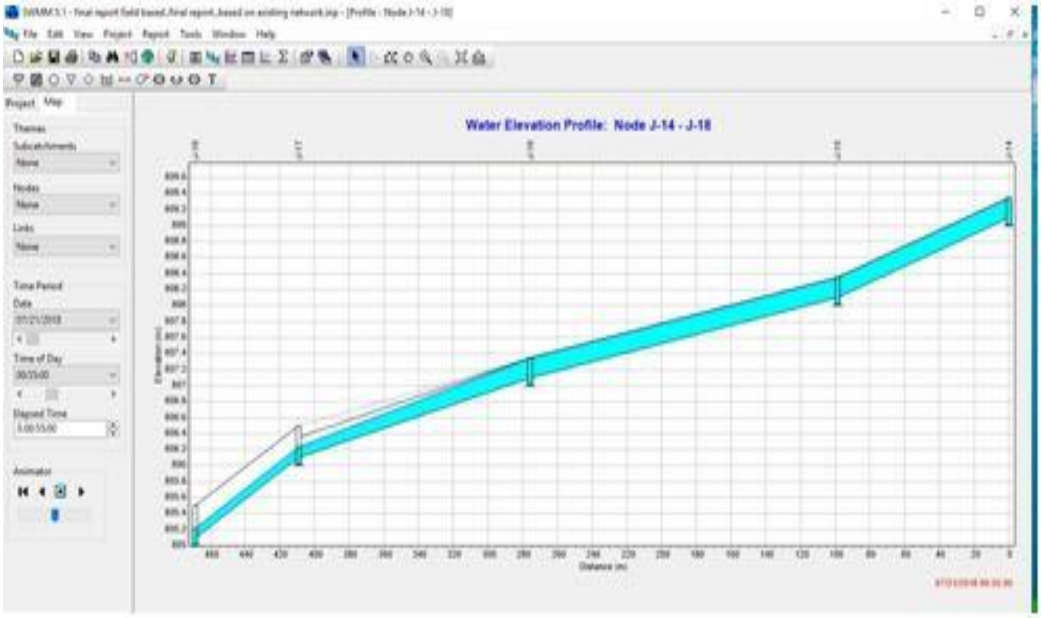
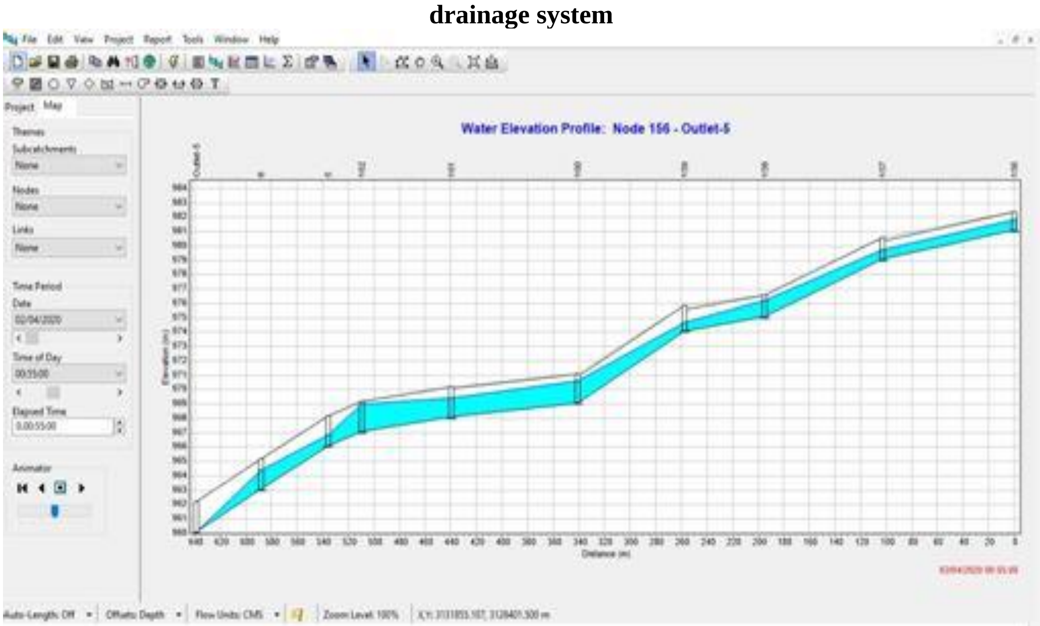


Figure 12 Longitudinal water elevation profile at 55 minutes interval at J-14 to J-18 for the proposed drainage system



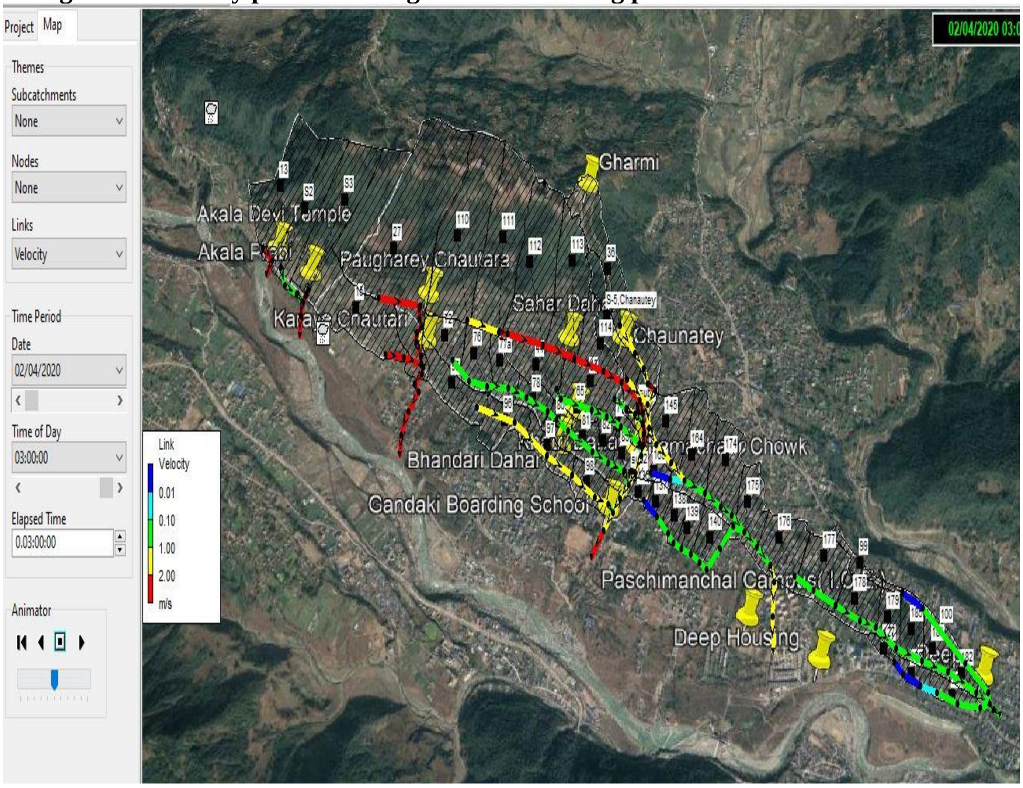
3.2. Introduction of Cross Drainage

Due to accumulation of water of all areas, the drain was insufficient to hold runoff during peak flows. Further increase in size of drain would be uneconomical. Hence, six outlets at different location were selected as per field observation. The velocity and volume factors were needed to be considered. The new drainage networks have been introduced in the study area for sustainable drain design. The drainage networks were designed based upon the earth elevation to make gravity flow. The shortest path for cross drainage was chosen from Google Map and field visit. The land area of the path belongs to 'Ministry of Irrigation' along with public land without having significant issues for land acquisition. The reasons for introducing cross drainage were sustainable and economic drain design diverting the run-off.

3.3. Longitudinal Profile and Velocity Profile during Peak Flow

As the existing drainage network was found to be insufficient to hold peak run off, cross drainages were introduced to reduce runoff. The dimension of proposed drainage system was calculated by Hit and Trial method analyzing longitudinal drain profile to be safe (Figure 12). The velocity profile of designed drain during peak flow at 55 minutes time interval after simulation in SWMM was found safe as shown in Figure 13.

Figure 13 Velocity profile in designed drains during peak rainfall at 3 hour interval



3.4. Calibration and Validation

With the procedure adopted to calibrate the events, a set of parameters that led to the best fit between the observed and the simulated hydrograms was obtained for each event. The peak run-off of catchment was calculated using rational run-off formula.

The Nash-Sutcliffe coefficient (NSE) was used as the objective function for the calibration. NSE has been defined as one minus the sum of the absolute squared differences between the observed and the simulated values, normalized by the variance of the observed value. The results were further assessed using RMSE observation standard deviation ratio (RSR) and coefficient of determination (R2). RSR was calculated as the ratio of the RMSE and standard deviation of measured data. In general, model simulation can be judged as satisfactory if NSE > 0.50 and RSR < 0.70 (Compendex et. al, 2016). Therefore the Nash-Sutcliffe efficiency, RSR and coefficient of determination were found to be satisfactory as those values were analyzed in Table 1.

Table 1 Calibration of model using coefficient of determination (R2), Nash-Sutcliffe coefficient (NSE), and RMSE observation standard deviation ratio (RSR) and comparison of modeled discharge with the peak runoff by Rational method

S.N.	SWMM Simulation		Rational Method				R^2	NSE	RSR
	Sub-catchments	Peak Runoff (m^3/s)	Rainfall (mm/hr)	Area (Hectare)	C based upon L.R.	Peak Runoff (m^3/s)			
1	27	4.44	139.302	34.3557	0.712625	9.474	0.469	0.612	0.271
2	65	0.82	139.302	1.287	0.712625	0.355	0.956	0.798	0.790
3	98	1.02	139.302	2.697	0.712625	0.744	0.977	0.817	0.848
4	99	1.02	139.302	1.55	0.712625	0.427	0.923	0.621	0.723
5	114	0.52	139.302	3.4338	0.712625	0.947	0.930	0.072	0.736
6	127	0.84	139.302	0.7605	0.712625	0.210	0.928	0.715	0.732
7	128	1.21	139.302	1.2675	0.712625	0.350	0.849	0.316	0.612
8	129	0.67	139.302	1.8759	0.712625	0.517	0.994	0.969	0.925
9	136	0.99	139.302	1.005	0.712625	0.277	0.903	0.590	0.688
10	137	1.27	139.302	1.508	0.712625	0.416	0.842	0.231	0.603
11	138	1.27	139.302	1.962	0.712625	0.541	0.870	0.263	0.640
12	145	0.81	139.302	3.7518	0.712625	1.035	0.978	0.601	0.853
13	178	1.14	139.302	2.9744	0.712625	0.820	0.966	0.685	0.817
14	179	1.12	139.302	1.7576	0.712625	0.485	0.907	0.508	0.695
15	181	0.68	139.302	1.7238	0.712625	0.475	0.990	0.950	0.902
16	182	1.27	139.302	1.0173	0.712625	0.281	0.812	0.205	0.567
17	sub2	0.02	139.302	0.1	0.712625	0.028	1.000	1.000	0.997
Total		19.110				17.38			
Mean		0.3822				0.35			

IV. CONCLUSION

Street flooding is one of the major problems in urban areas of Nepal. The roads turning into streams can be easily observed in Lamachaur, Pokhara and many other urban areas of Nepal especially during rainy seasons. Unplanned growth of areas, building constructions, pavement construction and other concrete structures decreases the natural drainage. The catchment was modeled with Storm Water Management Model (SWMM). The EPA SWMM is a physically based, deterministic model that simulates water inflows, outflows, and storages within a sub-catchment. The SWMM is freely available potential model for storm water management in urban areas of Nepal. The complete storm water drainage network of Lamachaur was drawn as line diagram in SWMM. The rainfall data of one hour at 5 mm interval was obtained from Tipping Bucket station at Pashchimanchal Campus, Lamachaur. The existing drainage network was modeled on SWMM. The cross section of drainage and network grid was obtained from field observation. In this study, the existing drainage system was observed to be inadequate with the runoff generated during the peak rainfall after analyzing the longitudinal profile of drain generated from SWMM. The drain was modeled to overcome the overflow problem during peak runoff. Moreover, six outlets were introduced at different location for sustainable and economic design reducing runoff. The rainfall data of ten-year return period obtained from IDF curve generated for Pokhara Airport was taken for modeling. The built-uparea was predicted to be 68.35 percentage of land on 2050 which was found by analyzing the trend from 2000 to 2020. The newly planned drainage networks with manholes have been recommended to address the overflow problems. Peak runoff obtained from SWMM was calibrated. Nash-Sutcliffe efficiency, RSR, Coefficient of determination for the peak runoff using SWMM was found to be satisfactory. Further the drainage designed using SWMM was compared by using Rational Method and found to be satisfactory. Therefore the modeled design of storm water drainage system for the

Lamachaur area using SWMM in this study plays important role in solving the overflow of drains into the roads of the area. In conclusion, with use of SWMM as a potential tool, it was observed effective to model and design for storm water management in vulnerable areas of Pokhara and other major cities of Nepal with key issue of overflow.

Conflict of interest
There is no conflict to disclose.

ACKNOWLEDGEMENT

The authors are thankful to the Department of Hydrology and Meteorology, Kaski, Nepal for providing the meteorological data. The authors are thankful to the Smart Phones for Water Nepal (S4W-Nepal) for helping in extraction of rainfall data from tipping bucket rain gauge at Pashchimanchal Campus, Pokhara.

REFERENCES

[1]. American Society of civil Engineers (ASCE) Manual. 1982. Gravity Sanitary Sewer Design and Construction, Manual Practice No. 60, New York, NY.
[2]. Basnet, K., Baniya, U., and Karki, S. 2018. "Comparative study of design discharge calculation approaches: a case study on Padhu Khola, Kaski, Nepal". Oodbodhan: A Journal of TUTA, Pashchimanchal Campus, 5 (5).
[3]. Basnet, K.and Neupane, M. 2018. "Storm water drainage design based on hydrologic analysis: A case study on Lamachaur catchment area, Pokhara, Nepal". Oodbodhan: A journal of TUTA
[4]. Department of Road, DoR. 2013. "Nepal Road Standard". Planning and Design Branch, Department of Road, Babarmahal, Kathmandu, Nepal.
[5]. Devkota, S., Shakya, N.M., Sudmeier-Rieux, K., Jaboyedoff, M., Van Westen, C.J., Mcadoo, B.G., and Adhikari, A., 2018. "Development of Monsoonal Rainfall Intensity-Duration-Frequency (IDF) Relationship and Empirical Model for Data-Scarce Situations: The Case of the Central-Western Hills (Panchase Region) of Nepal". Hydrology, p.27.
[6]. Khadka, S. and Basnet, K. 2019. "Storm Water Management of Barahi Chowk Area, Lakeside, Pokhara, Nepal using SWMM". Proceedings of 2nd International Conference on Engineering & Technology, KEC Conference, 2 (1), 320-325.
[7]. Kuichling, E. 1889. "The relation between the rainfall and the discharge of sewers in populous districts". Transactions of the American Society of Civil Engineers, 20 (1), p.1-56.
[8]. Mockus, V. 1949. "Estimation of total (peak rates of) surface runoff for individual storms, Exhibit A of Appendix B". Interim Survey Report Grand (Neosho) River Watershed, USDA, Dec, 1.
[9]. Poertner, H.G. 1974. "Practises in detention of urban storm water runoff".
[10]. S. Compendex, G. Elsevier, G. I. Services-usa, and L. Management. 2016. "Calibration & Validation of SWMM Model for Urban Watershed". International Journal of Earth science and Engineering, p.2457-2465.
[11]. S. R. Kansakar, D. M. Hannah, J. Gerrard, and G. Rees. 2004. "Spatial Pattern in the Precipitation Regime of Nepal", International Journal of Climatology, p. 1645–1659.
[12]. Storm water Best Management Practices Manual. 2004. "Computing Stormwater Runoff Rates and Volumes Chapter 5". New Jersey

Keshav Basnet, et. al. "Sustainable Urban Storm Water Drainage Design using SWMM: a Case Study of Lamachaur, Pokhara, Nepal." *International Journal of Engineering and Science*, vol. 10, no. 08, 2020, pp. 01-12.