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Effects of Urbanization on Storm Water Run-off : A Case Study of Kathmandu Metropolitan City, Nepal

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Abstract: In urban and suburban areas, much of the land surface is covered by buildings and pavements, which do not allow precipitation and snowmelt to soak into the ground. Instead, most developed areas rely on storm drains to carry large amounts of runoff from roofs and paved areas to nearby waterways. Hard surfaces such as streets, parking lots and built-up areas are impervious surfaces through which, water cannot pass through. As more and more landscapes are covered with hard impervious surfaces, the amount of water that infiltrates, decreases and the amount that runs off, increases. This research is focused on studying run-off conditions in context of urban areas. The study area is Kathmandu Metropolitan City (KMC). The City is in the stage of rapid urbanization and with it, a rapid increase in built-up spaces. As a result, the city is losing a balance between impervious and pervious cover. Loss of greeneries and unpaved open spaces are causing rapid drain of rain-water. This is creating a disturbance in the hydrological cycle of the area. For assessing the extent of runoff, total runoff was estimated of KMC, as per the surface characteristics and using rational method for calculation. Parameters for determining run-off coefficients were mainly land cover and land use data, soil type and slope of surface. Results show that current runoff is alarmingly high, indicated by the difference between the run-off values of pre and post-development scenarios. Urban development pattern has caused a major impact, in the prevailing run-off and it is very crucial that these issues are addressed in urban planning to promote effective solutions for maintaining water cycle and water resources in urban areas.

Keywords: Urbanization, Run-off, Hydrological cycle, Land use

1. Introduction

Urbanization is one of the most important demographic trends of the twenty-first century. Majority of the population growth is concentrated in towns and cities. In context to developing countries, most the urban growth is unplanned, leading to rapid densification, and associated construction of buildings resulting in dramatic increase in impermeable areas due to paving and built-up areas.

As population grows, demand for housing and commercial amenities naturally follows. The urbanization adds roads, rooftops, parking lots, sidewalks, and other imperviousness to the landscape. In recent years, researchers have reported that imperviousness is an effective predictor of environmental degradation [7]. Land surface is covered by buildings and pavement, do not allow rain and snowmelt to soak into the ground. Instead, most developed areas rely on storm drains to carry large amounts of runoff from roofs and paved areas to nearby waterways. The level of economic also has implications to urban hydrology and storm water management in other ways. For instance, the increasing use of the car and other forms of road transport results in a significant increase in impervious areas for the road surfaces and areas for parking. In heavily developed cities, roads and other transport related impervious surfaces can constitute up to 70% of the total impervious urban areas [10].

As per Parkinson & Mark [8], the increase in impermeable areas caused by urbanization has a number of important impacts on the hydrological response from a catchment related to:

1. **Reduced infiltration** capacity of catchment surfaces caused by increasing impervious surfaces and compaction of soil, which reduces the capacity of the soil to absorb moisture.
2. **Reduced surface** (depression) **storage capacity** because impervious urban surfaces are much 'smoother' than natural surfaces.
3. **Decreased evapo-transpiration** due to the loss in the natural retention capacity of soil, reduced vegetation wetting and interception by plants.

A combination of these factors results in a loss of natural attenuation capacity and runoff from urban catchments is characterized by increases in:

1. **Run-off velocity** (often measured as time of concentration)
2. **Run-off volumes** (i.e. the proportion of precipitation that becomes runoff)
3. **Discharge rates** and flood peaks

Figure 1 shows a relation between urban runoff and urban density. As indicated by the hydrographs, more is the density, more is the discharge due to high surface run-off.

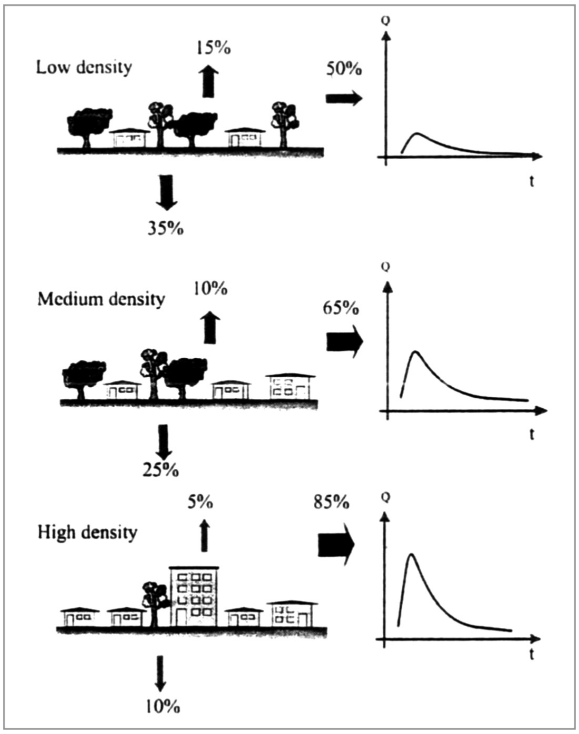


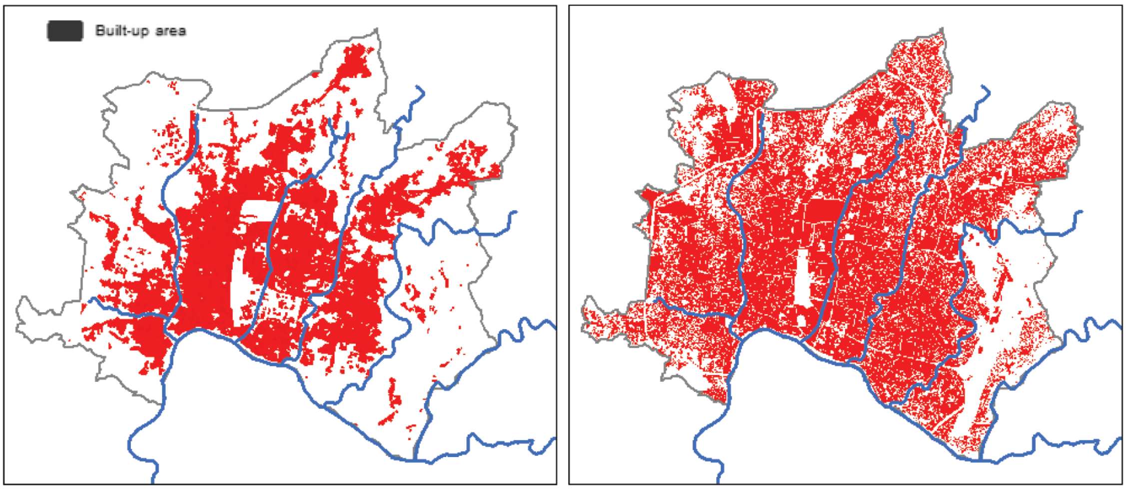
Figure 1: Relationship between surface runoff and impervious cover.

(Source: Butler and Davies, 2004)

2. Study area: Kathmandu Metropolitan Corporation (KMC)

Kathmandu Metropolitan City is a fast growing city with a population of 975, 453 as per census of 2011. The metropolitan city area is 50.67 square kilometers and has a population density of 19,250 per km². The city stands at an elevation of approximately 1,400 meters (4,600 ft) almost in the central part of Kathmandu Valley of Nepal.

Currently, KMC is experiencing a rapid population growth (Table 2) and as a result, substantial open spaces and agricultural land, forest land and vegetation has been converted to built-up area (Figure 1). The built-up area has almost doubled from 1996 to 2008 (Table 1) and still increasing. At the same time, city lacks proper city planning regulations that is leading to unplanned growth. This has given rise to numerous problems including that of rapid runoff. Although there has been few initiation towards addressing environmental concerns, but it is at very slow pace and thus outcome is almost negligible.



(A) (B)

(Source: Landuse 1996, SurveyDept, GoN) *(Source: Landuse 2008, KVDA)*

Figure 2: Built-up area of KMC: (A) Year - 1996; (B) Year – 2008

Table 1: Built-up area in KMC

Year	Built-up area of KMC (Ha)	Built-up %
1996	1,544.83	30%
2008	3,056.62	60%

Table 2: Population growth in KMC

Year	Population (KMC)[1]	Population Density (per Ha)
2001	671,846	133
2011	975,453	193

[1]*Central Bureau of Statistics, Nepal, 2001 & 2011*

With increasing population and built-up area, from the perspective of urban hydrology, the city is facing problems such as:

- Increasing impervious area and losing natural ground and recharge points.
- Loss of underground water table and at the same time excessive underground water extraction due to high water demand for increasing population. This trend will soon lead to rapid loss of underground water table.
- Occasional flash flood during rainfall
- Drying out of water sources and rivers

3. Methodology for Estimating Storm Water Run-off

For assessing urban run-off, it is necessary to estimate run-off volume. Calculating run-off volume is a very complex task as many factors are dependent on it. The methodology used in this research gives an approximate annual run-off volume, which is illustrated in Figure 3. The process is divided mainly into 5 phase.

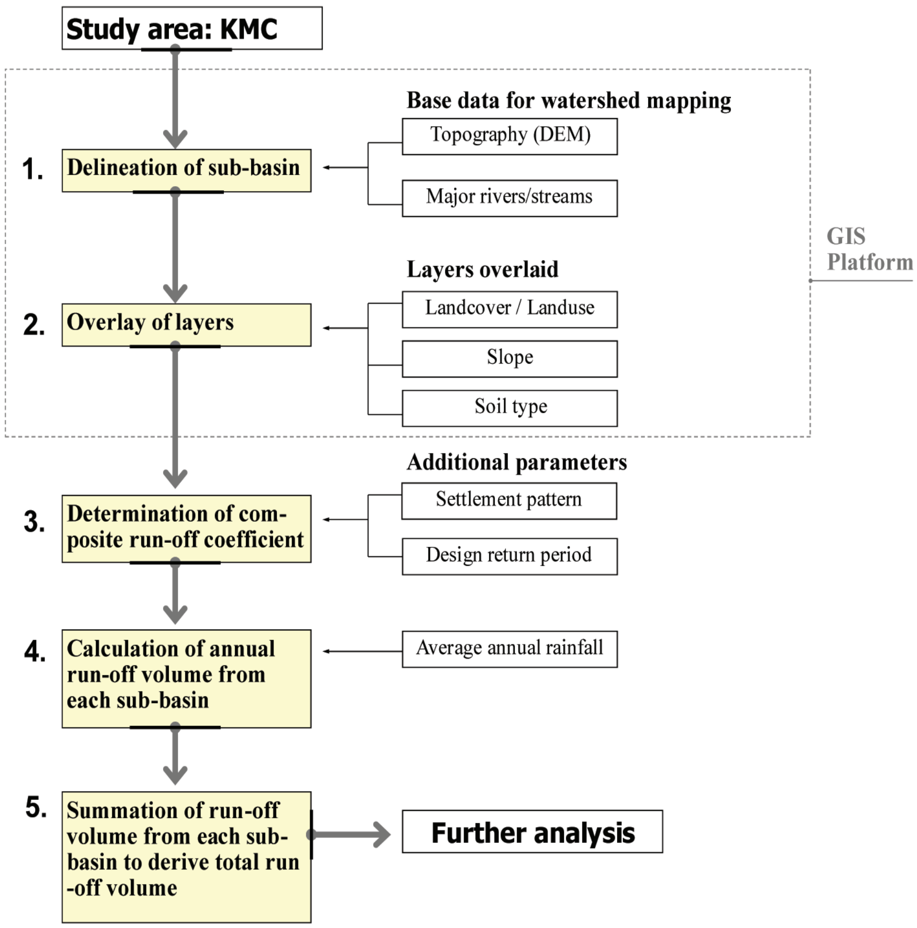


Figure 3: Overview of methodology for run-off estimation

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3.1. Delineation of Sub-basin

For urban run-off analysis, as the nature of surface is heterogeneous, to improve accuracy, analysis has to be carried out at the level of smaller sub-regions. For this research, the whole of the KMC area was divided into 10 sub-basins (watershed regions). Using Geographic Information System (GIS), sub-basins were identified, by watershed area delineation (Figure 4). The basis for delineation was the land topography and along major rivers/streams, taking pour points at the intersections.

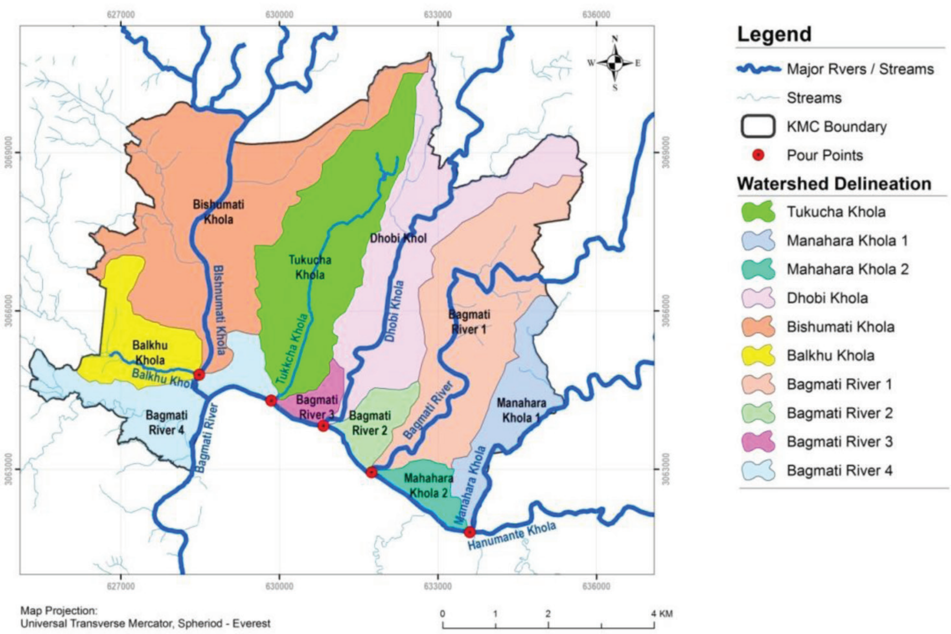


Figure 4: Sub-basins (Watershed Regions)

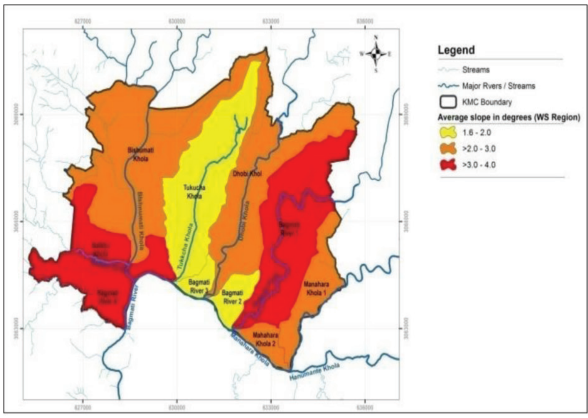
The sub-basins identified and their respective areas are shown in Table 3.

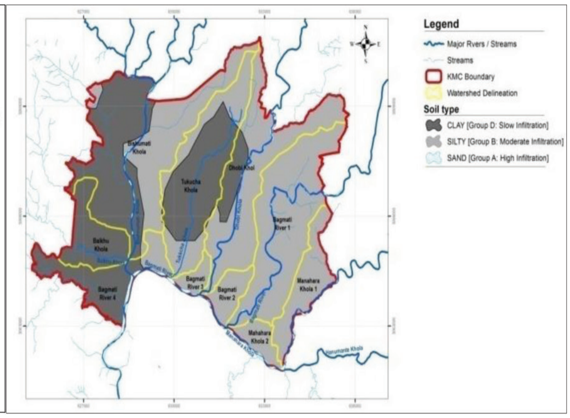
Table 3: Sub-basin description

Sub-basin No.	River	Area (Ha)
1	MahaharaKhola (1)	297.9
2	MahaharaKhola (2)	110.3
3	Bagmati River (1)	909.7
4	Bagmati River (2)	135.1
5	Bagmati River (3)	76.5
6	Bagmati River (4)	398.5
7	BalkhuKhola	299.3
8	TukuchaKhola	829.5
9	Dhobi Khola	844.9
10	BishumatiKhola	1,292.4

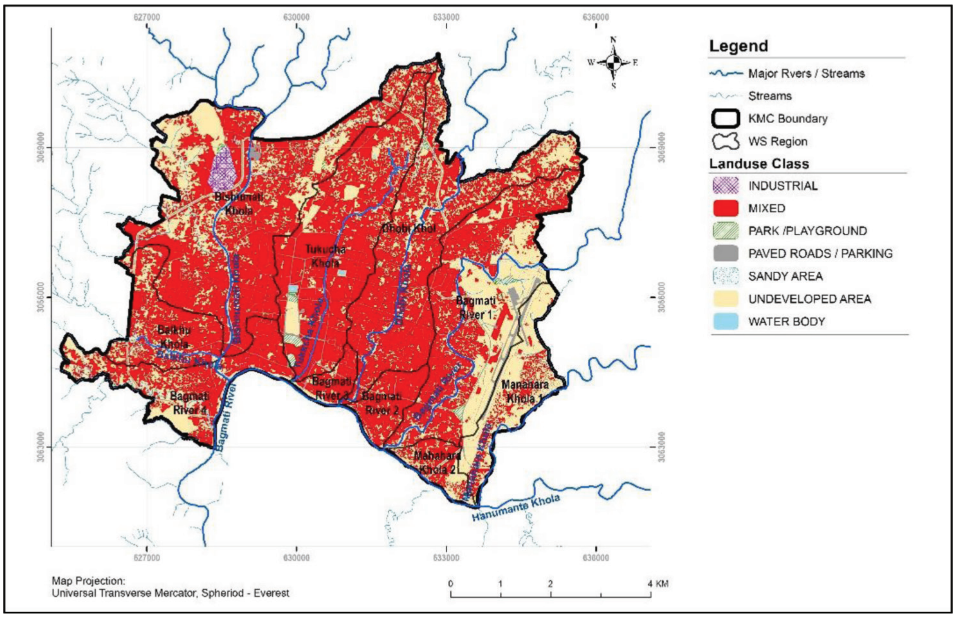
3.2. Overlays of Layers

The runoff coefficient mainly depends on the land-use/ land-cover, slope and soil type of the region. KMC area is relatively flat. Average slope of a watershed region varies from 1.6° to 4.0°. Hydrologic Soil groups found in KMC are Group A, B & D. Most of the region in the study area is of mixed land use.





(A) Average Slope (B) Soil Type



(C) Land-use

(Source: KVDA, 2008)

Figure 5: Different layers used for determination of run-off coefficient

3.3. Determination of Composite Run-off Coefficient

Data from landuse, soil type and slope layers were used further to determine the composite run-off coefficient for each watershed region. Design return period was taken as100 years for drainage area having more than 1000 ha [9]. The standard run-off coefficient values (Table 4) were used in the formula for calculating composite run-off coefficient

Table 4 : Standard Run-off coefficients for different surface types

Hydrologic Soil Group	**A**	**B**	**C**	**D**
Recurrence Interval	**100 years**			
Land Use or Surface Characteristics				
Business:				
A. Commercial Area	.95	.95	.95	.95
B. Neighborhood Area	.65	.70	.75	.80
Residential:				
A. Single Family	.30	.40	.50	.55
B. Multi-Unit (Detached)	.45	.50	.55	.65
C. Multi-Unit (Attached)	.55	.65	.70	.75
D. *1/2* Lot Or Larger	.25	.30	.45	.50
E. Apartments	.60	.70	.75	.80
Industrial				
A. Light Areas	.70	.75	.80	.90
B. Heavy Areas	.95	.95	.95	.95
Parks, Cemeteries,Playgrounds	.15	.25	.40	.45
Schools	.40	.50	.55	.65
Streets				
A. Paved	.95	.95	.95	.95
B. Gravel	.30	.45	.50	.50
Drives, Walks, &				
Roofs	.95	.95	.95	.95
Lawns				
A. 50%-75% Grass				
(Fair Condition)	.15	.25	.40	.40
B. 75% Or More Grass				
(Good Condition)	.10	.20	.30	.40
Undeveloped Surface [1] (By Slope)				
A. Flat (0-1 %)	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
B. Average (2-6%)	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
C. Steep	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38

(Source: IOWA, 2008)

The composite runoff coefficient was weighted, based on the area of each respective land use and can be calculated as:

$$C_w = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_i} \qquad (1)$$

where:

C_w = weighted runoff coefficient

C_i = runoff coefficient for area' **i** '.

A_i = area for land cover' **i** '

n = number of distinct land uses

3.4. Calculation of Annual Run-off Volume

For each sub-basin, annual storm water run-off volume was calculated, using formula having composite run-off coefficient. The total run-off volume was obtained by summing up individual run-off volume from each sub-basin.

A formula given by the rational method was used for calculating potential run-off from a watershed. Three terms - catchment area, composite run-off coefficient and annual rainfall depth were multiplied as shown below. This formula gives an approximate annual run-off volume.

$$V = A_w \times C \times R_D \qquad (2)$$

where,

A_w = Watershed Area

C = Composite Run-off Coefficient of the Watershed Region

R_D = Annual rainfall in mm [in average 1600mm for KMC area]

4. Results and Discussions

Formulation of scenarios and analysing them helps to assess the run-off pattern for different time periods for comparison and evaluation. For this research, the runoff values were derived for two scenarios - Pre and Post-development scenarios which are explained in the following topics.

4.1. Base Scenario: Pre – development

This scenario assumes a hypothetical scenario, whereby no development or settlements exist in the study area and all of the land form is the natural. The run-off co-efficient of all the surface was taken as undeveloped surface and the only influencing factor is the soil type (Figure 5-b). The total run-off resulting in this scenario is almost, 15 million cu.m per annum.

4.2. Current Scenario: Post – development

This scenario is the representation of current scenario, as a result of urbanization. The total run-off for this scenario was calculated based on current landuse, soil type, slope (Figure 5) and standard run-off coefficients.

The run-off values for different watershed regions for both scenarios are tabulated in Table 5 and shown in graph of Figure 6. At the present context, the total runoff is estimated to be almost 40 million cu. m. per annum. When comparing this figure with that of the base-scenario, it is found to be 2.7 times higher. The difference is found to be 25 million cu.m per annum, and this is the excess annual run-off, due to urbanization. This has caused deficit of water that should have infiltrated into the ground as underground water-table or in other forms.

Table 5: Estimated annual run-off from watershed regions

Watershed Region	Annual Runoff in cu.m			Ratio (Post:Pre)
	Pre-Development	Post-Development	Difference	
Bagmati River 1	2180620.7	5962020.8	3781400.1	2.7
Bagmati River 2	322160.9	1112708.3	790547.5	3.5
Bagmati River 3	201477.1	608579.8	407102.7	3.0
Bagmati River 4	1424664.5	3139403.3	1714738.8	2.2
BalkhuKhola	1107088.9	2764498.4	1657409.5	2.5
BishumatiKhola	4062043.6	10479909.1	6417865.5	2.6
Dhobi Khola	2188764.6	6480854.6	4292090.0	3.0
ManaharaKhola 1	715564.4	1443210.5	727646.2	2.0
MahaharaKhola 2	278996.8	682103.2	403106.4	2.4
TukuchaKhola	2633067.4	7595781.1	4962713.6	2.9
Total	**15114448.9**	**40269069.3**	**25154620.4**	**2.7**

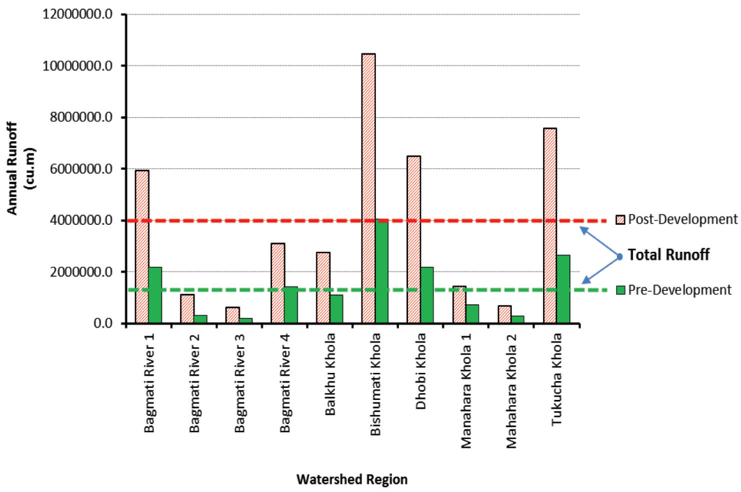


Figure 6: Annual runoff comparison: Post vs Pre-development

4.3. Analysis of Current Run-off and Associated Factors

For accessing the run-off, Annual Excess Runoff per hectare indicator was used. It measures the excess annual runoff per hectare only due to current developments and urbanization, excluding natural runoff. It is the difference between Current runoff (Post-development) and Run-off of base scenario (Pre-development). This indicator is important in analyzing the actual resulting run-off due to man-made developments and changing of natural land form into built-up area.

Figure 7 visualizes this indicator, whereby areas with darker shade show high annual excess run-off and vice versa. Tukucha Khola, Balkhu Khola and Bagmati River 2 watershed regions shows high runoff values. The resulting runoff is mainly due to prevailing development pattern in the regions.

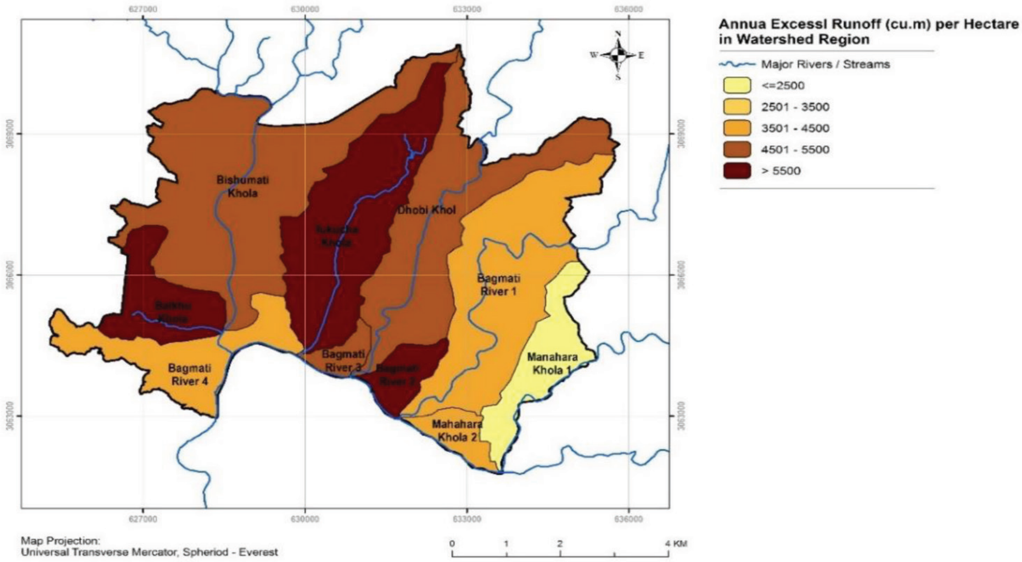


Figure 7: Annual excess runoff per hectare in Watershed Region

(Post-development runoff – Pre-development runoff)

4.4. Regression Model

For studying the factors associated with the run-off, resulting from the city development pattern, a regression model was developed out of three parameters using the data of Table 6. The parameter description is as follows

Dependent variable : Annual excess runoff per hectare (R)
Independent variables : Population density in hectare (D) and Unpaved surface percentage (U)

Table 6: Parameters for regression model

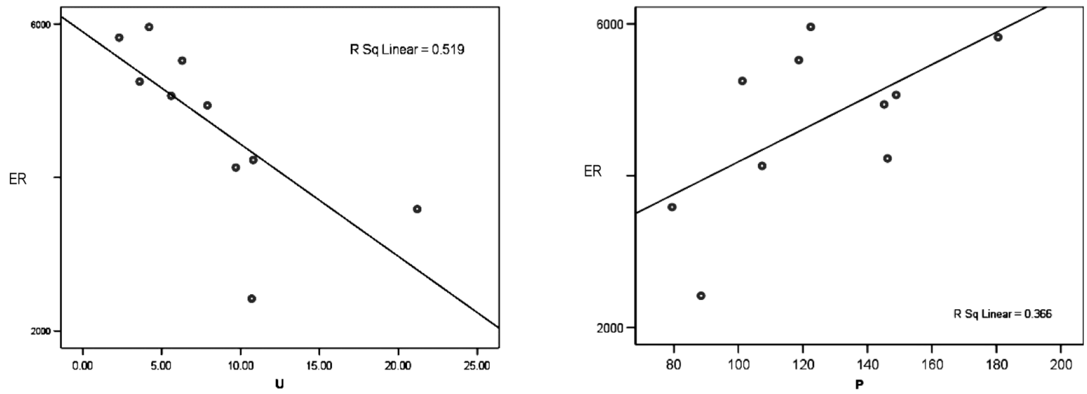
Watershed Region	Population Density (Population per hectare)	Unpaved surface (%) *	Annual excess runoff per hectare
	D	U	ER
Balkhu Khola	118.7	6.3	5524
Bishumati Khola	145.2	7.9	4939
Bagmati River 1	107.3	9.7	4131
Bagmati River 2	180.5	2.3	5825
Bagmati River 3	101.2	3.6	5249
Bagmati River 4	146.2	10.8	4228
Dhobi Khola	148.9	5.6	5065
Manahara Khola 1	79.4	21.2	3588
Manahara Khola 2	88.4	10.7	2420
Tukucha Khola	122.4	4.2	5960

* Open spaces, undeveloped surfaces without any impervious pavements

The regression model equation was derived as follows:

$$\boldsymbol{ER} = (9.6 \times \boldsymbol{D}) - (113.4 \times \boldsymbol{U}) + 4436 \quad [R^2 = 0.57] \qquad (3)$$

The model accounts for 57% of the variation, as indicated by R^2 value of 0.57, showing a dominant role of population density and unpaved surface percentage on urban runoff. Further, to analyze the individual role of each the two factors, they were correlated with the runoff and the results are discussed below.



(a) (b)

Figure 8: Scatter plot diagram (a) ER & U (b) ER & P

The model shows the strong negative correlation (r = - 0.720), between the runoff volume and available open spaces that are unpaved (Figure 8 (a) and Table 7)

The model also shows a moderate positive correlation (r = 0.605) between the run-off volume and population density (Figure 8 (b) and Table 8).

Table 7: Correlation between R & U

		ER	U
ER	Pearson Correlation	1	-.720(*)
	Sig. (1-tailed)		.009
	Number of observations	10	10
U	Pearson Correlation	-.720(**)	1
	Sig. (1-tailed)	.009	
	Number of observations	10	10

** Correlation is significant at the 0.01 level (1-tailed).*

Table 8: Correlation between R & P

		ER	P
ER	Pearson Correlation	1	.605(**)
	Sig. (1-tailed)		.032
	Number of observations	10	10
P	Pearson Correlation	.605(*)	1
	Sig. (1-tailed)	.032	
	Number of observations	10	10

*** Correlation is significant at the 0.05 level (1-tailed).*

Tukucha Khola watershed region is showing the highest excess runoff per hectare, indicated by low unpaved surface percentage and comparatively high population density. In contrary, Manahara Khola 1 has the least runoff value of all, due to more availability of open spaces and less densely populated area. The rapid urbanization has led to sharp increase in population density and built-up area in recent years.

As indicated by the regression model and correlation coefficients, available unpaved surface has a significant role to minimize runoff, shown by a strong negatively correlated relation. But current city planning regulations lack the guidelines to address this issue and as a result, city is becoming more and more compact and loosing most of its open spaces. Population density has also a major role to play in the runoff, as it is the demanding factor for more of the built-up areas (Table 1). Also there is a rapid increment in population in the core city area (Table 2), mainly due to concentrated economic activity and fast immigration of people.

5. Scope and Limitations

Analyzing run-off is a very complex task and many factors related to rainfall characteristics, watershed characteristics, metrological factors and storage characteristics are affecting the actual runoff [1]. The Rational Method, used for calculating run-off used in this research, gives an approximate value. It is generally suitable for small watershed areas, where it is assumed to have uniform rainfall intensity. For precise results, advanced methods such as hydrograph based methods, can be used, that requires complex calculations and advanced computer modeling.

For analysis, in this research, more focus was made from urban planning perspective and thus two main parameters are considered – Availability of Open spaces and Population density. The regression model could further be improved by including other parameters as mentioned above that were not discussed in this research. Even though, from the methodology applied in this research, the results obtained, are approximate, it still provides important clues for planners and policy makers to for scenario evaluation and to study the impact of runoff on environment.

6. Conclusion and Recommendation

The run-off estimation reveals the high overall run-off value, mainly due to two associated factors i.e. increased population density and less availability of open spaces. Almost all of the watershed regions identified, have high run-off value, resulting from the rapid urbanization in all areas of KMC. With urban expansion and development, more of the natural landform will be converted into impervious surface. So, in context of urbanization, it is a major challenge to manage run-off issues in creating a balance among number of factors mainly population growth, scarcity of land, growing water demand, and increase in impervious surface

For any implementation to be successful there has to be a multidisciplinary approach. Government planning agencies should be effective enough for the involvement of all stakeholders like urban planners, architects and engineers, sociologists, hydrologists and other related stakeholders for joint effort in promoting sustainable city development strategies.

The current city development regulations and building bye-laws needs to be updated or amended to address run-off issue, both at city level and individual household level. For instance, a new regulation can be established regarding minimum plot size, which is currently 2.5 anna for a residence. This lower limit should be increased to avoid dense settlements and to create a possibility of having more of the open spaces and natural landscapes. Urban land-use planning should be effective enough in creating a proper balance between open spaces and built-up spaces.

To establish a balance between run-off and infiltration, there can be recharge centres, amidst the dense urban areas. This would insure the excess rain water to infiltrate rain water back to soil. This would require a detail study of the natural landforms to identify existing recharge points or to establish a new recharge point in the vicinity.

At individual household level, there should be sufficient awareness to address this issue. More of the rainwater harvesting technique can be used to meet the water demand as well as for reducing water volume, sent to drain. There can also be a possibility of recharge pits so that rain water is sent directly to underground level rather than to drain channels. People should be encouraged to have more of the natural landscape, wherever possible to minimize sealed surface. To make people fully aware of these techniques and issues, different awareness campaign and community workshops can be conducted to as to impart proper knowledge to them.

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References

[1] AgriInfo (2011), URL: http://www.agriinfo.in/?page=topic&superid=8&topicid=60; Accessed date: September 21, 2013.

[2] Bulter D and Davies J (2004), *Urban Drainage;* E & FN Spon, London.

[3] Central Bureau of statistics (2001, 2011), National Planning Commission Secretariat, Government of Nepal.

[4] Department of Survey (1996), Government of Nepal, GIS Data.

[5] IOWA (2008), "*Stormwater Management Manual*"; URL: http://www.ctre.iastate.edu/pubs/stormwater/documents/2C-4RationalMethod.pdf; (Accessed date: May, 2013)

[6] Kathmandu Valley Development Authority (2008), KMC Land use GIS Data

[7] Moglen G E and Kim S (2007), Limiting imperviousness. *Journal of the American Planning Association* **73(2) :** 161-171.

[8] Parkinson J and Mark O (2005), *Urban Storm water Management in Developing Countries*. IWA Publishing, UK.

[9] Ponce VM, *Return period to be used for design,* URL: http://ponce.sdsu.edu/return_period.html, (Accessed date: May, 2013)

[10] Wong T, Breen P, Somes N and Lloyd S (2000), *Water Sensitive Road Design - Design puons for Improving Storm water Quality of Road Runoff*, Co-operative Research Centre for Catchment Hydrology. Technical Report 00/1. Monash University Australia.