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Urbanization Effect on Watershed Hydrology : A Case Study of Asan River Watershed

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Abstract

Human beings keep on modifying their environment, especially land use/land cover (LULC), in pursuance of comfort and development. The subsequent impact of urbanization to the environment, especially land cover change, now occurs on scales that significantly affect hydrologic variations. The altering environment makes it necessary to understand and quantify various hydrological components for efficient water resource management. Regarding this matter, the hydrological modelling technique can help to gain an understanding of the hydrological system in order to provide reliable information for managing water resources in a sustained manner at a larger scale.

The Asan River watershed, Dehradun district, Uttarakhand State, India, has been chosen as the study area since the evident urbanization/industrialization has been taken place in the watershed. This research studies the change in LULC initially. Then, its impact on hydrology of watershed is studied. For this purpose, LULC change detection during the year 2000 through 2010 has been carried out using the satellite data of Landsat TM of this period. The variable infiltration capacity (VIC) semi-distributed hydrological model is used for hydrological simulation due to its various advantages. It is a grid-based model which includes the representation of sub-grid variability in soil infiltration capacity and vegetation classes. To run this model, it requires four main input files, namely vegetation library, vegetation parameter, soil parameter and meteorological forcing.

The monthly LAI and albedo correspond to each LULC class were derived from MODIS data products, and other vegetation parameters were taken from LDAS database. Soil map has been procured from NBSS&LUP, and standard parameters were used based on FAO. The gridded rainfall and temperature data procured from IMD has been used to generate forcing file. For topographic parameters, ASTER GDEM 30 m resolution has been utilized. The results show that there is a huge increase in built-up/urbanization by 27.25 % (within class) and ~1% (overall) during the period under consideration. Consequently, increasing trend in runoff has been observed. It was realized that a slight change in LULC impacts the entire hydrology of the watershed significantly.

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1. Introduction

Water has a vital role in human life. Water is useful in each and every purpose such as agricultural, industrial, commercial, civil, etc. However, urban development has affected the availability of water and its quality. According to the hydrologic cycle, the water balance is in terms of moisture contained in the atmosphere, surface and oceanic water, and groundwater. The amount of water is circulated through global system by various process namely precipitation, infiltration, evaporation, transpiration and percolation; those have been studied through hydrological models. However, aggravated human development has affected the environment, especially the change of the land use land cover (LULC). The small change in LULC affects the above mentioned hydrological processes and, finally, the water balance.

In pursuance of excel, comfort and development, human beings keep on modifying the environment, especially LULC resulting in huge urbanization that significantly affects hydrologic variations. The altering environment makes it necessary to understand and quantify various hydrological components for efficient water resource management. The water resources management requires a system approach that includes not only all of the hydrological components, but also the links, relations, interactions, consequences, and implications among these components. A thorough knowledge and understanding of the different hydrological phenomena and hydrological cycle as a whole is required in studying the implications of these changes. In this regard, the hydrological modeling technique can help to gain an understanding of the hydrological system in order to provide reliable information for managing water resources in a sustained manner at a larger scale.

Therefore, this project has been taken up to study the impact of urbanization on hydrological regime of Asan River watershed, Dehradun, India. Huge industrialization has taken place within the watershed since Uttarakhand has been declared separate state from Uttar Pradesh. In the present study, variable infiltration capacity (VIC) semi-distributed hydrological model has been used for hydrological simulation. It is a grid based macro-scale model, but its takes in account the sub-grid variability in soil infiltration capacity and vegetation classes.

1.1 Objectives

- To detect land use and land cover change in Asan River watershed
- Hydrological modeling of Asan River watershed
- To quantify the effect of urbanization on watershed hydrology

1.2 Research questions

What is the impact of urbanization on watershed hydrology?

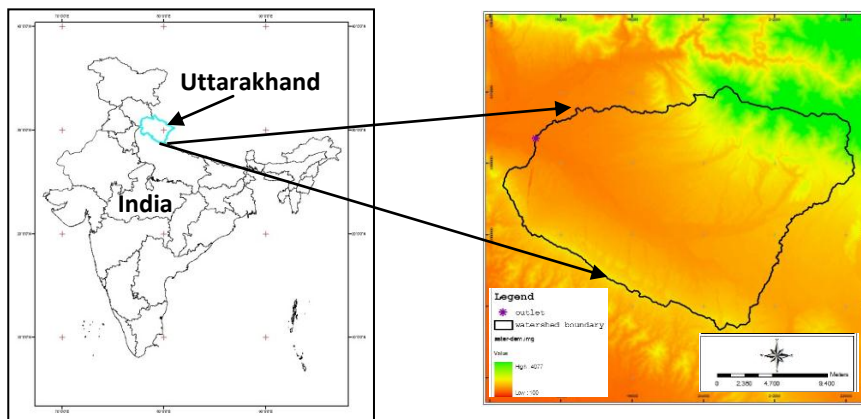


Fig. 1. Study Area: Asan River Watershed

2. Asan River watershed

The Asan River watershed is located between latitudes 30_ 14' 14" N to 30_ 29' 54" N and longitudes 77_ 39' 42" E to 78_ 05' 30" E, Dehradun district, Uttarakhand State, India as shown in Figure 1. It covers an area of approximately 654.47 km. It is bound in the north by the Lesser Himalayan range and in south by the Siwaliks. It forms an asymmetrical synclinal valley. The study area is a part of the intermountain valley situated in the foot hill of lesser Himalaya. Physiographically, the area can be broadly divided into three regions. The northernmost part of the area is occupied by the Himalayan Mountainous Ranges, and high denudation processes occur in it. Geomorphologically, it can be classified as a denudation hill. Northern Siwalik ranges can be found between the Himalayan ranges and alluvial plain as a structural hill. In the southernmost part of the area, Siwalik ranges are highly dissected by the streams due to the lesser compaction of Upper Siwalik rocks and formed as highly dissected structural hill.

Asan river is flowing in the central portion of the area from south-west to north-east direction and flows into the Yamuna river, as a western margin of the area. The tributaries of these two rivers make gentle slopping piedmont plain on both sides of the Asan river. The river terraces can be seen in the area. Due to neotectonic activities of the area, alluvial material underlain by the Siwalik rocks are uplifted and formed as residual hills near the northern margin of piedmont zone with the structural hill. The major drainage present in the area are parallel to sub-parallel, sub-dendritic, trellis, angular, rectangular, intermittent and braided. The drainage of the area is the result of the climatic condition, tectonic structures, unlying geologic formation and geomorphology. The major tributaries of Asan river are Koti, Nun, Suarana, Tons and Sitla Rao. These tributaries emerge from the south slope of Mussoorie hills flowing S-SW and joining the NW flowing main river. And also, many other minor ephemeral tributaries are accompanied during monsoon season. Sub-dendritic pattern and structurally controlled drainage is normally seen in the upper reaches while sub-dendritic to sub parallel drainage is found in the region of Siwalik formation.

The climate of the studied area is sub-tropical to temperate on higher elevation (more than 1,800 m.) It varies greatly from tropical to severe cold depending upon the altitude of area. The average annual temperature is 21°C in the summers and 5°C in the winter. Most of the annual rainfall in the studied area receives the most rain during the months from June to September, July and August. The mean annual rainfall in the watershed is around 1,917 mm. Relative humidity is recorded as 91% in January. There are three distinct seasons of Monsoon, winter and summer. The extreme temperature recorded in the area was 0° to 42° during the winter and summer seasons respectively.

3. Methodology adopted

The effect of the urbanization on the hydrological regime of Asan River watershed has been studied through the hydrological modeling approach. Initially, the change in LULC has been detected between the two periods; i.e., 2000 - 2010. For this purpose, the cloud free Landsat TM satellite images, which cover the entire Asan River watershed area of date 25 November 2000 and 15 December 2010 (Path 146, Row 39) are downloaded (<http://glovis.usgs.gov>) as shown in Figures 2 and 3, respectively

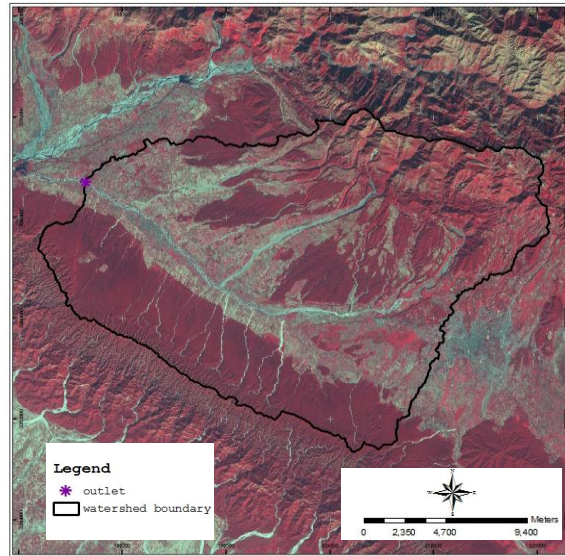


Fig. 2. Landsat TM satellite image of the study area (date: 25.11.2000)

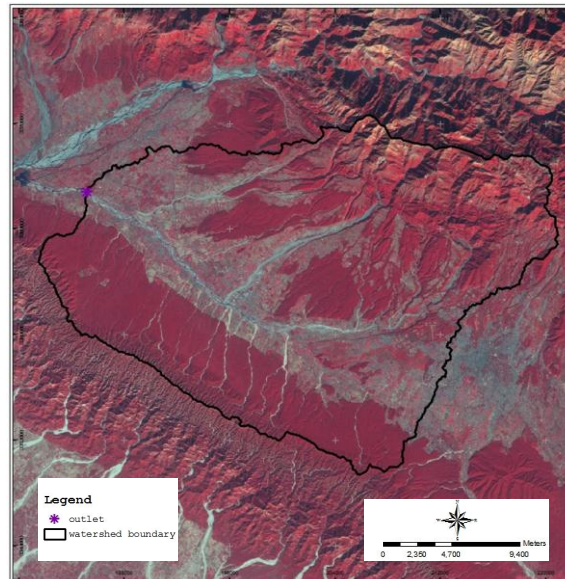


Fig. 3. Landsat TM satellite image of the study area (date: 15.12.2000)

These Landsat images have been used to derive land use/ land cover map of each year 2000 and 2010. The supervised classification derived LULC maps of year 2000 and 2010 are shown in Fig. 4 and 5, respectively. The LULC has been classified into eight classes namely cropland, Sal forest, Pine forest, grassland, plantation, built up, water and dry riverbed. The Selaqui, Sahaspur and Sidhonwala were good agriculture and forested areas before year 2000. However, now Selaqui, which has become huge industrial area after the declaration of Uttarakhand state in year 2000, can easily be interpreted visually. The Sidhonwala region, which was dense Sal forest, is now the hub for new educational institutions and universities. Similarly, Sahaspur and Premnagar towns have grown much faster to cater the needs of these industrial and institutional areas. The year wise fraction of the area of each class and subsequent change has been given in Table 1. It was noticed that most agricultural area has been converted into urban in the watershed.

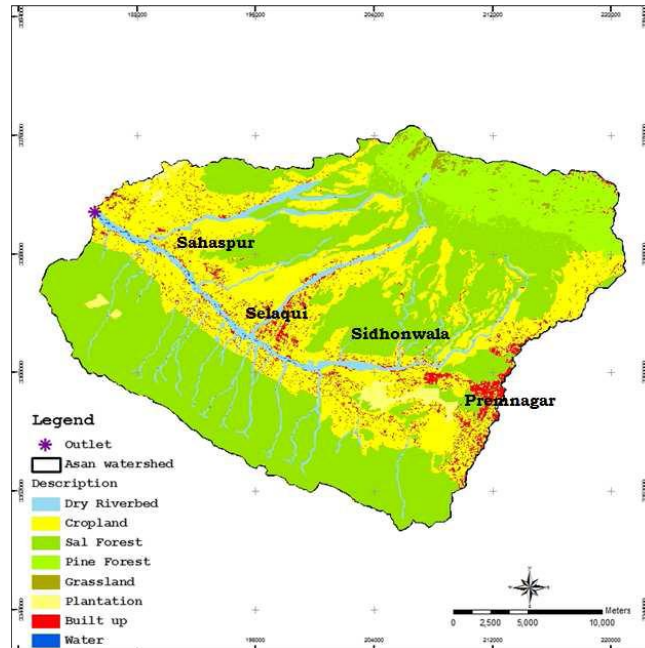


Fig. 4. LULC map of year 2000

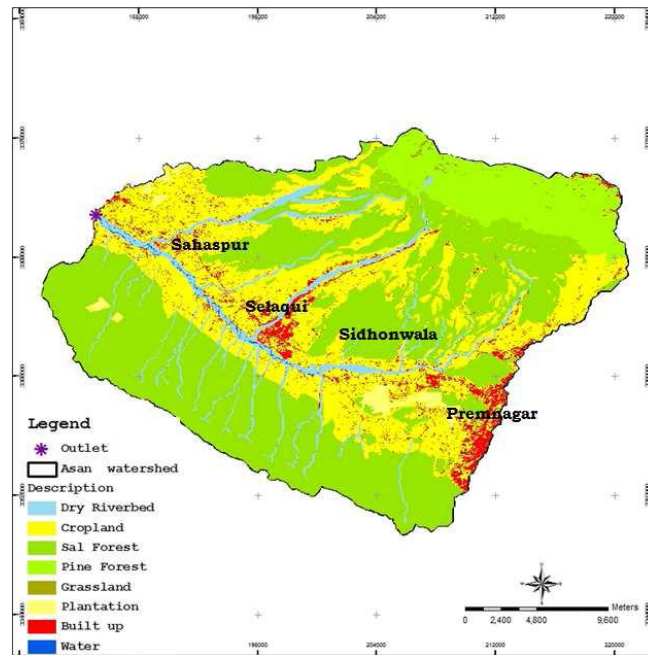


Fig. 5. LULC map of year 2010

Table 1. LULC class area and change from 2000 to 2010

LULC Description	Area in year 2000 (km ²)	Area in year 2010 (km ²)	Change (km ²)	% Change	
				Within Class	Overall
Pine forest	59.47	61.37	1.90	3.19	0.29
Sal forest	315.75	316.60	0.85	0.27	0.13
Grassland	4.73	0.90	-3.83	-80.97	-0.58
Cropland	206.63	201.92	-4.71	-2.28	-0.72
Plantation	8.84	8.79	-0.05	-0.57	-0.01
Built up	22.31	28.39	6.08	27.25	0.93
Dry Riverbed	37.44	36.70	-0.74	-1.98	-0.11
Water	0.90	1.40	0.50	55.56	0.08
Total	656.07	656.07			

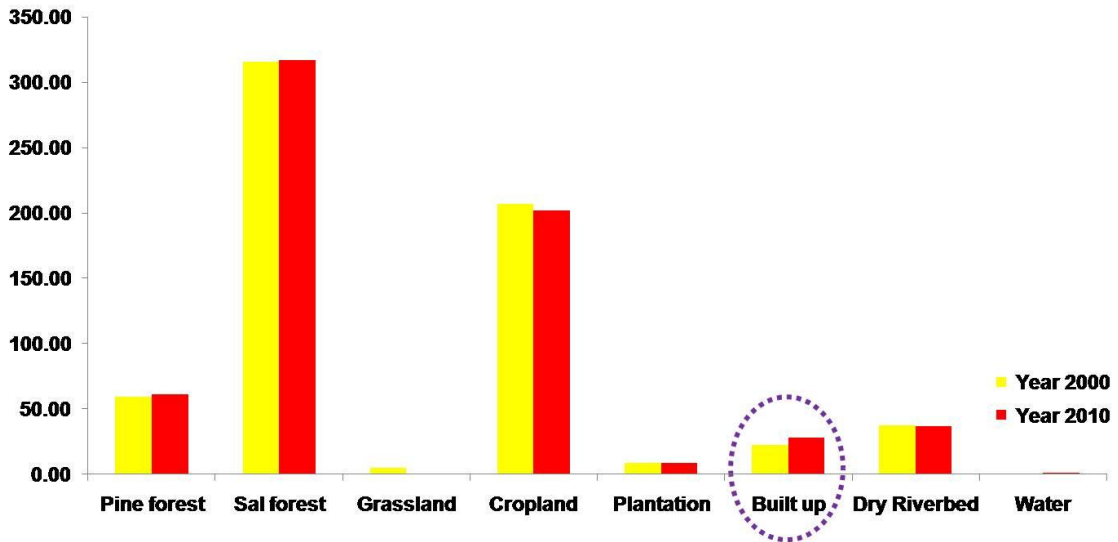


Fig. 6. (a) Land use/land cover change on year 2000 to 2010

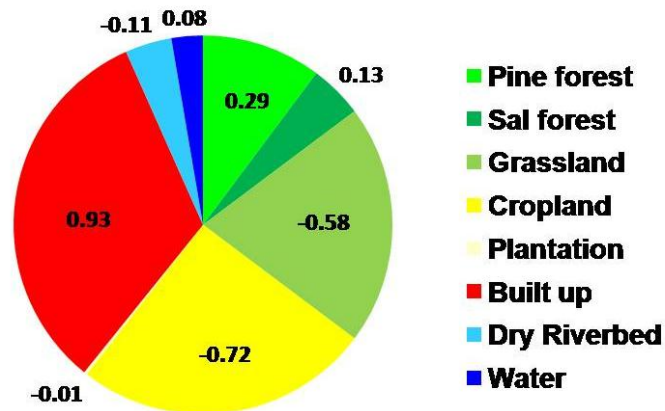


Fig. 6. (b) % Land use/land cover change on year 2000 & 2010 (overall)

Table 1. and fig. 6. depict that there is change in LULC, mainly from cropland to built-up due to industrialization/urbanization. Therefore, there will certainly be some impact of these changes on hydrology of the watershed as well. To analyze these impacts, the hydrological modeling approach has been adopted. In order to simulate watershed hydrology, the VIC macroscale hydrological model has been adopted, which works on grid basis.

3.1 VIC hydrological modeling

VIC is a semi-distributed macroscale hydrological model, developed to study surface energy, hydrological fluxes and states at scales from large river basins to the entire globe. It is a grid based semi distributed hydrological model which quantifies the dominant hydrometeorological process taking place at the land surface atmospheric interface. VIC computes the vertical energy and moisture flux in the grid cell based on the specification at each grid cell, considering soil properties and vegetation coverage. Also, it includes the representation

of sub grid variability in soil infiltration capacity and all mosaic of vegetation classes in any grid cell. The further details about the model can be found at VIC website <http://www.hydro.washington.edu/Lettenmaier/Models/VIC>. The successful application of the model for hydrological simulation can be seen in Liang (1994), Liang et al. (1994), Liang et al. (1996), Abdulla et al. (1996), Nijssen et al. (1997), Wood et al. (1997), Lohmann et al. (1998a, b), Cherkauer and Lettenmaier (1999), Lettenmaier (2001), Maurer et al. (2001a,b), Yuan et al. (2004), Liang et al. (2004) and Gao et al. (2009). The model has also been used to study the impact of LULC change on hydrology by various researchers across the world (Matheussen et al. 2000; VanShaar et al. 2002; Dadhwal et al. 2010).

As mentioned above, the model works on grid basis, a square grid of area 1 x 1 km. was generated over the studied area (Asan watershed) as shown in Fig. 7.

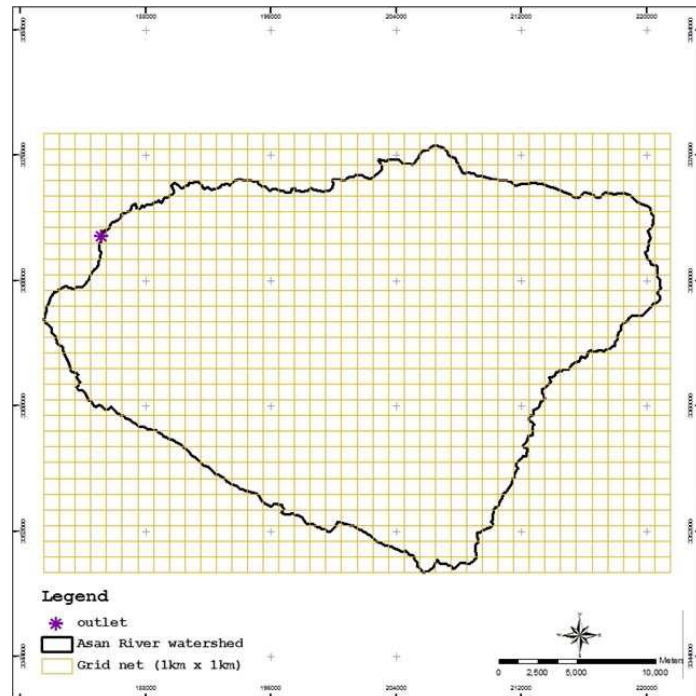


Fig. 7. The 1 x 1 km grid map of the Asan watershed

The grid map was intersected with the watershed boundary, and it was identified that 676 numbers of grids out of 1,120 lie within the watershed boundary which are to be run for analysis. The extracted grid network for the watershed was used to overlay with the other thematic layers and, hence, to define the distribution of various parameters and properties in watershed. The VIC model requires the definition of input parameters for each grid distributed uniformly over the area. In order to implement the VIC model, five main input files are required namely forcing, soil parameter, vegetation parameter, vegetation library and global parameter file in ASCII format.

The main aim of the study was to study the impact of LULC change on hydrological regime of Asan River watershed; therefore, the meteorological forcing has been kept constant. For the preparation of the meteorological forcing, the Indian Meteorological Department (IMD) gridded data of daily rainfall (0.5_o); maximum and minimum temperature (1.0_o) corresponding to year 2005 was used. However, the soil parameter file was derived based on the texture retrieve from the National Bureau of Soil Survey and the Land Use Planning (NBSS&LUP) as shown in Figure 7. It was observed that mainly loam, sandy clay loam and silt loam are present in studied area. The soil parameters such as bulk density, field capacity, wilting point, saturated hydraulic conductivity ($ksat$), slope of retention curve (b) corresponding to each texture were taken from the

standard table and the remaining was calculated as available/directed on the VIC model website under the VIC model input section. The ASTER digital elevation model (DEM) with 30 m resolution, shown as base map in the Fig.1, has been used for elevation and slope parameters. For the average rainfall, 30 years (1976 - 2005) IMD gridded rainfall data has been averaged for each grid under consideration.

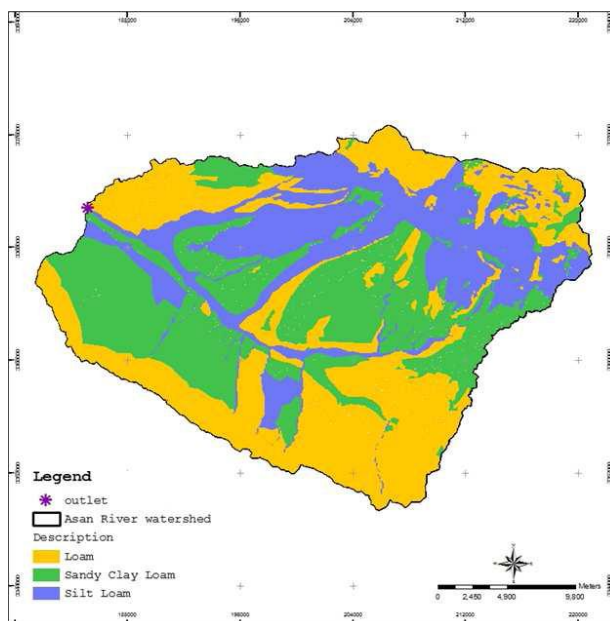
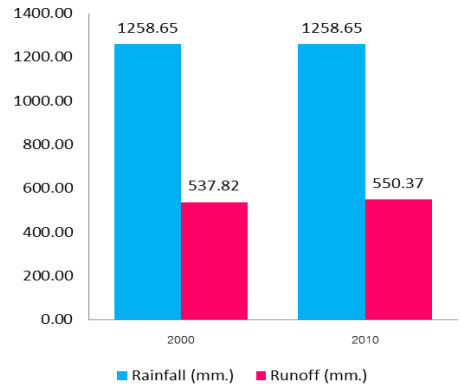
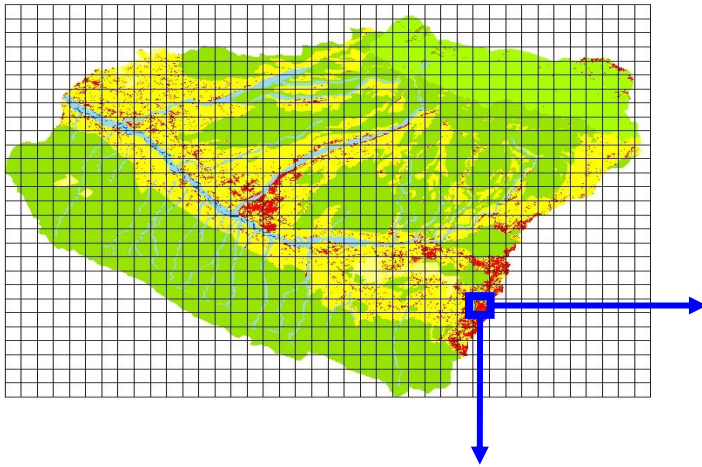


Fig. 8. NBSS&LUP soil map of the Asan River watershed

The vegetation parameter and vegetation library files were prepared corresponding to LULC classes present in LULC maps derived earlier. The fraction of each LULC class under each grid has been extracted and saved as vegetation parameter file. However, the parameters namely leaf area index, albedo, roughness length, displacement height, over-story, architectural resistance, minimum stomatal resistance corresponding to each LULC class for the generation of vegetation library file have been taken from the Land Data Assimilation System data (<http://ldas.gsfc.nasa.gov/nldas/NLDASmapveg.php>). Finally, the global parameter file, which is the main control file, comprised of all instruction and location of all input files has been prepared. Then, the VIC model has been run on the Linux platform, and the results obtained are discussed in following section.

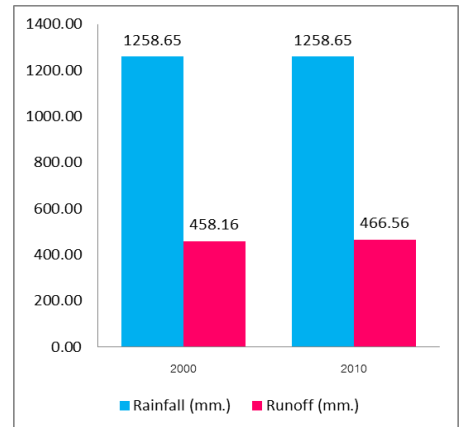
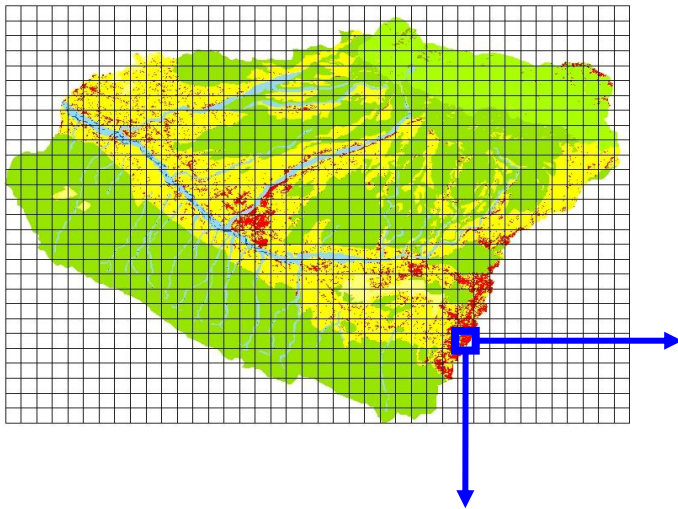
4. Results and Conclusions

To study the impact of LULC change on the hydrological regime of Asan River watershed, the VIC hydrological modeling approach has been adopted. The VIC model is a grid based model as mentioned above. Initially, the grid has been identified where the maximum change especially urbanization has taken place. In this section, results based on runoff potential have been discussed for the grids that have been transformed to urban/industry from some other LULC class. It was noticed that mainly such grids are located in the Selaqui and Premnagar regions of the basin. For example, the grid wise results of grid number 870 and 910 which belong to Premnagar; and grid number 577, 537 and 617 those belong to Selaqui industrial area are discussed here with a bar chart showing some change in their runoff potential in Fig. 9.



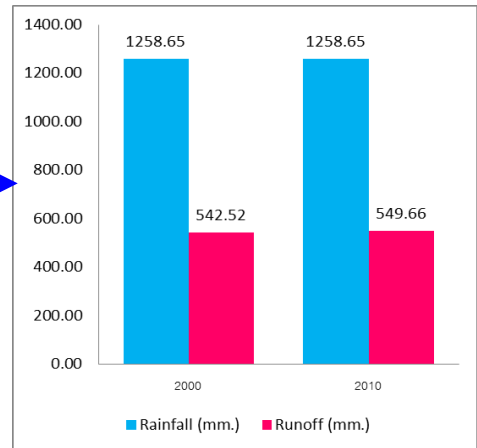
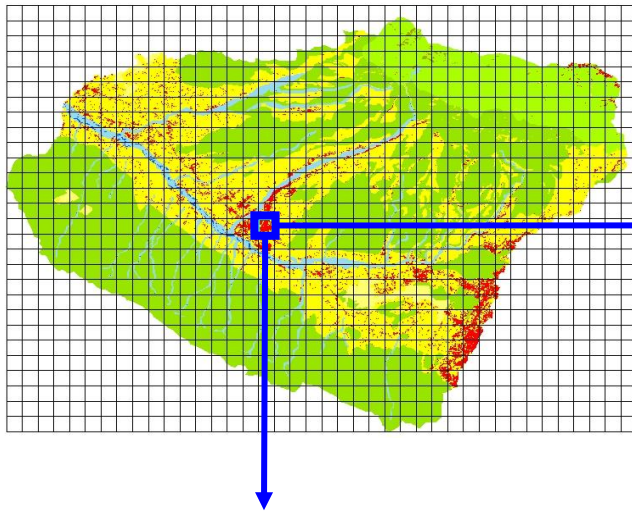
Grid No 870	Built up (km2)	Rainfall (mm.)	Runoff (mm.)
Year 2000	0.27	1258.65	537.82
Year 2010	0.77	1258.65	550.37
Change	0.50	-	12.55

(a) Grid No. 870



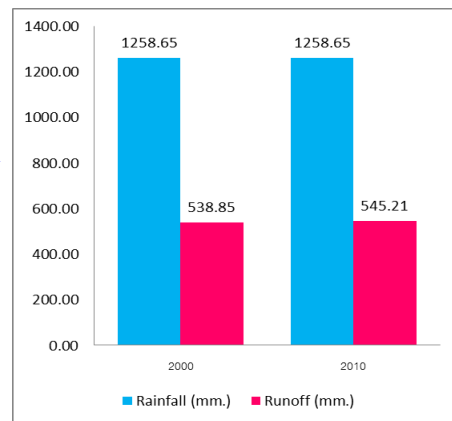
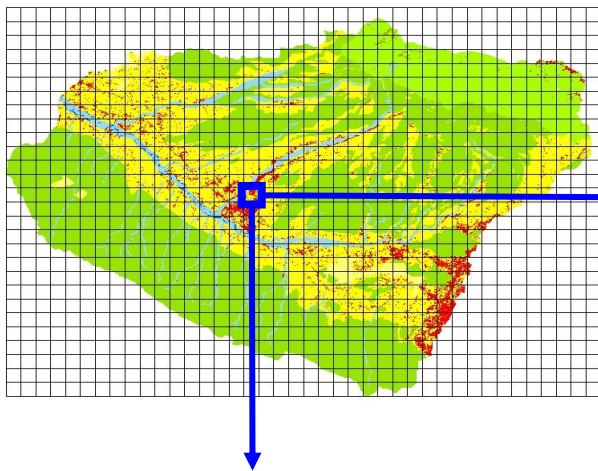
Grid No 910	Built up (km2)	Rainfall (mm.)	Runoff (mm.)
Year 2000	0.28	1258.65	458.16
Year 2010	0.62	1258.65	466.56
Change	0.34	-	8.40

(b) Grid No. 910



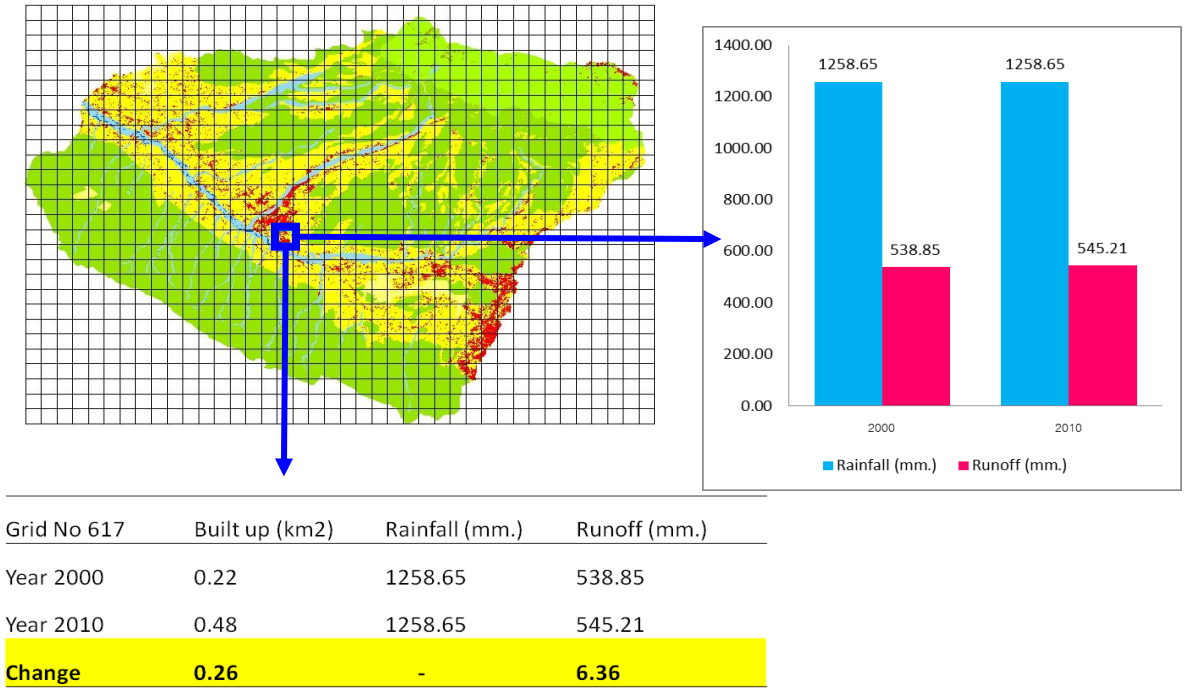
Grid No 577	Built up (km2)	Rainfall (mm.)	Runoff (mm.)
Year 2000	0.38	1258.65	542.52
Year 2010	0.67	1258.65	549.66
Change	0.30	-	7.14

(c) Grid No. 577



Grid No 537	Built up (km2)	Rainfall (mm.)	Runoff (mm.)
Year 2000	0.15	1258.65	538.85
Year 2010	0.39	1258.65	545.21
Change	0.24	-	6.36

(d) Grid No. 537



(e) Grid No. 617

Fig. 9. Grid wise effect of LULC change on hydrology

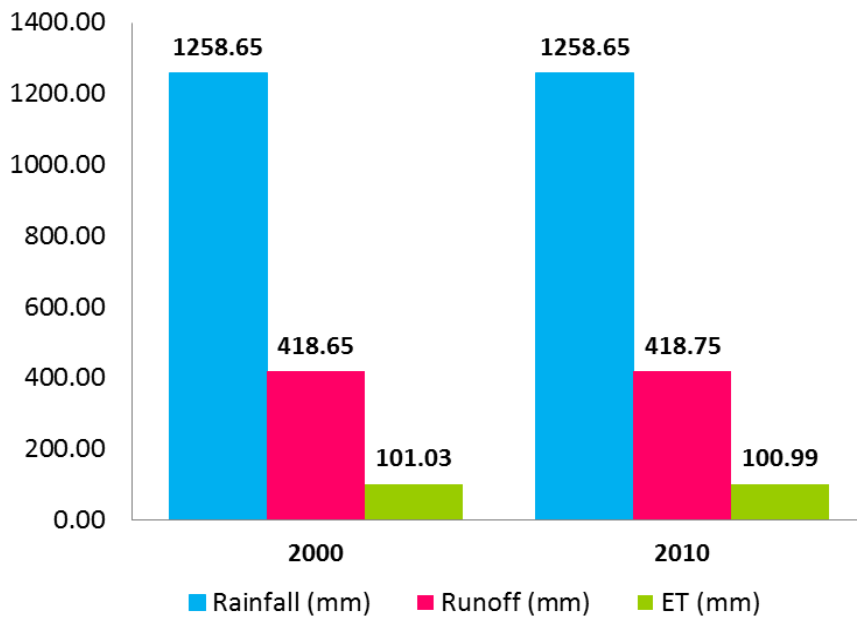


Fig. 10. Plot of Average Rainfall, Estimate Runoff and Evapotranspiration

A summary of the result of the impact of LULC change of hydrology (runoff potential) of each grid under consideration is provided in Table 2.

Table 2. Summary of results showing change in built-up fraction and consequently Runoff

Grid No.	Fractional Area of Built Up				Estimated Runoff (mm)			
	2000	2010	Change	% Increase	2000	2010	Increase	% Increase
617	0.22	0.48	0.26	118.18	538.85	545.21	6.36	1.18
537	0.15	0.39	0.24	160.00	538.85	545.21	6.36	1.18
577	0.38	0.67	0.29	76.32	542.52	549.66	7.14	1.32
910	0.28	0.62	0.34	121.43	458.16	466.56	8.40	1.83
870	0.27	0.77	0.50	185.19	537.82	550.37	12.55	2.33

According to Table 2, grids 577, 537 and 617, belong to the Selaqui industrial area; those are mostly comprised of the built-up area, especially the industries. They have come after the year 2000 when Uttarakhand State has been divided from Uttar Pradesh State. As the capital and plane region of hilly state Uttarakhand, the Dehradun city is a favorable spot for industrialization. Moreover, the Government of Uttarakhand has taken steps to develop industry in Dehradun city for economic growth of the state. Since then, huge industries are established and the number of industries are being constructed in this area. However, grids 870 and 910, those belong to Premnagar, Dehradun city, exposed to maximum increase in built up area, become urban to cater the needs of Selaqui industrial and Sidhonwala institutional areas.

The impact of this industrialization/urbanization has been studied in the present study. It was noted that wherever built-up area increases, runoff potential increases. Such change in hydrology may lead to urban flooding in years to come in the region. Moreover, the industrialization in the region has been taken place along the tributaries of the river Asan, which may lead to pollution and deteriorate the quality of water. It was also realized that due to its distinguishing characteristics such as subgrid variability in land surface vegetation classes, soil moisture storage capacity, base flow as a nonlinear recession, and the inclusion of topography (that allows for orographic precipitation and temperature lapse rates), the VIC model results in more realistic hydrology in mountainous regions.

References

- [1] Abdulla, F. A., et al. (1996), Application of a macroscale hydrologic model to estimate the water balance of the Arkansas Red River basin, *J. Geophys. Res.-Atmos.*, 101(D3), 7449-7459.
- [2] Abdulla, F. A., and D. P. Lettenmaier (1997a), Development of regional parameter estimation equations for a macroscale hydrologic model, *Journal of Hydrology*, 197(1-4), 230-257.
- [3] Abdulla, F. A., and D. P. Lettenmaier (1997b), Application of regional parameter estimation schemes to simulate the water balance of a large continental river, *Journal of Hydrology*, 197(1-4), 258-285.
- [4] Anil Kumar Misra, Impact of Urbanization on the Hydrology of Ganga Basin (India), © Springer Science+Business Media B.V. 2010.
- [5] Ahn, G.C., 2007. The effect of urbanization on the hydrologic regime of the Big Darby Creek Watershed, Ohio, PhD dissertation, The Ohio State University, Columbus, Ohio, 172p.
- [6] Arora, V. K. (2001), Assessment of simulated water balance for continental-scale river basins in an AMIP 2 simulation, *J. Geophys. Res.-Atmos.*, 106(D14), 14827-14842.
- [7] Calder, I. R. (1993), Hydrological effects of land-use change. Handbook of Hydrology, D.R. Maidment, Ed., McGraw-Hill, 3.1-3.50.
- [8] Card, D.H., 1993, Examination of a simple surface composition model of the urban environment using remote sensing, Doctoral dissertation, The Department of Geography, The University of Utah.

- [9] Carlson, T.N and S. T. Arthur, 2000, The impact of land use - land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective, *Global and Planetary Change*, 25: 49-65.
- [10] Cherkauer KA, Bowling LC, Lettenmaier DP (2003) Variable infiltration capacity cold land process model updates, *Global Plan. Change* 38:151-159.
- [11] Cherkauer, K. A., et al. (2003), Variable infiltration capacity cold land process model updates, *Global Planet Change*, 38(1-2), 151-159.
- [12] Dufour, K, M. Meehan, A. Van Kely, B. Weber, R. Will, I. Yeo, S. Gordon, and M. Conroy, 2001, Development and change in the Big Darby watershed, City and Regional Planning Regional Planning Studio, The Ohio State University, 120 pp.
- [13] Evans, J. and Schreider, S.: 2002, 'Hydrological impacts of climate change on inflows to Perth, Australia', *Clim. Change* 0(3), 361–393.
- [14] Goodchild M. F. (1996), the application of advanced technology in assessing environmental impacts, In *Application of GIS to the Modeling of Non-point Source Pollutants in the Vadose Zone* edited by D. L. Corwin and K. Loague, Soil Science Society of America: 1-17.
- [15] Haddeland, I., et al. (2007), Hydrologic effects of land and water management in North America and Asia: 1700-1992, *Hydrology and Earth System Sciences*, 11(2), 1035-1045.
- [16] Hellweger F. L. and Maidment D. R. (1999), Definition and connection of hydrologic elements using geographic data, *Journal of Hydraulic Engineering* 4: 10-18.
- [17] Huang, M. Y., and X. Liang (2006), On the assessment of the impact of reducing parameters and identification of parameter uncertainties for a hydrologic model with applications to ungauged basins.
- [18] Hurkmans, R., et al. (2008), Water balance versus land surface model in the simulation of Rhine river discharges, *Water Resour Res*, 44(1).
- [19] John R. Herald, 1989. *Hydrological Impact of urban development in the Albany basin, Auckland, PhD dissertation, the University of Auckland, Auckland, New Zealand.*
- [20] Liang, X., Lettenmaier, D. P., Wood, E. F., and Burges, S. J.: 1994, 'A simple hydrologically based model of land surface water and energy fluxes for general circulation models', *J. Geophys. Res.* 99, 14,415–14,428.
- [21] Liang, X., Lettenmaier, D. P., and Wood, E. F.: 1996, 'One-dimensional statistical dynamic representation of subgrid spatial variability of precipitation in the two-layer variable infiltration capacity model', *J. Geophys. Res.* 101, 21,403–21,422.
- [22] Liang, X., et al. (1996), Surface soil moisture parameterization of the VIC-2L model: Evaluation and modification, *Global Planet Change*, 13(1-4), 195-206.
- [23] Liang, X., et al. (1999), Modeling ground heat flux in land surface parameterization schemes, *J. Geophys. Res.-Atmos.*, 104(D8), 9581-9600.
- [24] Liang, X., and Z. H. Xie (2003), Important factors in land-atmosphere interactions: surface runoff generations and interactions between surface and groundwater, *Global Planet Change*, 38(1-2), 101-114.
- [25] Liang, X., et al. (2003), A new parameterization for surface and groundwater interactions and its impact on water budgets with the variable infiltration capacity (VIC) land surface model, *J. Geophys. Res.-Atmos.*, 108(D16).
- [26] Liang, X., et al. (2004), Assessment of the effects of spatial resolutions on daily water flux simulations, *Journal of Hydrology*, 298(1-4), 287-310.
- [27] Mitas L. and Mitasoca H. (1998), Distributed soil erosion simulation for effective erosion prevention. *Water Resources Research* 34: 505-16.
- [28] Mizyed N (2009) Impact of climate change on water resources availability and agricultural water demand in the west bank. *Water Resour Manage* 23(10):2015-2029.
- [29] Michael O'Driscoll, Sandra Clinton, Anne Jefferson, Alex Manda and Sara McMillan, Urbanization Effects on Watershed Hydrology and In-Stream Processes in the Southern United States. www.mdpi.com/journal/water.
- [30] Shultz G. A. (1997), Use of remote sensing data in a GIS environment for water resources management, in *Remote Sensing and GIS for Design and Operation of Water Resources Systems*, edited by Baungartner M, Schultz G. A. and Johnson A. L., IAHS Press, Institute of Hydrology, Wallingford, Oxfordshire, UK.
- [31] Myneni, R. B., et al. (1997), Estimation of global leaf area index and absorbed par using radiative transfer models, *Ieee Transactions on Geoscience and Remote Sensing*, 35(6), 1380-1393.
- [32] Nijssen, B., et al. (2001b), Global retrospective estimation of soil moisture using the variable infiltration capacity land surface model, 1980-93, *J. Clim.*, 14(8), 1790-1808.
- [33] O'Donnell, G. M., et al. (2000), Macroscale hydrological modeling using remotely sensed inputs: Application to the Ohio River basin, *J. Geophys. Res.-Atmos.*, 105(D10), 12499-12516.
- [34] Su, F. G., and Z. H. Xie (2003), A model for assessing effects of climate change on runoff in China, *Progress in Natural Science*, 13(9), 701-707.
- [35] Wood EF, Lettenmaier DP, Zartarian VG (1992) A land-surface hydrology parameterization with subgrid variability for general circulation models. *J Geophys Res* 97:2717-2728.
- [36] Xie, Z. H., et al. (2007), Regional parameter estimation of the VIC land surface model: methodology and application to river basins in China, *Journal of Hydrometeorology*, 8(3), 447-468.
- [37] Zhu, C. M., et al. (2009), Evaluating the influence of antecedent soil moisture on variability of the North American Monsoon precipitation in the coupled MM5/VIC modeling system, *The Journal of Advances in Modeling Earth Systems*, submitted.