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Surface Water Flow of Urban Areas and Sustainable Urban Planning

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***Abstract*—**Urban planning is associated with land transformation from natural areas to modified and developed ones which leads to modification of natural environment. The basic knowledge of relationship between both should be ascertained before proceeding for the development of natural areas. Changes on land surface due to build up pavements, roads and similar land cover, affect surface water flow. There is a gap between urban planning and basic knowledge of hydrological processes which should be known to the planners. The paper aims to identify these variations in surface flow due to urbanization for a temporal scale of 40 years using Storm Water Management Mode (SWMM) and again correlating these findings with the urban planning guidelines in study area along with geological background to find out the suitable combinations of land cover, soil and guidelines. For the purpose of identifying the changes in surface flows, 19 catchments were identified with different geology and growth in 40 years facing different ground water levels fluctuations. The increasing built up, varying surface runoff are studied using Arc GIS and SWMM modeling, regression analysis for runoff. Resulting runoff for various land covers and soil groups with varying built up conditions were observed. The modeling procedures also included observations for varying precipitation and constant built up in all catchments. All these observations were combined for individual catchment and single regression curve was obtained for runoff. Thus, it was observed that alluvial with suitable land cover was better for infiltration and least generation of runoff but excess built up could not be sustained on alluvial soil. Similarly, basalt had least recharge and most runoff demanding maximum vegetation over it. Sandstone resulted in good recharging if planned with more open spaces and natural soils with intermittent vegetation. Hence, these observations made a keystone base for planners while planning various land uses on different soils. This paper contributes and provides a solution to basic knowledge gap, which urban planners face during development of natural surfaces.

***Keywords*—**Runoff, built up, roughness, recharge, temporal changes.

I. Introduction

PHYSICAL planning nowadays is equipped with modern means as well as best technologies, but the basic knowledge of natural processes is still lagging behind from the hands of urban planners. Development of schemes, projects, cities etc. are only supported by plans and statistics of natural resources but indulging this knowledge in planning and in implementation are too less than required.

As per present world facts and conclusions from various summits, conferences, researches and programs, it has been observed that there is dramatic change in urbanization as well as in natural systems all over the world. The facts of increasing urbanization and variations in natural systems are identified by different organizations, scientists and various departments like IPCC, [1] UNEP, UNESCO [2] USGS, Rio Summit, and MDG etc. The panelists at World Water day [3] identified rapid urbanization, [4] poor planning, inadequate investments and overdependence on external resources [5] as the main challenges facing water management in cities. Surface runoff occurs relatively rapidly in the urban watershed [6], since storage and infiltration capacity have been reduced to particularly zero. Much of the surface consists of impervious materials such as concrete or asphalt.

Urbanization is a major issue in present scenario [7] and water scarcity and floods too [8] are directly linked with urban areas correlating the increasing built up areas and resulting runoff leading to declining ground water levels.

The project aims to detect the changes and correlate the parameters like built up and runoff with temporal scale and use this correlation for urban planning and management, in accordance with by laws and guidelines. To identify above identified relation as crucial consideration in urban development and planning by proposing local as well as regional level planning laws for workable natural conditions during urban development by planners.

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II. Aim

The study aims to develop an understanding of relationship between surface water runoff and ground water recharge with respect to changes in land characteristics resulting from urbanization in the study area.

A. Objective

1. To examine variations in surface runoff in varied spatial and temporal scale and its relationship to land cover and land characteristics. To examine provisions and prospects related to land characteristics in different physical planning parameters with respect to natural water availability in form of infiltration and develop the relationship for sustainable urban planning (Land Characteristics). In this paper, land characteristics means built up area as impervious surface due to buildings, roads, parking, pavement, roof and paved surfaces.

B. Scope

1. Land characteristics are studied on following parameters: built up, open spaces, parks, commercial areas, residential areas, paved parking, roofs, driveway, streets and roads only.

2. Study is confined to areas having particular soil types like Deccan, Basalt, sandstone and Alluvial and physical features have slope 0 meter to 20 meter (+-20%), width (0 km to 15 km) +-20% and Manning's 'n' for impervious area ranging from 0.11 to 0.84. The depression storage for impervious is from 0.11mm to 90mm and for, pervious surface from 60 to 250mm.
3. Use of calculations in MS Excel and computer aided model for simulation. Software's for digitizing and detailing -Civil 3D, SWMM, Excel, MS Word.
4. The study is confined to observations of built up character and runoff analysis giving results for flooding, storage, ponding in depressions, flooding in junctions, obtained from simulation

C. Limitations

1. Finding out the possibilities of no recorded data available from rain gauge for runoff, observations from computer models (like SWMM/Civil 3d and others) and different methods will be used.
2. Information on aspects such as urbanization, built up, colony data and ground water levels will be collected through primary data or through any secondary source.
3. On basis of observed correlations and effects of urban and hydrological parameters, develop a model explaining interdisciplinary perspective of the urban land characteristics and water replenishment.

III. Methodology

Following methodology has been used to correlate the two cycles-urban and water cycle.

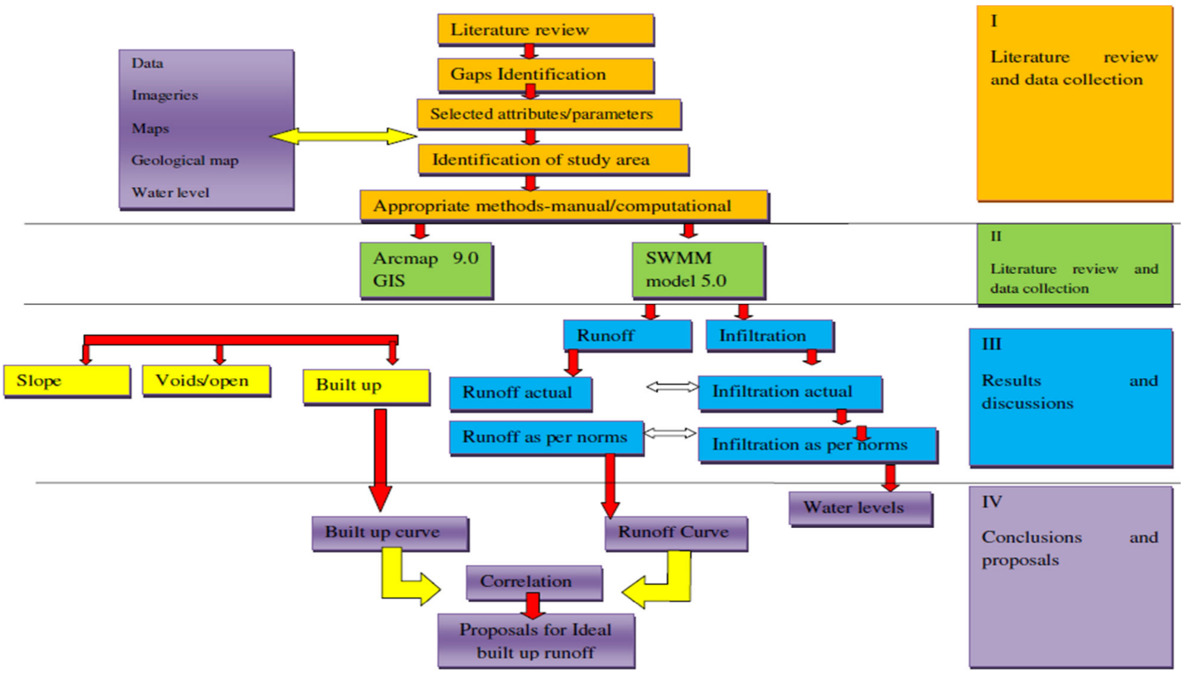


Fig. 1 Methodology finalized

A. Methods Used

1. Stage One

- After finalizing the aim, objectives and methodology, data was collected.
- Study area was decided.
- The imageries for required temporal years were obtained from MPCST.
- The imageries were digitized on basis of Arc GIS and land covers were found for following years.
- Water level data was obtained from Master Plan and State Ground water board, Bhopal.
- The catchments were subdivided into Sub-catchments and digitized to calculate the built up area from 1971 to 2013 for each area.

2. Stage Two

- Each catchment was categorized as per the SCS curve number, Manning's N and Soil group according to geological map by GSI.
- Water level data for each catchment of 40 years was observed and verified for decline in recharge, and critical parts were scrutinized.
- The data was imported in SWMM Model and detail network of Road, Drain ages and junctions with storage areas were developed.
- For simulation time series data for 6 months' critical rainfall was added to the simulation and simulation was run for the whole temporal period keeping precipitation value same.

- The observations were analyzed for changes in infiltration, runoff and stage.
  - Scenario 1 - Constant Precipitation, varying Built up
  - Scenario 2- Varying Precipitation, Constant Built up
- Then simulation was run for only one monsoon period and observations were made.
- To have a clear justification, simulation was done using different values of precipitation for the same catchments and same built ups.

3. Stage Three

- The reports of simulation were imported to MS Excel for all the years and all variables.
- Binomial regression analysis was done for all to obtain coefficient of determination.
- Once the coefficient of determination was obtained, the further analysis was to compare the geological subdivisions and the respective variations in surface runoff and infiltration for each category.
- Then, correlation coefficient was verified for different time scales and different ratios of impervious and pervious surfaces as per Rules and regulations. Some more observations were done for various permutations and combinations.
- A correlation was obtained, for the geology and resulting runoff observations for various precipitations and built up changes.
- Conclusions were made as per the final equations and correlations identified
- Proposals were suggested on basis on conclusions for physical planning parameters.

B. Studied Parameters

Parameters studied for the correlation are as per Table I.

TABLE I
STUDIED PARAMETERS

✓ infiltration,	• Urban Lands
✓ runoff,	• Land use-Land Covers.
✓ evaporation	• water,

IV. STUDY AREA

Bhopal was selected to observe and record the response of ground regime to the natural and anthropogenic stresses of recharge and discharge parameters with reference to geology, climate, physiography, land use pattern and hydrologic characteristics. The natural conditions affecting the regime involve climatic parameters like rainfall, evapotranspiration etc., whereas anthropogenic influences include land cover changes, declining recharge due to urbanization etc. were studied for the study area.

Since the aim of the study is to analyse the runoff due to urbanization we need to concentrate on the overland flow from small watersheds. Hence, the study area was finalized with urban areas within small watersheds. The catchment map shows total 19 catchments having 6 lakes and 13 catchments with development. The area in red color hatching in Fig. 2 shows the demarcated area for critical zone as per SGWB [10] and CG report. After obtaining catchments with rapid development, (catchments experiencing development more than 30 to 50% in a decade and catchments with planned and unplanned development were identified. The geological map (Fig. 2) obtained from the geological survey of India was observed for geology of these catchments and the different soil layers under these catchments. The hydrogeological characteristics of the area were determined.

Present water prospects of the study area: The areas which were sensitive to water development and the areas which have great natural potential or carrying capacity were highlighted such as catchments named BSHC, BOBC, BOCC and catchments with poor water prospects such as BSHC (upper part), BOBC-lower part and BLPC (Fig. 3) as per CGWB and Master plan 1991 (Town and country planning department, Bhopal.

Total Study Area= 5255.51acre
2126.829 hectare= 21268294.496sqM = 21.26829 SQKM

A. Model Scale and Temporal Scale

1. Model Scale: Plot, Colony, Neighborhood and Zonal Level
2. Temporal Scale: 40 years period from 1971 to 2011

The scale of modeling and observations extend from plot level to the zonal level as shown in Fig. 4 including various wards and water sheds of the study area to get clear picture of effects of natural and urbanized areas on water cycle.

B. Stage 1: Calculation of Built up Area for Temporal Years

Figs. 5 and 6 show the snapshots of SWMM modeling and GIS used to calculate increasing built up and the rainfall runoff modeling.

SWMM modeling shows the successful event with runoff and errors less than 0.05 % which is permissible and hence we get the runoff value for each catchment.

Fig. 6 shows the calculation of built up in the various catchment as per the imageries studied and displays the land use parcels with built up and open values.

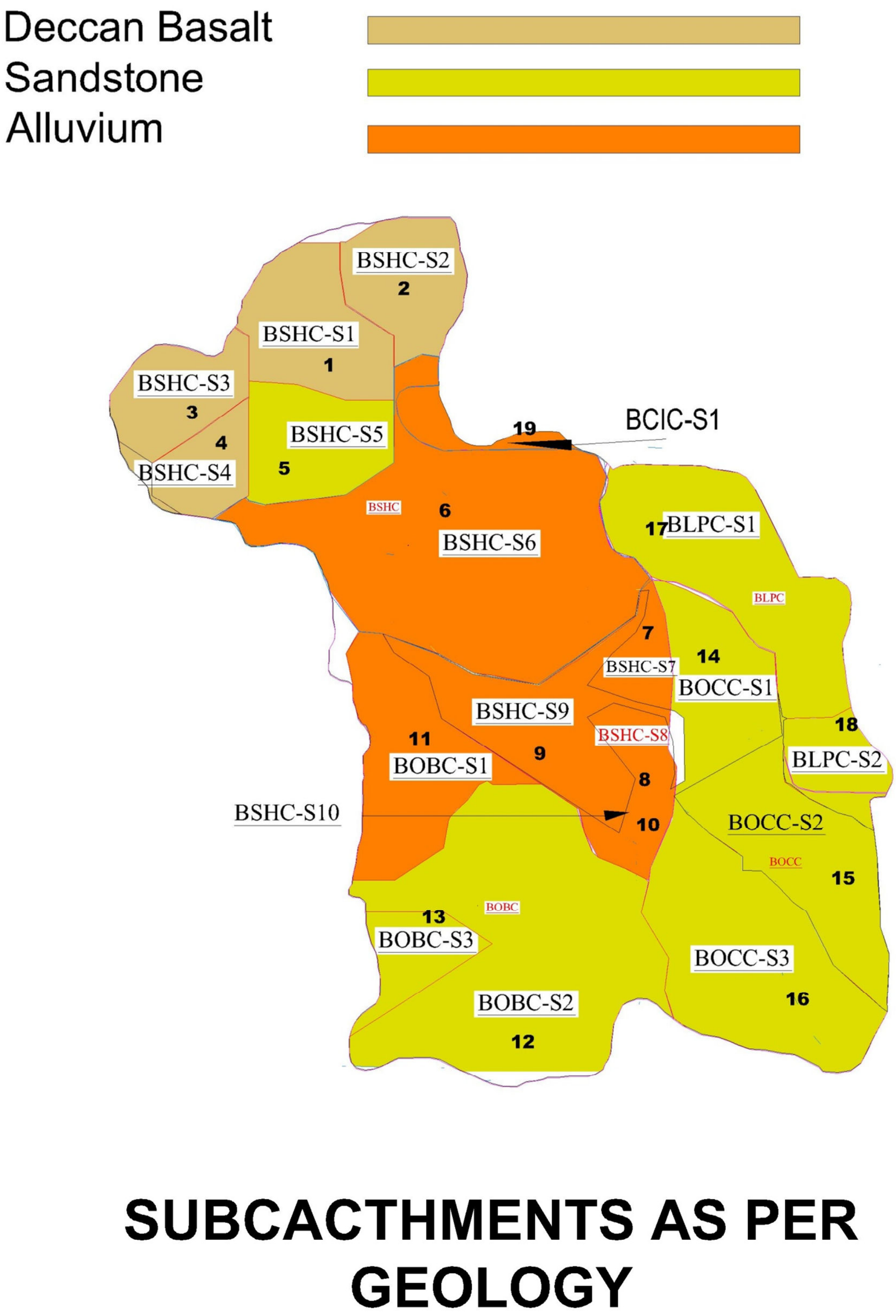


Fig. 2 Geology map for the study area, CGWB, BHOPAL, GSI, India

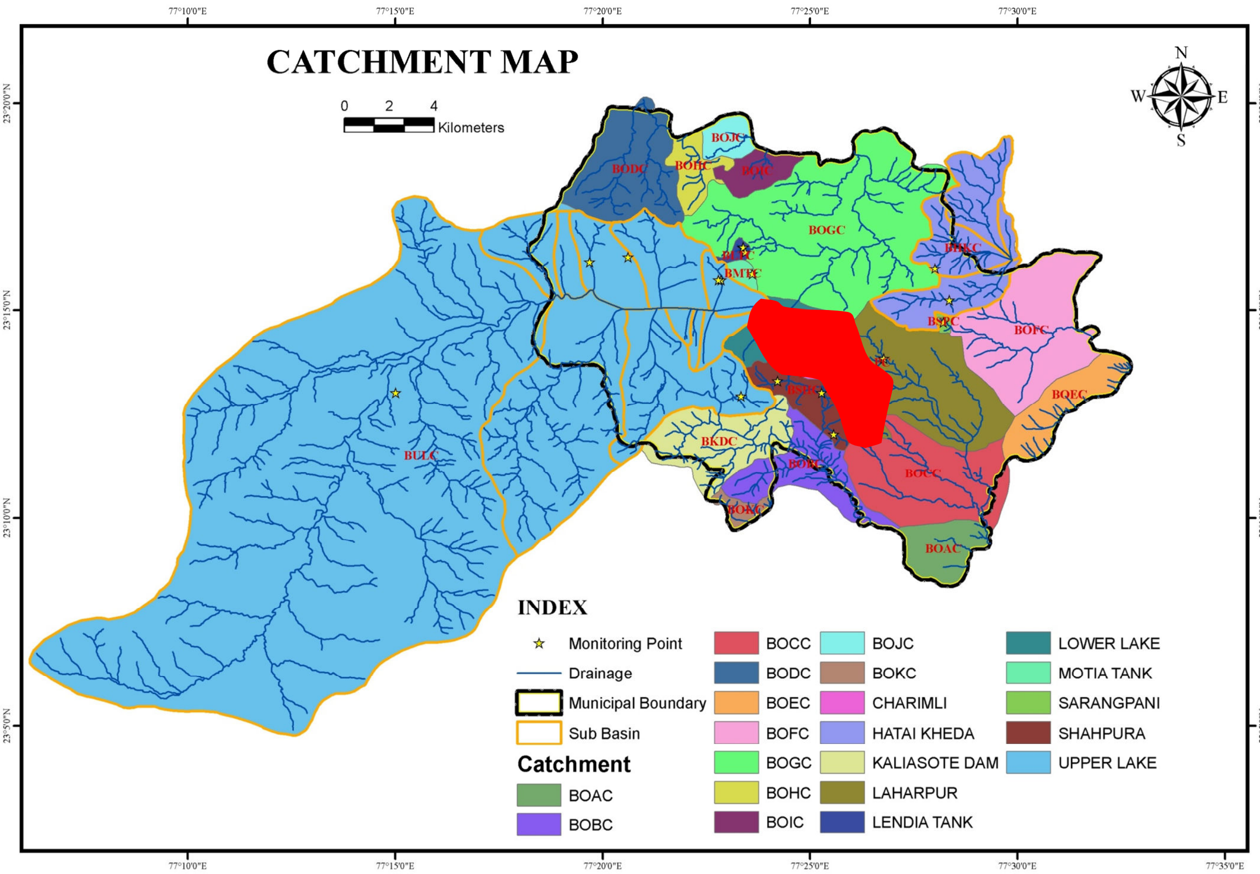


Fig. 3 Catchment map for Bhopal District [10]

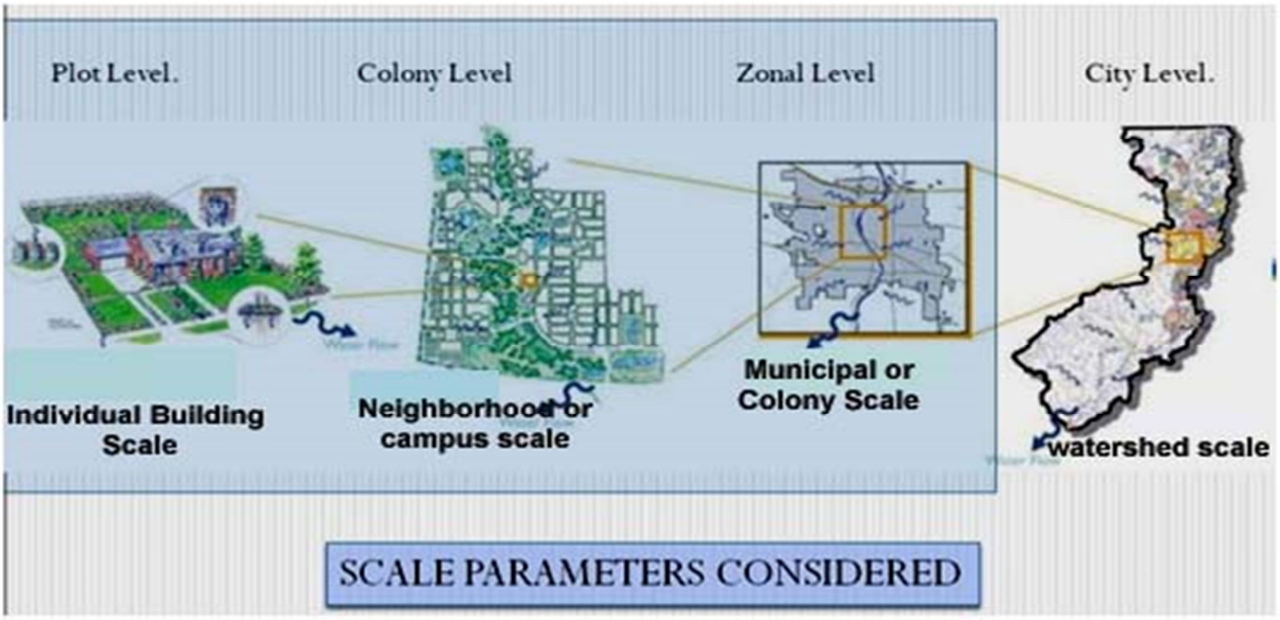


Fig. 4 Model Scale

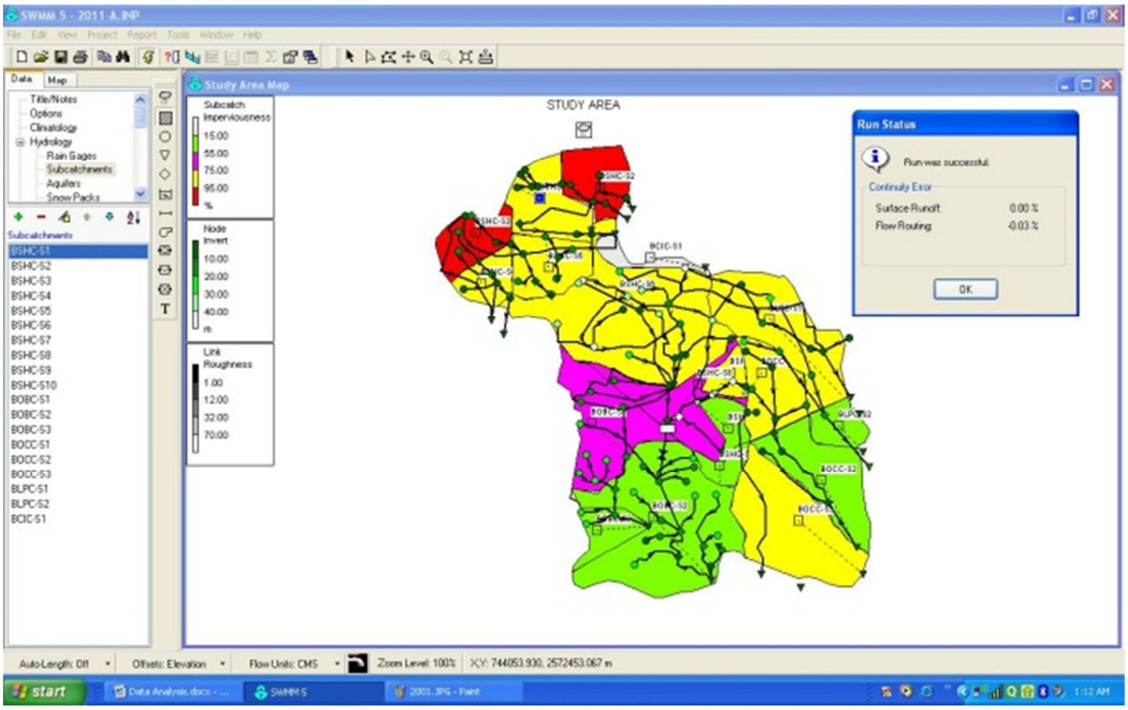


Fig. 5 Snap shot 1-SWMM modeling 1

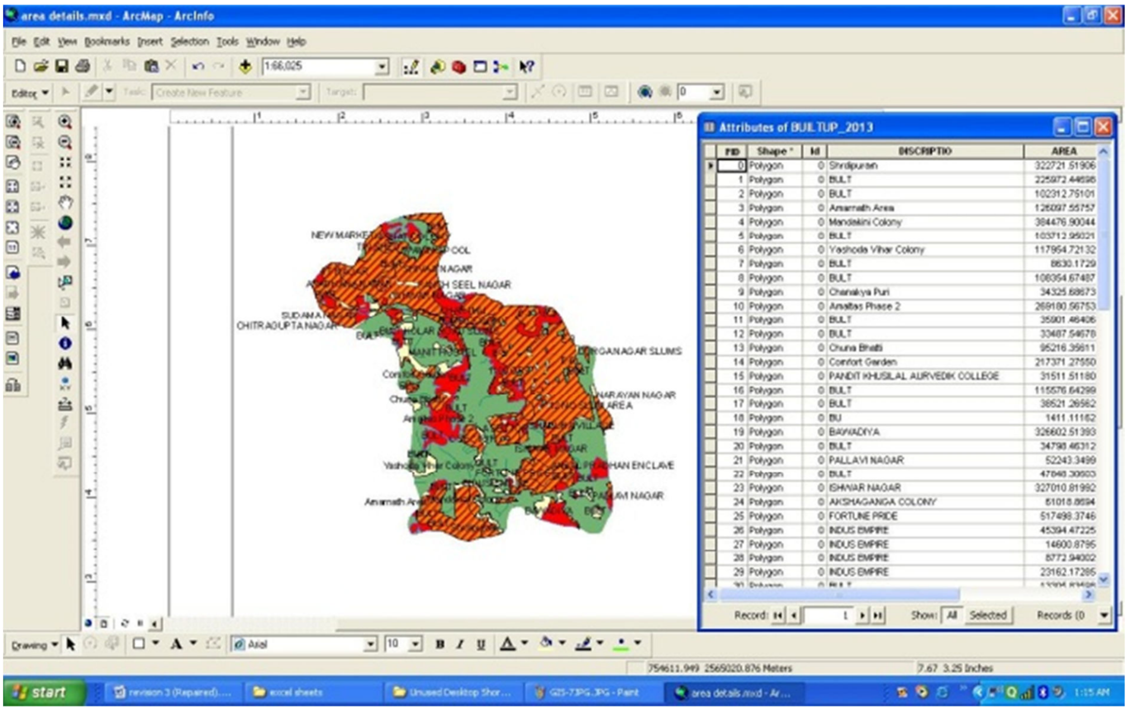


Fig. 6 Snap Shot of Built up area as per GIS- 2013

C. Sub-Catchment Analysis

1. The subcatchments were categorized as per their geology as in Table II.
2. The percentage of built up area was calculated for each decade as in Table III.

TABLE II
DIVISION OF CATCHMENTS AS PER GEOLOGY (NOMENCLATURE AS PER CATCHMENT MAP, SGWB)

Deccan basalt	Sandstone	Alluvium
BOBC-S3	BSHC-S1	BOBC-S1
BSHC-S5	BSHC-S2	BSHC-S6
BSHC-S7	BSHC-S3	
BSHC-S8	BSHC-S4	
BSHC-S9	BCIC-S1	
BSHC-S10		
BOCC-S1		
BOCC-S2		
BOCC-S3		
BLPC-S1		
BPLC-S2		

TABLE III
BUILT UP PERCENTAGE IN STUDY AREA FROM 1971 TO 2013
(REFER FIGS. 5 & 6)

S.no	Sub catchment	Total area (Sqmt)	%1974	%1981	%1991	%2001	%2011	%2013
1	BSHC-S1	70351.56	41.07	69.58	77.85	83.71	83.92	83.92
2	BSHC-S2	796863	9.44	12.59	55.83	55.06	91.42	99.97
3	BSHC-S3	667820.6	46.78	48.61	87.01	99.98	100	100
4	BSHC-S4	467654.2	1.91	66.09	75.35	92.44	92.44	92.44
5	BSHC-S5	847028.4	7.11	56.47	64.53	67.14	81.42	82.71
6	BSHC-S6	3455035	2.36	17.18	42.37	46.93	77.89	87.18
7	BSHC-S7	292338.3	0	0	66.79	90.25	92.75	92.75
8	BSHC-S8	336526.1	2.54	18.88	34.14	51.86	59.08	59.08
9	BSHC-S9	1077419	0.48	12.81	18.66	38.82	43.72	46.26
10	BSHC-S10	253820.2	0	16.67	24.46	36.78	51.12	51.12
11	BOBC-S1	1446194	4.85	5.20	10.92	46.85	54.09	55.30
12	BOBC-S2	3267546	0	5.07	30.26	32.50	51.42	51.87
13	BOBC-S3	443747	0	12.37	31.15	45.20	45.20	47.62
14	BCIC-S1	241845.1	0	0	0	0	9.45	9.45
15	BOCC-S1	926885.2	2.00	65.16	90.92	93.15	94.48	94.48
16	BOCC-S2	1342964	0	23.83	33.04	42.66	42.66	45.50
17	BOCCS3	2056776	0	19.20	68.17	79.92	80.68	80.68
18	BLPC-S1	1850300	0.71	58.51	75.50	84.28	85.22	86.91
19	BLPC-S2	425139.3	0	11.88	11.88	49.91	51.60	51.2

D. Stage 2

1. Hydrological Modeling

Urbanization affects the roughness and imperviousness of the land surfaces, which increases the runoff volumes. As surface roughness is decreased, the stream exhibits a faster response time and peak flows to precipitation. Since the objective of the study is to determine the impact of urbanization on the hydrologic systems, a spatially distributed precipitation-runoff method is desirable for a more accurate observation of the changes in built up and runoff, hence SWMM was used to analyse the hydrological behavior. As per the literature review SWMM was opted as best method for Hydrological Modeling.

2.Process

The output of the Arc GIS Model is shape files, image files and word files. These files were used as reference files in SWMM model as back drop image and geo-referencing with the help of word files. The subcatchments were drafted manually in the SWMM model with the help of backdrop image and characteristics were entered as input parameters in the properties table, based upon the district hydrogeology report and the geological map by GSI, 1980 (India). Land Covers were identified and observed by remote sensing, analyzing historical images of Google earth, Topo sheets, master plans for 1991,2005, 2013) and photographs along with physical primary survey. The SCS curve numbers and the curve number (CN) was based on USGS Data. Standard formats used by EPA SWMM were used as default inputs.

The digitization was carried out in three stages:

- GIS Maps for watershed imageries.
- GIS and Geology map, ward map, road, built up and land use map for subcathments.
- Colony maps by town & country planning, Bhopal.
- Contour Map, Digital Elevation Model.

The land cover analysis was minutely divided on the basis of imageries and colony maps in the study area for:

i. Impervious areas (Roads, Buildings, Pavements, parking's etc.)
ii. Natural land with grass covers – more than 20%, less than 20%.
iii. Land with bushes and trees.
iv. Water Bodies.
v. Natural barren land.

After classification of the land covers they were again separated into two categories i.e. impervious & pervious. After dividing them in two heads each land cover was assigned by a Manning' n for the type and category as mentioned above by USGS.

Accordingly, a basic model of the study area in Bhopal city developed using the Arc GIS with integration of different layers for different time. The precipitation data obtained from the meteorological dept. and on basis of the report of CWC, Centre water commission [11] WRD 2008 the normal rainfall series and the critical rainfall series were decided. The rainfall data was available in hourly basis as well as monthly basis for monsoon period. Auto cad civil 3D software was used to categories subcathments on basis of water drop flows and contours of Google surface to facilitate analysis of surface flows. Then the natural drainage paths and the man made conduits along with the junctions and nodes were formed in the SWMM model. The sub catchments were assigned the related properties and detailing for length, width, slope, impervious percentage, flow routing, inflows, dry weather inflows, etc. were addressed. The outlets and conduits were assigned properties such as circular pipe, trapezoidal, natural etc. Manning N for the concrete pipes and the natural rains were assigned. The storage units and the aquifers were assigned data as per Hydrogeology reports. Thus, a whole set of parameters were formed to set a model where simulation for various runoff, peak runoff etc. can be observed. The two methods for simulation used were-

1. By keeping precipitation and slope, width constant for respective years and

2. By changing precipitation on hourly and daily basis to observe long term Runoff changes and short term peak flow changes.

The runoff changes for constant precipitation with decadal built up were analyzed first. The combinations of inter location runoff and the intra location runoff were used to form the correlation equation and the constants ($y=ax^2+bx+c$) where y is runoff and x is built up.

The correlation observations for each catchment for each decade was plotted to see the trend line and the resulting equation. To calibrate the hydrologic model the LULC data was prepared in an 8m grid. The time series data was made for hourly rainfall event.

Finally, the simulation was run for different years as per conditions prevailing for that specified period and the continuity errors as well as flow routing errors were minimized to get accurate results. The obtained report of the rainfall runoff was then observed and compared with varying precipitation and built up observations for viewing results and changes in the parameters. The correlation analysis was performed to obtain a correlation and best fit method was used to get minimum error value. The correlation thus formed was observed for various catchments individually i.e. inter location and then with others with same characteristics over all the study area i.e. intra location.

V. Modeling Procedure

To correlate and analyse these two cycles closely the modeling was done with different combinations of land covers and precipitations so as to achieve the best results for relation between two. Modeling procedure and observations are explained in Table IV.

VI. Observations-1

A. Comparison of Built up and Runoff: Remark 1

Figs. 7-12 show the variation in runoff and built up in different catchments for different years. Figs. 7-12 show that runoff increases with built up in almost all catchments except catchments having more natural vegetation and water bodies as BSHC-S9, BSHC-S10, BSHC-S8. Apart from this, runoff observations for alluvial soil group also favor infiltration up to some extent but for less intensity rainfall and vegetated land cover like BSHC-S6, BSHC-S7, BOBC-S1, BOBC-S2, and BLPC-S1. Thirdly, the sandstone areas with barren land, less vegetation and built up to 50-60% have supported infiltration satisfactorily with connected impervious layers as well as combination of unconnected pervious surfaces such as BOBC-S3, BOBC-S2, BOCC-S2 acting as recharge pits.

TABLE IV
Modeling Procedure

	Scenario	Varying parameter	Constant	Observation	Result	Remark
1	Actual scenario	Increasing built up	Constant precipitation	Individual catchment	Runoff	1
2.	Guidelines	Built up as per Municipal bye laws	Constant precipitation	Individual catchment	Runoff	2
3	Climate	Precipitation	Built up	Individual catchment	Run off	3
4	Land cover and Geology	Roughness-land cover	Precipitation	Group of catchment as per geology	Run off	4

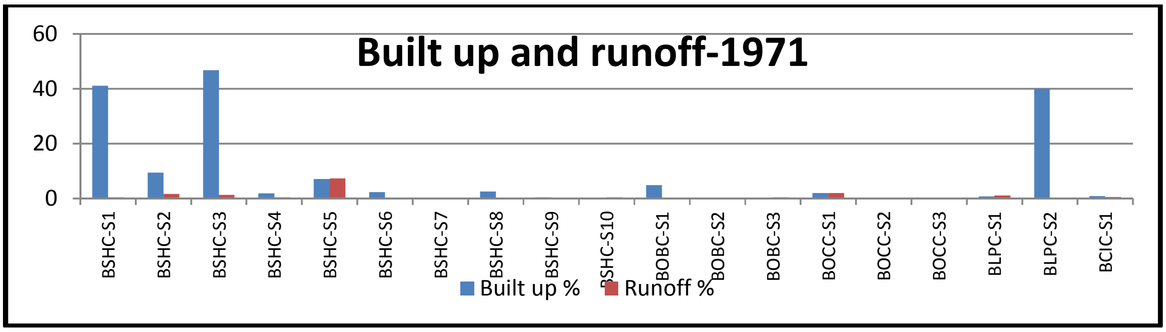


Fig. 7 Built up and runoff in catchments for 1971

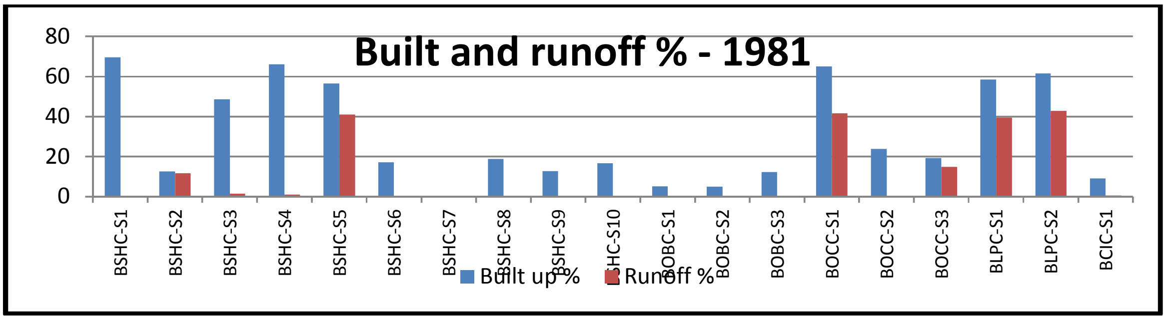


Fig. 8 Built up and runoff in catchments for 1981

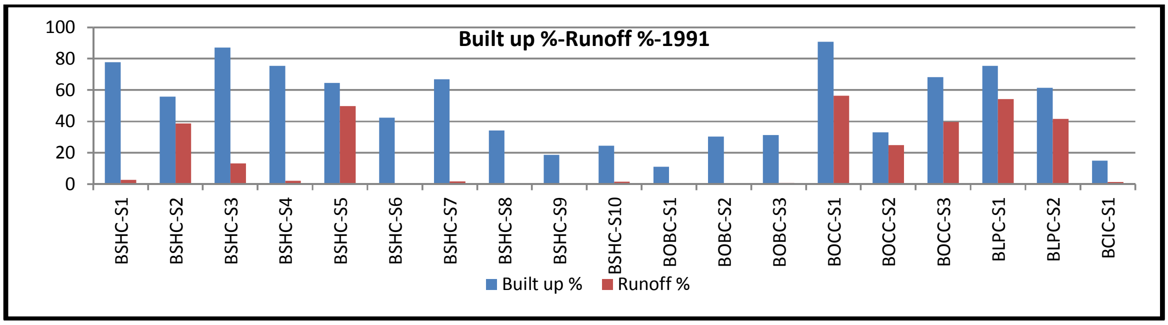


Fig. 9 Built up and runoff in catchments for 1991

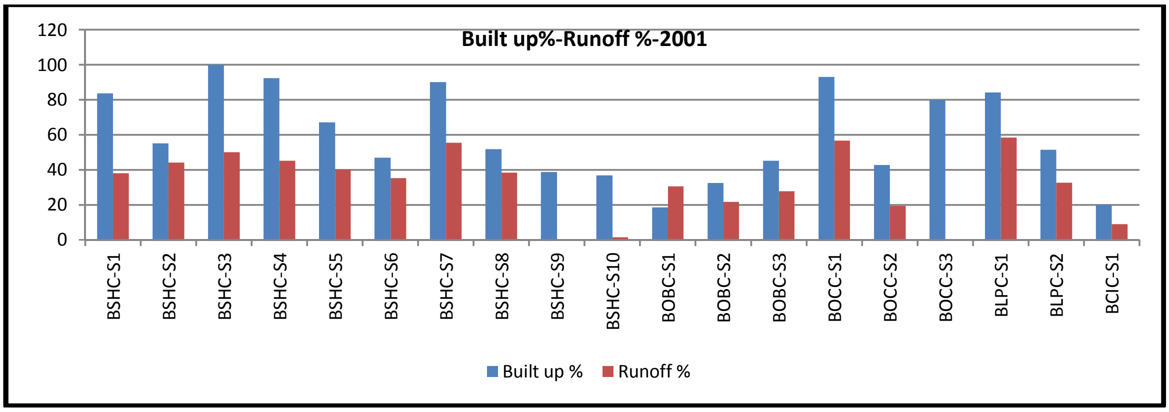


Fig. 10 Built up and runoff in catchments for 2001

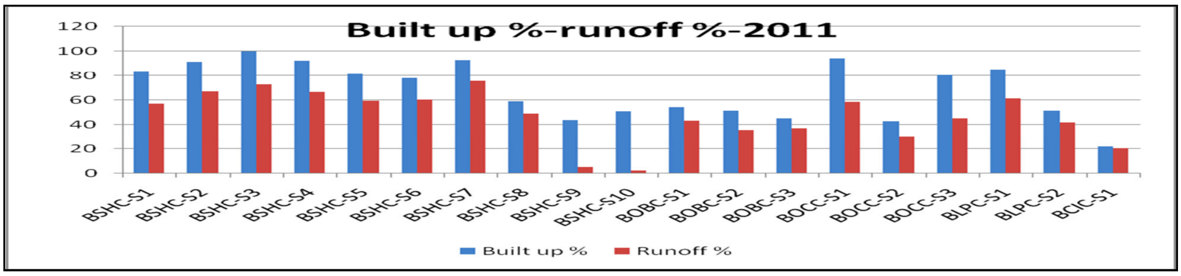


Fig. 11 Built up and runoff in catchments for 2011

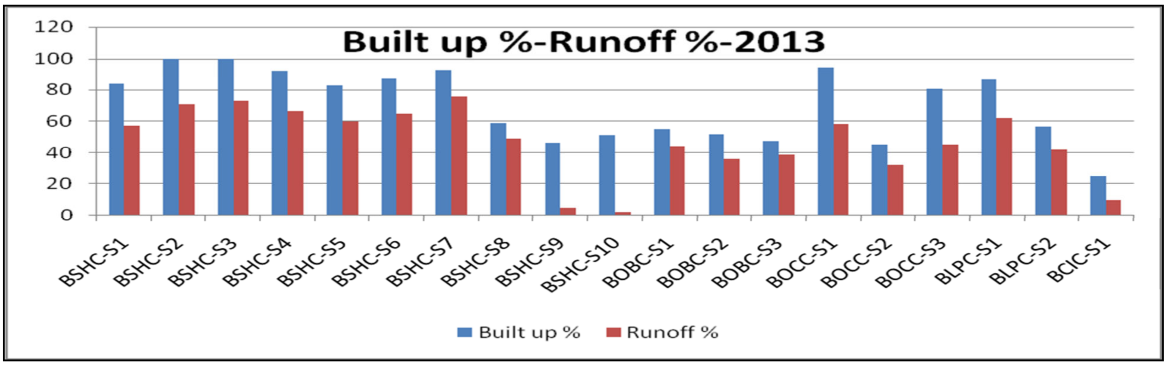
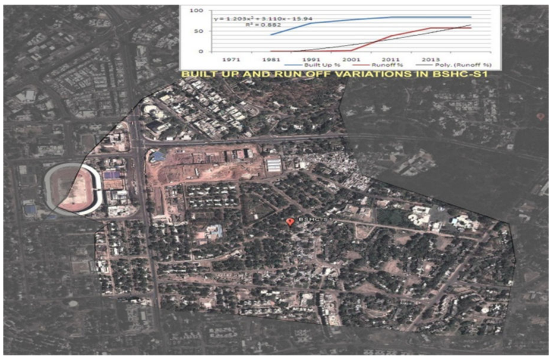


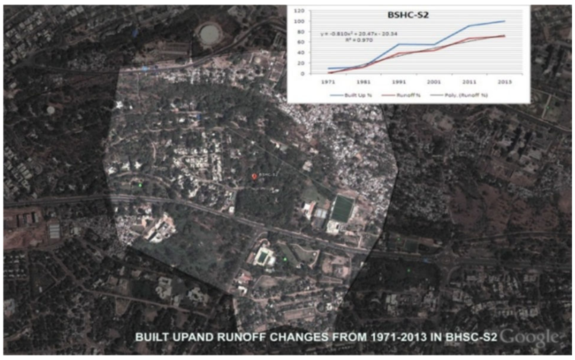
Fig. 12 Built up and runoff in catchments for 2013

TABLE V
CHARTS FOR GOOGLE IMAGES AND BUILT UP RUNOFF FOR INDIVIDUAL CATCHMENT

BSHC-S1



BSHC-S2



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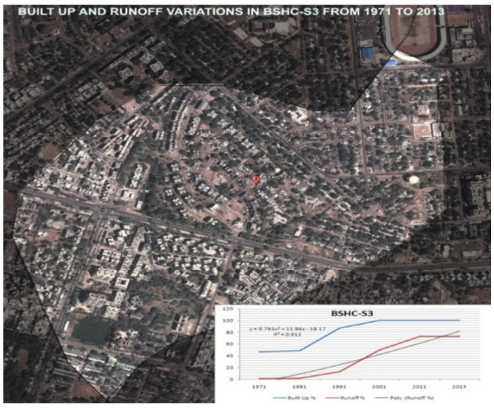

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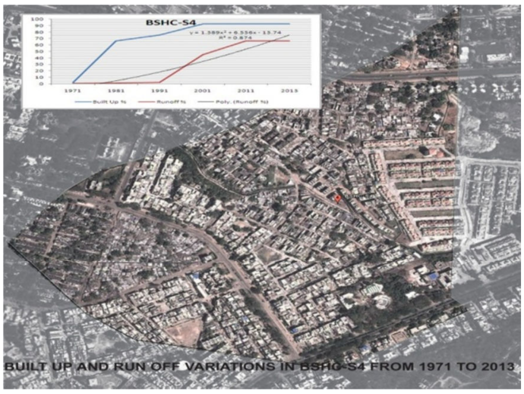
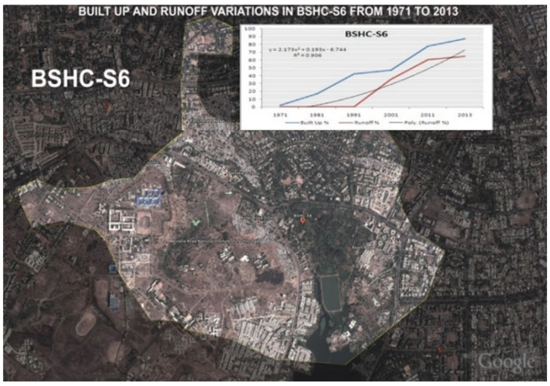


BSHC-S5



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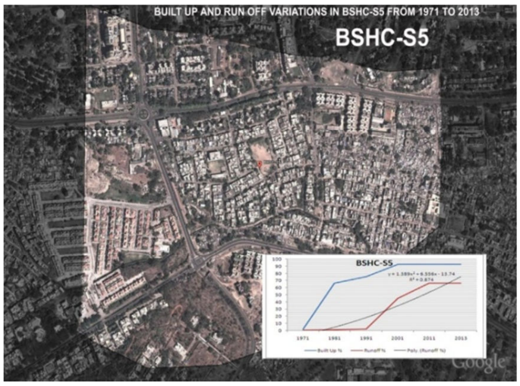
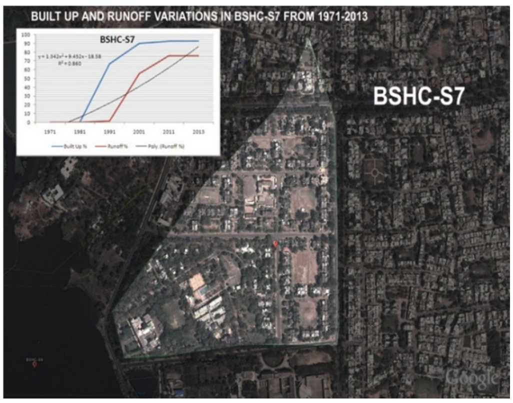
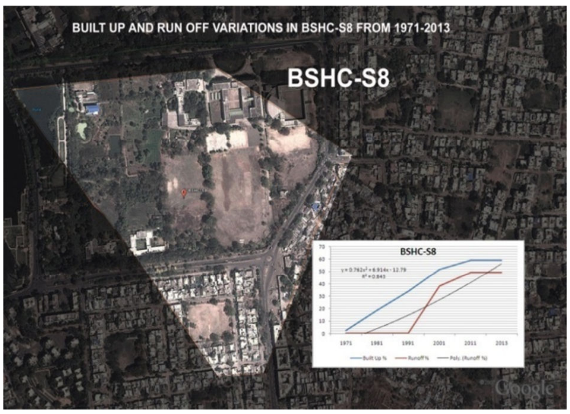


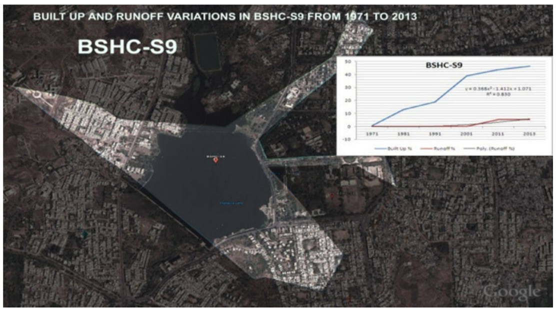
BSHC-S7



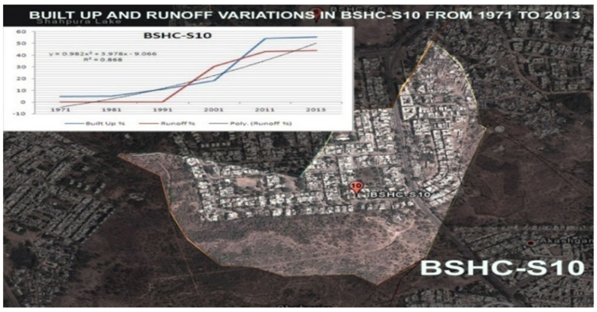
BSHC-S8



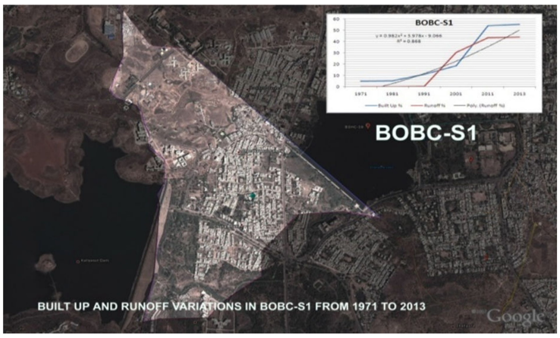
BSHC-S9



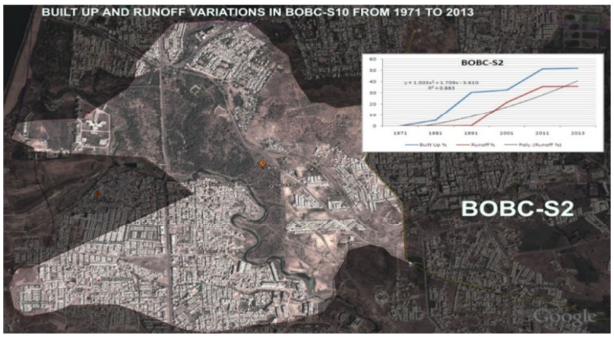
BSHC-S10



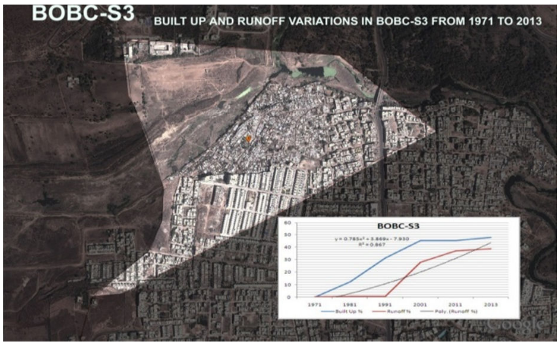
BOBC-S1



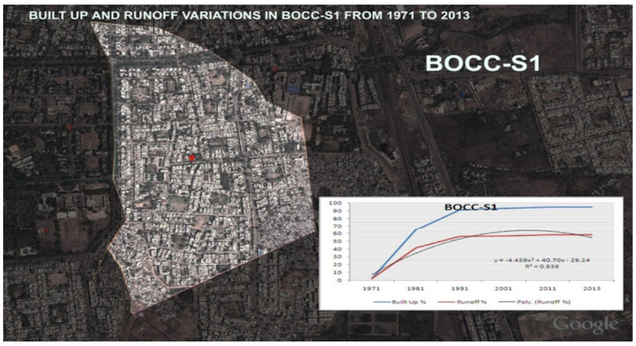
BOBC-S2



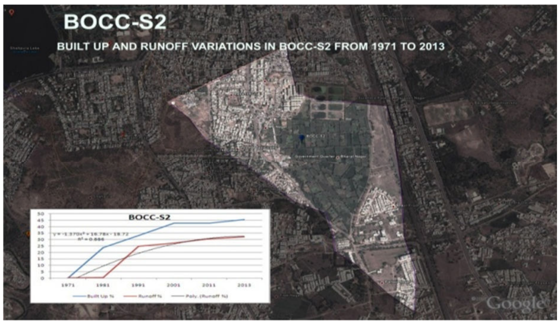
BOBC-S3



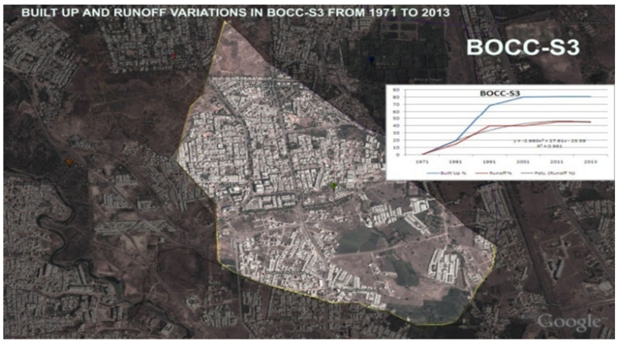
BOBC-S1



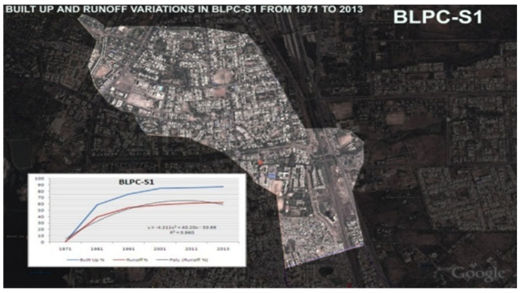
BOCC-S2



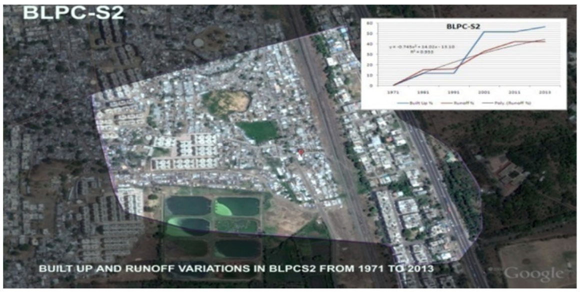
BOCC-S3



BLPC-S1



BLPC-S2



B. Verification of Results for Calibration and Validation for Individual Catchments

The coefficient of determination and correlation coefficient were than compared to the calibrated one for validation using more number of observations as shown in Table VI and the trend line was observed for variation in behavior.

TABLE VI
STATISTICS FOR VALIDATED AND CALIBRATED EVENTS FOR INDIVIDUAL CATCHMENTS

Event (catchment wise)	Calibration	Validation	Confidence level (0-1)	Trend line and runoff pattern for built up
BSHC-S1	$R^2 = 0.874$	$R^2 = 0.824$	0.9	fast developing area resulting rapid runoff
BSHC-S2	$R^2 = 0.970$	$R^2 = 0.988$	0.9	balanced development. Runoff increased gradually.
BSHC-S3	$R^2 = 0.912$	$R^2 = 0.938$	0.92	Runoff increased more than 40% after 2001 with new city
BSHC-S4	$R^2 = 0.874$	$R^2 = 0.915$	0.89	runoff increased after 2001 as old city was congested.
BSHC-S5	$R^2 = 0.817$	$R^2 = 0.960$	0.91	runoff increasing similar to built up
BSHC-S6	$R^2 = 0.906$	$R^2 = 0.887$	0.85	runoff increased after 1990 with rapid development
BSHC-S7	$R^2 = 0.860$	$R^2 = 0.987$	0.88	Rrunoff increased after 2001 when area was developed as new city
BSHC-S8	$R^2 = 0.843$	$R^2 = 0.978$	0.87	Runoff increased after 2009 when green belt was converted into residential.
BSHC-S9	$R^2 = 0.830$	$R^2 = 0.751$	0.86	Being a water body it has least surface runoff value.
BSHC-S10	$R^2 = 0.917$	$R^2 = 0.909$	0.9	Natural wood near water body hence least value runoff
BOBC S1	$R^2 = 0.868$	$R^2 = 0.933$	0.89	linear trend< maximum value runoff
BOBC-S2	$R^2 = 0.883$	$R^2 = 0.877$	0.95	Runoff increased by fluctuation after 2001
BOBC-S3	$R^2 = 0.867$	$R^2 = 0.941$	0.91	area developed by Municipal corporation, runoff increased after 1999
BOCC-S1	$R^2 = 0.936$	$R^2 = 0.999$	0.93	large open spaces in area but runoff increasing similar to built up
BOCC-S2	$R^2 = 0.886$	$R^2 = 0.883$	0.92	undeveloped area with less density, runoff increasing similar to built up
BOCC-S3	$R^2 = 0.961$	$R^2 = 0.989$	0.94	natural drainages blocked here so runoff increasing similar to built up
BLPC-S1	$R^2 = 0.960$	$R^2 = 0.998$	0.91	develop zone hence runoff increasing similar to built up
BLPC-S2	$R^2 = 0.953$	$R^2 = 0.958$	0.99	parks and schools with open spaces result with runoff fluctuating.
BCIC-S1	$R^2 = 0.906$	$R^2 = 0.906$	0.99	When area was fully developed in 1991 runoff increased after 1991.

Note

The built up runoff correlation could have been demonstrated by a single chart, but the main aim of these correlation to be observed individually was to correlate the pattern of runoff variations with built up and with other characteristics like land cover and roughness and Geology so that the individual pattern of variations in runoff for same built up can be analyzed further for finding the responsible components for these difference in variations in runoff. Thus each catchment was observed independently not only for variations in runoff for these correlations but also further for different correlations of roughness and geology making a clear picture for interpretations. The observations of trend lines and coefficient in determination also correlated the confidence level for runoff observations along time period and scale of impervious and pervious areas.

C. Observations for Varying Precipitation Remark 2

The results for varying precipitation on constant built up as per Fig. 13 shows almost similar increase in runoff along with the precipitation in some catchments. Some interesting facts are that catchments which showed increasing runoff with increasing built up like in BOBC-S3, BOCC-S1, BOCC S3 have not shown such increase with constant precipitation. Catchments like BSHC-S6, BLPC-S1, BOBC-S2 and BSHC-S2 have experienced highest runoff % for increasing precipitation with constant built up. Highest runoff percentage is read as 56.38 percent as compared to 75.86 of same year with increasing built up. BSHC-S9 and BSHC-S10 have relatively less run off as it contains water body and natural vegetated land around in it with less built up. Reason behind such variations are rapid increase inbuilt up sealing the surfaces, no planning for direction of flow of water, increased volumes due to continuous impervious areas and decrease in peak runoff due to presence of vegetation in the path of flowing water or depression storage available nearby.

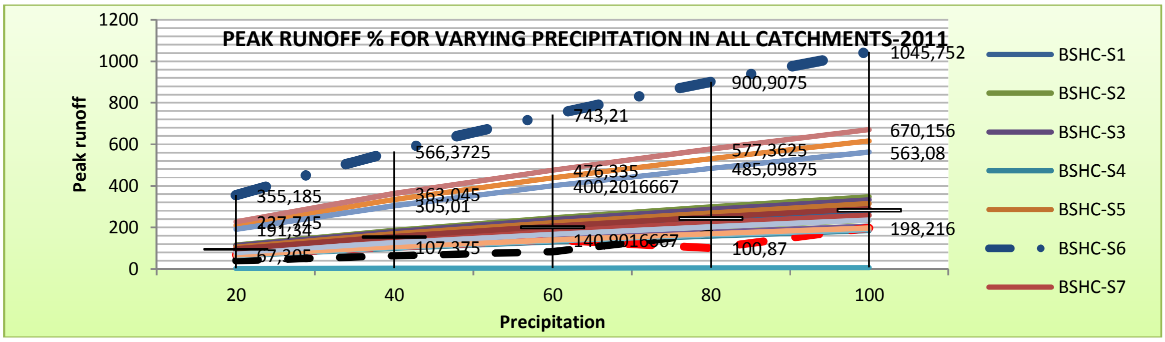


Fig. 13 Built up and runoff in catchments for precipitation at 20,40,60,80 and 100mm

D. Observations for Bye Laws and Guidelines

The survey clearly showed that every plot and colony had occupied more area as impervious than permitted which makes an important issue and parameter to be considered in planning and implementation of local plans and master plans. Also, it was observed that smaller plots covered more impervious surface than large plots which comparatively had more open spaces maintained in them. This survey also observed that roads and parking's were made of compact impervious layers and roads and parking's contributed to about 20 to 25% of space in a colony along with other land uses. Now, it was necessary to know the increase in runoff from these extra impervious areas in the study area so that difference in actual runoff and the runoff which would have been obtained if the open spaces were maintained, could be calculated. This difference being in large quantity is defiantly affecting the natural working up to a great extent along with the other effects of urbanization in the catchments. For this, colonies in study area were inspected, their approved maps were obtained from the Bhopal Municipal Corporation and the Town and country planning department. The permissible limits were tabulated for them. Then actual measurement and observations for the open spaces left at plot level, colony level and Ward level were also tabulated to have a comparative assessment of both values. From Table V, it is clearly seen that variations in open spaces and ground coverage for study area was about 63% more than permissible limit. Means buildings had violated the bye laws and covered more space of 60% more than prescribed.

Considering this value as an effective value for behavior of runoff and recharge based on land cover, the runoff results for this difference were calculated by running simulation in study area, keeping all other things common. Only permissible Built up limit was considered in calculating runoff. Then following analysis was carried out for the maps.

Data was collected on basis of following points.

1. Colony details different sizes and numbers of plots in the colony.
2. Open, built up and land use pattern as per municipal norms.
3. Impervious area as per rule.
4. Runoff routing analysis for colony level and resulting changes in runoff.

Simulation was carried out for the runoff being produced from two different scenarios- (Fig. 11)

- Area with open areas as per rules.
- Area with actual open and impervious areas.

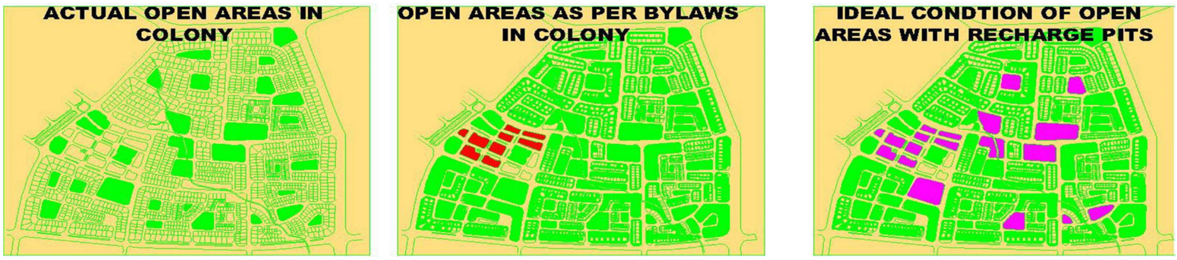


Fig. 14 Open spaces in colony asper rule, actual and in ideal conditions

E. Observations for Variations: The Results for Catchments for Runoff, Infiltration and Built up Along with Geology. Table VII: Remark 3

TABLE VII
COMBINED OBSERVATIONS FOR VARIATIONS IN BUILT UP, RUNOFF AND INFILTRATION AS PER RULE AND ACTUAL SCENARIO

Catchment	Variation in land cover (built up) rule & actual (+)	Variation in runoff (+) rule and actual	variation in infiltration (-) Rule and actual	Geology Group
BSHC-S1	60.02	22.91	-84.86	Sandstone
BSHC-S2	88.72	35.86	-68.38	Sandstone
BSHC-S3	62.39	38.66	-88.09	Sandstone
BSHC-S4	42.68	27.35	-68.28	Sandstone
BSHC-S5	36.31	45.77	-82.13	Deccan Basalt
BSHC-S6	17.82	19.24	-31.15	Alluvial
BSHC-S7	20.04	31.87	-51.33	Deccan Basalt
BSHC-S8	16.00	22.84	-39.52	Deccan Basalt
BSHC-S9	9.51	0.30	-31.98	Deccan Basalt
BSHC-S10	15.15	0.80	-19.83	Deccan Basalt
BOBC-S1	20.00	11.32	-12.98	Alluvial
BOBC-S2	11.10	12.57	-32.68	Deccan Basalt
BOBC-S3	10.65	16.42	-30.49	Deccan Basalt
BOCC-S1	47.82	50.07	-100.17	Deccan Basalt
BOCC-S2	14.25	17.82	-38.11	Deccan Basalt
BOCC-S3	31.33	27.46	-76.96	Deccan Basalt
BLPC-S1	40.58	53.29	-86.12	Deccan Basalt
BLPC-S2	140.59	85.67	-122.47	Deccan Basalt
BCIC-S1	14.92	5.91	-9.56	Sandstone

VII. CONCLUSION

From above observations in Table IV, it was concluded that if buildings are constructed as per bye laws, almost 20 to 35% of the normal runoff can be reduced for the same area and same precipitation. Apart from built up as per bye laws, other mean of balancing runoff is the correlation of land cover and geology. Geological base plays an important role in the behavior of runoff. The results of runoff having different geology had same observations and some with same geology had different observations. Hence, to correlate this correlation among them needs to be identified. The correlation of geology and land cover upon it are having separate effects on runoff is the assumption of the next simulation modeling. For this, catchments with their soil type and the existing land cover upon it are examined for resulting runoff. The correlation thus includes observations for group of catchments based on soil type and hence it is named as intra location analysis.

VIII. RESULTS AND DISCUSSION

After all the analysis and correlations, a final table has been made to find out the gaps and need for better working of natural behavior of soil and runoff in accordance with increasing built-up.

TABLE VII
BEHAVIOR OF CATCHMENTS FOR RUNOFF WITH MAXIMUM BUILT UP IN CONTEXT OF GEOLOGICAL CHARACTERISTICS

S.N.	Catchment	Soil(Geology)	Max Built up& Runoff		% recharge (less)	Remarks
			Built up	Runoff		
1	BSHC S1	Loamy Sandstone	83.92	56.63	49	Needs connected pervious areas.
2	BSHC s2	Loamy Sandstone	99.97	69.29	89	Needs conservation of natural drainage pathways
3	BSHC S3	Loamy Sandstone	95	71.61	75	Open space as prime land cover
4	BSHC S4	Loamy Sandstone	92	65.41	89.21	Interception storage needed.
5	BSHC S5	Deccan Basalt Lineament rock	82.71	52.87	73.72	Allows built up with open spaces.
6	BSHC S6	Alluvial Soil	87.18	64.59	61.77	Large chunks of open spaces allow recharge
7	BSHC 7	Deccan Basalt	92.75	75.75	90.51	Dense vegetation helps recharge and less runoff
8.	BSHCS8	Deccan Basalt	59	48.92	57.2	Porosity makes recharge better
9	BSHC-S9	Deccan Basalt	46	5.13	24.86	Water body hence good storage
10	BSHC S10	Deccan Basalt	51.12	44.01	16.38	Excellent for recharging.
11	BOBC-S1	Alluvial Soil	55.30	44.01	56.40	Natural drainages, excellent storage
12	BOBC-S2	Deccan Basalt	51.87	35.76	53.34	Lineament fractures make recharge less.
13	BOBC-S3	Deccan Basalt	47.62	38.22	46.14	Impervious layer affect recharge.
14	BOCC-S1	Deccan Basalt	94.48	56.36	49.77	Impervious layer affect recharge
15	BOCC-S2	Deccan trap	45.50	32.09	44.03	Large open spaces needed with built up
16	BOCC S3	Deccan trap	80.68	44.23	50.82	Steep slopes and built up affect recharge
17	BLPC-S1	Deccan trap	86.91	60.24	67.68	Impervious surface affect recharge, intensify runoff
18	BLPC-S2	Deccan trap	51.60	42.14	83.21	Impervious surface affect recharge.
19	BCIC-S1	Sandstone	9.45	20.68	20.15	Green spaces help percolation.

A. Observations: Remark 4

Observations of different catchments and land covers show that the catchments having land cover with cement and hard rock had very less infiltration and most runoff due to absence of vegetation. Similarly, concrete and dense bushes showed slightly better behavior in catchments BSHCS4, BLPC S1 etc. grass and mud surfaces helped more in reducing the runoff intensity and thus helped satisfactory infiltration.

Permissible and exceeding percentage values for built up and resulting runoff with four groups of land cover roughness and a broad range of built up that allows satisfactory recharge are considered as acceptable features of physical planning along with some man made efforts needed for better performance. Pervious connected areas and unconnected impervious area play vital role in intercepting the rain water and allowing the rainwater to flow in desired direction. Thus it is concluded that natural system sustains its working till its carrying capacity is exceeded and with some planning principles and man made efforts this capacity can be extended to support the normal working of natural system in developed conditions

Land cover with scanty grass and concrete does not support infiltration to a satisfactory level and hence development should be proposed on such pockets with impervious base and least grass or natural cover. These observations help to decide the planning perspective based on geology and land cover. This perspective can be further confirmed with long time variations in water levels which reveal the infiltration pattern of natural cycle in urban areas.

IX. Suggestions

Connected impervious areas and disconnected pervious areas play an important role in handling the runoff as BSHC S9 where pervious areas and impervious have combination of 25 to 55% connectivity. Such connecting areas can be planned in cities to ascertain the speed of runoff from different land uses. Similarly, land use like residential with 40 to 50% are acceptable for water cycle if open spaces are left in natural state and developed with efforts with grass, bushes and trees to minimize the intensity of runoff. Infiltration gets very much affected in basalt soil as it is poor in holding runoff. Hence special land cover planning is must for this soil group.

Peak runoff is largely produced by alluvial soil and basalt soil as in BSHC—S6 and BOBC S2, but Alluvial if treated merely with grass and natural soil state pockets also helps in fast infiltration whereas basalt is unable to infiltrate rain so easily with normal land covers. It needs proper land use allotment and planning to work satisfactorily. Even least connected areas pf impervious and pervious areas like 25 and 15% as in BSHC-S4, have more runoff generation but since sandstone infiltrated rain water easily, peak runoff can be avoided in such areas with land use and land cover planning. Hence planning in urban areas with mostly roughness values of 0.011 to 0.017 are to be planned wisely for the resulting runoff. Thus, it is concluded that natural system sustains its working till its carrying capacity is exceeded and with some planning principles and manmade efforts this capacity can be extended to support the normal working of natural system in developed conditions.

1. Runoff in urban areas varies from 25.15% to 88.21%.
2. Some catchments produce more runoff than others though having same built up %. This is due to Physiography and Geological characteristics (to be studied in detail later).
3. Catchments with connected open spaces have less run off, whereas unconnected pervious areas act as interception storages at bigger scale.
4. Lineaments and fractures add to runoff or add to Ground water depending upon the land cover characteristics.
5. Runoff from 5.35 to 50% can be manipulated with help of basic use of hydrological knowledge in planning urban landscapes.

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