Chapter 7

Water Challenges of an Urbanizing World

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Additional information is available at the end of the chapter

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Abstract

The urban landscape has many impacts on the local climate such as reduced average wind speed due to the blocking effect of buildings and greater frequency of flash flooding owing to the higher proportion of ground sealed with concrete and asphalt and a corresponding reduction in natural drainage. Detailed estimate of climate change impacts and landscape modifications on water resources at the regional and local level are currently inaccurate due to inadequate data for water cycle and hydrogeology relations. Physical planning though equipped with modern means and best technologies is still lagging behind from the hands of urban planners due to their insufficient knowledge of natural systems and their correlations. Physical development as part of regional development such as construction of buildings, housings, roads, bridges and public utilities are continuously increasing due to the development in all sectors. Physical developments require land space and give positive impacts for the benefits of the people. However, it also creates negative impacts to the physical environment. It can be understood since a physical development is directly related to the land where constructions stand on, where water occurs as a source for water supply of men living on it and where the air is available for supporting life.

Keywords: urban development, runoff, recharge, hydrological changes, land use planning

1. Introduction

Natural systems are already responding increasingly making their presence by extreme weather events in the recent decades such as floods, droughts, tsunamis, earthquakes along with world's rivers, lakes, wildlife, glaciers, permafrost, coastal zones, disease carriers and many other elements of the natural and physical environment leading to imbalance and natural hazards. Many activities like UNESCO, UNEP, Intergovernmental Panel on Climate Change (IPCC) and UNHSP at the international level during the last decade have been developing a basis for the rational use and conservation of the resources of biosphere to overcome the impacts of climate change for the improvement of the relationship between man and environment within the natural and social sciences (ScienceDaily-IPCC 2007) [1]. The assessment reports of IPCC 2007 and 2013 have stated that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, the sea level has risen and the concentrations of greenhouse gases have increased. Each of the last three decades has been successively warmer at the earth's surface than any preceding decade since 1850. Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterward. (E.B, The State of Resource, Chapter 4 2004) (Hengeveld) [2, 3].

The most notable changes observed are related to the urban and hydrological system where urban areas have increased from 100,000 to 500,0000, and as per United Nation's projections, half of the urban population would live in urban areas, and by 2050, 64.1 and 85.9% of the developing and developed world respectively will be urbanized. Built-up associates with urban areas have also had a noticeable change of 145.68% as compared to 54.05% change in population growth from the year 1971 to 1999 (**Figure 1**). Also UN report of 2013 stated that

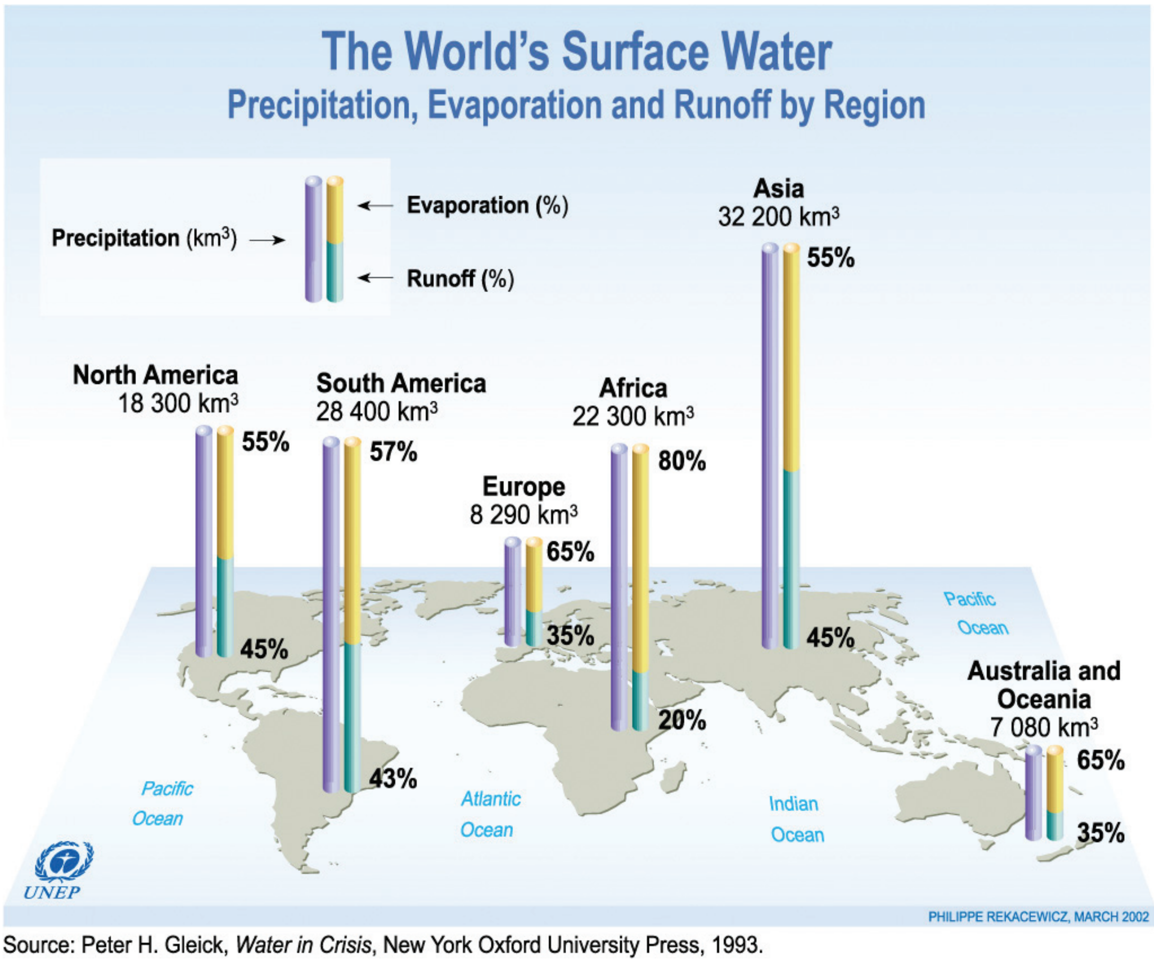

Figure 1. Variations in Worlds Surface water. (Gleick, Chapter 1. Peak Water, World's water 2008–2009). Note: It is observed that world's surface water has runoff and has a prime component varying with precipitation [8].

the urban population will increase from 29.1% in 1950 to 66.6% in 2050. As per the State of resource, UNESCO reported that (UNESCO, State of Resource Chapter 4) water is predicted to be the primary medium through which early climate change impacts will be felt by people, ecosystems and economies. (White 2006) [2]. As per the UNEP and IGRAC, hydrology has suffered drastic changes in its components and felt changes in recharge that dropped from 45 to 50% in 1961 to −10 to −30% in 2050.

Hydrological changes may have impacts that are positive in some aspects and negative in others. For example, increased annual runoff may produce benefits for a variety of both in stream and out-of-stream water users by increasing renewable water resources, but may simultaneously generate harm by increasing flood risk (IPCC, Linking climate change and water resources 2007) [4]. Water scarcity, on the other hand, is expected to become an ever-increasing problem in the future for various reasons. First, the distribution of precipitation in space and time is very uneven, leading to tremendous temporal variability in water resources worldwide (Climate 2007–2010) [1]. Second, rising temperatures are accelerating the hydrological cycle and causing rivers and lakes to freeze later in the autumn. Scientists are increasingly confident that, as global warming continues, certain weather events and extremes will become more frequent, widespread or intense. According to IPCC 2007, human activities and urbanization are likely to affect climate change, which in result will impose extreme weather events (M. Stephenson 2004) [5].

Both observational records and climate projections provide strong evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by the increasing urban areas. Possible impacts of climate change due to changes in extreme precipitation-related weather and climate events, based on projections to the mid- to late twenty-first century indicate areas with heavy precipitation increasing intensities, increase in areas affected by droughts, and intense tropical cyclone increase, damage to crops, soil erosion, land degradation, lower yields, damage to ability of land to cultivate. More intense rainfall events will increase runoff percentages and will overload the capacity of sewer systems and water and wastewater treatment plants more often. One reason is that precipitation variability is *very likely* to increase, and more frequent floods and droughts are anticipated.

Thus, changes in land use and land cover due to urbanization are likely to impact water requirement as some places are suffering from water scarcity and some with flash floods. Dynamic land use changes and transitions bring challenges not only for social systems but also for ecological systems and decision-making processes, creating an urgent need for planning and developing parallel solutions to changing world.

Broad-scale changes in land systems influence climate in several ways. Vegetation affects the physical characteristics of the land surface, which affect water evaporation and transpiration, the reflection or absorption of solar radiation and the transfer of momentum with atmospheric flows. These processes determine water and energy exchanges with the atmosphere at its lower boundary and can exert a major influence on climate at all scales. Land systems also affect the cycling of chemical elements, the most prominent and well-known being the carbon cycle, in particular, the role of land systems in modulating atmospheric concentrations of the greenhouse gases such as carbon dioxide and methane.

From several studies and worldwide reports of World Water day 2007,2010, IPCC 2008, (CARA 2006) (Booth 1991) (White 2006) [6, 7], it is observed that when an area is developed for housing or other urban purposes, the immediate hydrologic effect is to increase the area of low or zero infiltration capacity and to increase the efficiency or speed of water transmission in channels or conduits and in physical terms the most obvious landscape-level change is the extent to which previously natural surfaces are covered with engineered, impervious ones. Once vegetation and soil is replaced with buildings and paved surfaces, the infiltration potential for precipitation is greatly reduced, resulting in increased surface runoff, decreased lag time and increased peak discharge in streams and roads leading to flash floods and ponding. (Booth) [7]

In regional development, if spatial usage is not wisely regulated, then spoiling of its usage and deterioration of spatial quality might occur. Therefore, physical planning is required to arrange its usage on magnitude of activity, type of activity, location function, space quality and environmental esthetic bases.

Looking at one of physical planning objectives, the role of hydrogeology delivers a significant contribution, that is, how to establish the arrangement of spatial usage whether an area as a groundwater protection or groundwater development area.

As long as groundwater resources are concerned, a wise physical planning which is based on its usage, balance and preservation principles would support the sustainability of groundwater. It established eventually a better quality of life.

Some facts at the global level observations verify these changes as sensitive issues for urban areas that are given in **Figure 1**.

Urbanization can be termed as a social phenomenon and a physical transformation of landscapes by the people and for the people. Most of the changes in natural systems such as floods, droughts, climate changes and global warming, due to urban development are irreversible and give a very strong reflection of impact of anthropogenic activities on it.

As per present world facts and conclusions from various summits, conferences, researches and programs, it has been observed that there is a dramatic change in urbanization and 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 such as IPCC (IPCC 2007), UNEP, USGS, Rio Summit, MDG, etc. The panelists at World Water Day 2011 (Worldwater 2007) [8] identified rapid urbanization, poor planning, inadequate investments and overdependence on external resources as the main challenges facing water management in cities. Thus, urbanization has become one of the main reasons for the overdependence as well as over exploitation of resources, and also poor planning cannot be ruled as a result of unplanned developments in many places around world.

Hence, it is necessary to know about urbanization and how it affects the vital parameters of these natural systems. The relation between these is to learn first to tackle future possibilities of both affecting each other. To start with a short description of urbanization, its meaning in different ways and facts about its rapid increase are discussed. Following this, a short description of hydrology (water cycle) is discussed with its main components, and facts for present variations of it are illustrated. Then a relation between these two is identified with different scenarios like within undeveloped (natural) state, urbanized state and with climate change.

2. Effects of urbanization on hydrological cycle

2.1. **Urbanization**

Urbanization is the process by which large numbers of people become permanently concentrated in relatively small areas, forming cities. A country is considered to urbanize when over 50% of its population live in the urban areas. Historically, human populations have led rural lifestyles as hunters, gatherers and farmers. However, since the industrial revolution, human societies have been transitioning from a rural lifestyle to a more urban one, at an exponential rate. From 1800 to 1900, the number of people who lived in urban areas increased from less than 5 to 14% of the total population. Between 1900 and 1950, rates of urbanization more than doubled up to 30% and by the year 2000, 47% of the human population, or 2.8 billion people, lived in urban areas. By 2030, demographers estimate that approximately 65% of humans will live in urban areas. (umich.edu 2008) [9].

Urbanization results in rapid development of landscape and housing leading to physical modification of habitats, which often results with degradation of the ability of ecosystems to maintain their structures and properties, thus providing ecosystem imbalances. When an area is developed for housing or other urban purposes, the immediate hydrologic effect is to increase the area of low or **zero infiltration** capacity and to increase the efficiency or speed of water transmission in channels or conduits (Dunne and Leopold) [10].

Perhaps the most obvious landscape-level change to accompany urbanization is the extent to which previously natural surfaces are covered by engineered, impervious ones (May 1997). Once vegetation and soil is replaced with buildings and paved surfaces, the infiltration potential for precipitation is greatly reduced, resulting in increased runoff, decreased lag time and increased peak discharge in streams. Urbanization has steadily replaced open spaces and forced dramatic changes to watersheds in the process. Natural drainages have been replaced by changes in hydrological components:

Changes in many subsystems and components of hydrological systems are observed worldwide as per IPCC 2007 and World Water Day report of 2007, 2011. **Table 1** shows the simulated changes of the global values of groundwater recharge, total runoff from land and total cell runoff (which include evaporation from lakes and wetlands as well as evaporation of the water that is withdrawn for human water use).

While both runoff values increase by approximately 9% between 1961–1990 and the 2050s (in the case of the ECHAM4 A2 scenario, with an increase of continental precipitation of 4%), groundwater recharge increases by only 2%.

The effect of neglecting increased future climate variability on groundwater recharge as computed by WGHM cannot be estimated without actual computations of groundwater recharge

	1961–1990 (A)	2050s (ECHAM4,A2)(B)	Change between A and B (%)
	Km^3/a	Km^3/a	
Ground water recharge	122,882	13,112	+1.8
Total runoff from land	38,617	42,062	+8.9
Total cell runoff *	36,621	39,755	+8.6
Continental precipitation	107,047	111,572	+4.2

Including the water balance of lakes and wetlands and evapotranspiration of withdrawn water (assumed to remain unchanged, and equivalent to the renewable water resources).

Source: page no 13. Global-Scale Estimation of Diffuse Groundwater Recharge, August 2005, (Flörke 2005) [11].

Table 1. Simulate changes for recharge and runoff globally.

under the impact of changed climate variability, as the effect is expected to be both cell-specific and depending on the precise change of climate variability.

2.2. **Effects of urbanization**

Studies carried out at University of California-USC libraries and online sources like HOMER, USC Library and Guide book on Hydrologic Effects of urban land use by LUNA Leopold (1968) (Leopold 1968) state that there are some separable effects of land use changes on the hydrology of an area.

2.2.1. *Changes in hydrological system*

Human activities accompanying development can have irreversible effects on drainage basin hydrology, particularly where

- Subsurface flow predominated.
- Vegetation is cleared and soil is stripped and compacted.
- Roads are installed, collecting surface and shallow subsurface water in continuous channels.
- Degrading eliminates previously undrained depression.
- Subsurface utilities intercept yet deeper subsurface water and rapidly pipe out subsurface water out of the basin as surface flows.
- Construction adds impervious areas that intercept rainfall before it can reach the soil surface.
- The most measurable effect in the hydraulic response of a drainage basin is the increase in the maximum discharge associated with floods.

- Hydraulic equation stated that: Rainfall-losses = runoff.
- Water losses, interception losses due to surface vegetation.
- Evaporation from water surface and from soil surface.
- Transpiration from plant leaves.
- Evapotranspiration from irrigated or cropped land.
- Infiltration into the soil at the ground surface.

2.2.2. *Changes in urban systems*

As people are increasingly living in cities, and as cities act as both human ecosystem habitats and drivers of ecosystem change, it has become increasingly important to foster urban systems that contribute to human well-being and reduce ecosystem service burdens at all scales.

There are numerous subsystems and corresponding resources:

A. Natural

- Water
- Energy

B. Urban

- Financial,
- Urban lands,
- Land Use land cover.
- Transport.
- Waste
- Social Systems
- Economic.

2.2.3. *Urbanizations leads to*

Urbanization results in rapid development of landscape and housing leading to physical modification of habitats, which often results with degradation of the ability of ecosystems to maintain their structures and properties, thus providing ecosystem imbalances. An area when developed for housing or other urban purposes, the immediate hydrologic effect is to increase the area of low or **zero infiltration** capacity and to increase the efficiency or speed of water transmission in channels or conduits ((D. &. Leopold 1978). [10].

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New data collection from CIESIN's Global Rural Urban Mapping project (GRUMP 2005) [12] shows that as much as 3% of the Earth's land area has already been urbanized, which is double previous estimates. While the world's urban population grew very rapidly (from 220 million to 2.8 billion) over the twentieth century, the next few decades will see an unprecedented scale of urban growth in the developing world. By 2030, the towns and cities of the developing world will make up 81% of urban humanity. (UNFPAChapters 2007).

As per report, an increase in urban land area of 58,000 km^2 from 1970 to 2000 was observed worldwide. India, China, and Africa have experienced the highest rates of urban land expansion, and the largest change in total urban extent has occurred in North America. Across all regions and for all three decades, urban land expansion rates are higher than or equal to urban population growth rates, suggesting that urban growth is becoming more expansive than compact.

This chapter aims to detect the changes and correlate the parameters like built-up and runoff areas with geological endowments and use this correlation for urban planning and management, in accordance with bye-laws and guidelines. The study is to develop an understanding of relationship between surface water runoff and ground water replenishment with respect to changes in land characteristics resulting from urbanization in the city of Bhopal.

3. Observations

Urban watersheds of Bhopal were observed for the changes in land cover and variations in runoff and water table. The observations were based on GIS Maps and SWMM modeling. Following figures show the catchments and their related variations in runoff (**Figures 2–5**).

a. BSHC-S1

Increase in built-up is 42.75% and simultaneously increase in runoff is 56.63%. Increase in runoff was gradual till 1991–2001, but sudden increase was observed in after 1991 from 2.01 to 45.24%. Though built-up has marginal increase in 0.29% at 2001 to 2011, runoff increased 20%. Coefficient of determination is 0.68 and value of R^2 is 0.874.

b. BOBC-S3

Basically, a slum area out of the city municipal limits having kaccha houses and less R.C.C Construction near the paths of water flows has now turned to developing colonies over the hill tops and rapidly converting hills to flat mounds by excessive excavation of rocks. It also consists of a natural park along its natural drains in one part. The increase in built-up was observed gradually but being a peri-urban area, it did not affect runoff till 1995 and showed a weak relation till then. The runoff increased after 2001.

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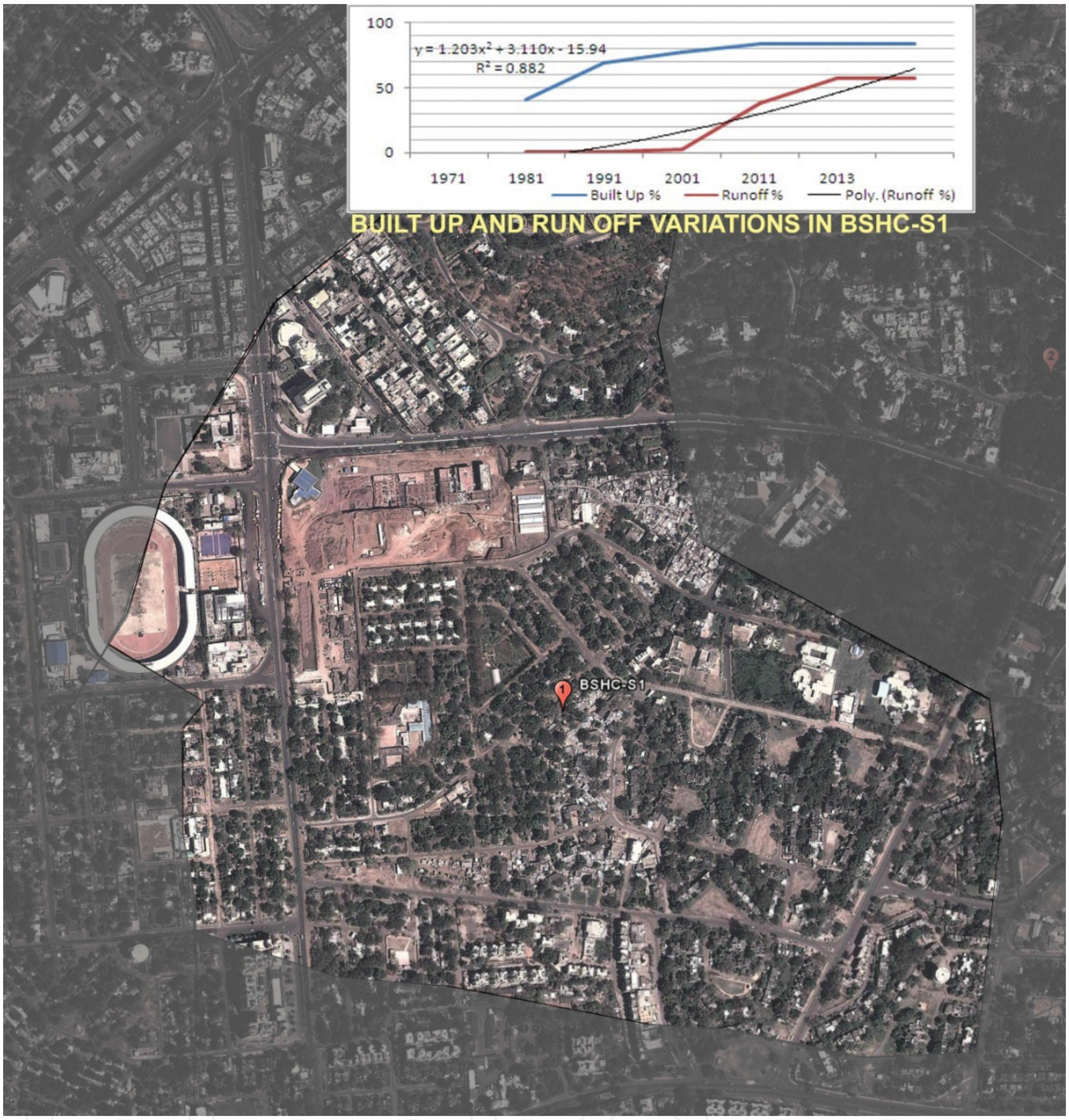

Figure 2. Built-up and runoff variations in catchment BSHC-S1.

c. BSHC-S6

This catchment has a part with geological characteristics of alluvium soil and has experienced increase in built-up from 2.36 to 87.18% and runoff from 0.18 to 64.77%. The roughness values for this catchment showed a variance for impervious surface of 0.012 roughness to 0.011 and for pervious 0.13 to 0.05, before and after predevelopment as most of the natural area was made impervious, though some natural parks and open spaces are still restored as natural ones. The recharge potential for this area is too high and has maintained satisfactory water levels in all seasons.

Coefficient of determination = 0.915 and R^2 = 0.906.

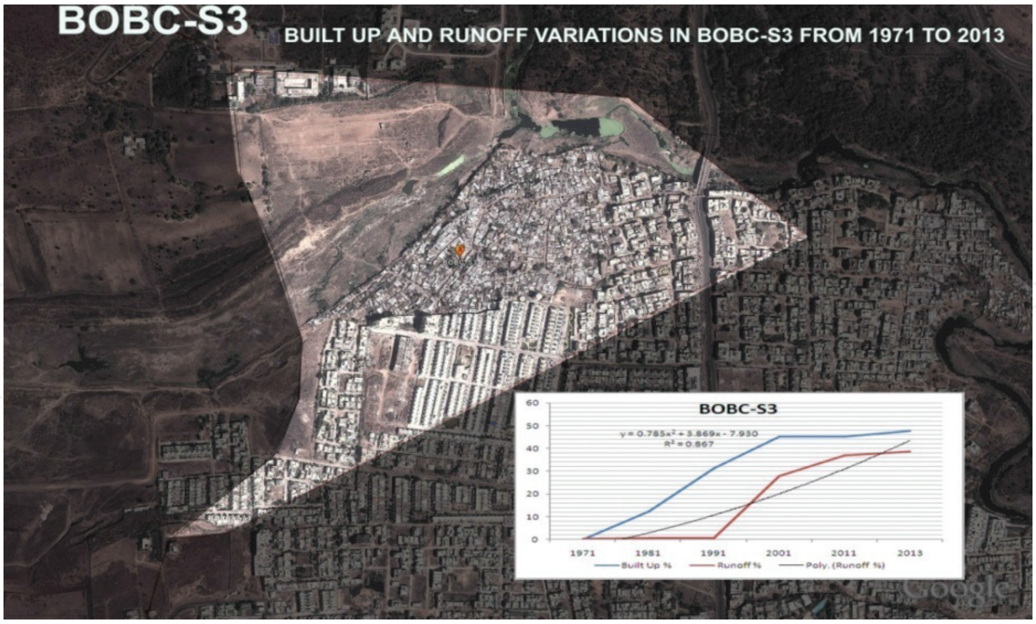

Figure 3. Built-up and runoff variations in catchment BOBC-S3.

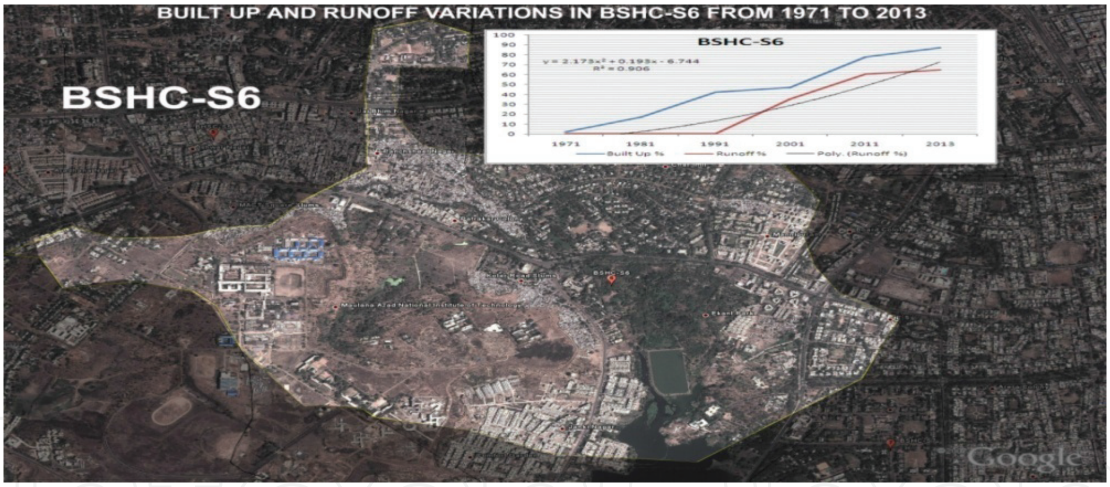

Figure 4. Built-up and runoff variations in catchment BSHC-S6.

d. BSHC-S9

This catchment has water body around 50% of its area and experiences increase in build-up from 0.49 to 46.25% and resulting runoff from 0.0031 to 5.14%. The commercial activities in and around the water body has disturbed the peak flows for this area still maintaining the overall runoff very much less thus helping the recharge potential a lot. Water levels in this area show satisfactory recharge.

Coefficient of determination = 0.749 and R^2 = 0.830.

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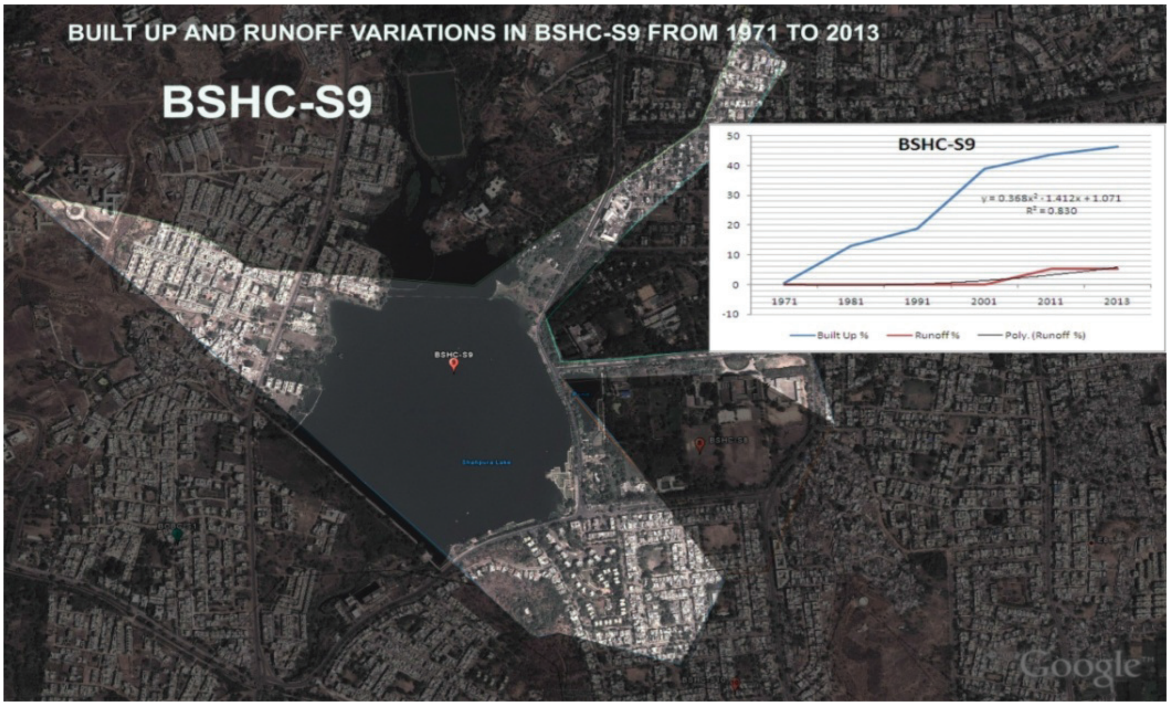

Figure 5. Built-up and runoff variations in catchment BSHC-S9.

4. Conclusions

Urban land cover changes the natural capacity of land and working cycle. Increasing built-up and resulting runoff with different 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. "Catch water where it falls"—we have to catch water as soon as it falls in the form of precipitation because once it is converted into runoff, it is difficult to control and catch. The soil or urban land needs to be planned in such a way that as soon as water falls on it, it should percolate below.

Land use like residential with 40–50% with open spaces left in natural state and developed with efforts with grass, bushes and trees, minimizes 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.

Alluvial soil and basalt soil result in peak runoff, but alluvial if treated merely with grass and natural soil state pockets also helps in fast infiltration, whereas basalt does not allow infiltration of rain so easily with normal land covers. It needs proper land use allotment and planning to work satisfactorily. Impervious and pervious areas like 25 and 15% as in mixed land use 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 0.011–0.017 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 man-made efforts; this capacity can be extended to support the normal working of natural system in developed conditions.

- Runoff in urban areas varies from 25.15 to 88.21%.
- Some catchments produce more runoff than others though having same built-up percent.
- Catchments with connected open spaces have less runoff, whereas unconnected pervious areas act as interception storages at bigger scale.
- Runoff from 5.35 to 50% can be manipulated with the help of basic use of hydrological knowledge in planning urban landscapes.

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