# Impact of Urbanization on the Hydrology of Ganga Basin (India)

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Anil Kumar Misra
THE NORTHCAP UNIVERSITY…

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# Impact of Urbanization on the Hydrology of Ganga Basin (India)

**Anil Kumar Misra**

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**Abstract** Large scale emigrations from rural areas to urban areas and population growth have been uninterrupted and accelerating phenomena in parts of Ganga basin, where urbanization is increasing at an unprecedented rate. Urban agglomeration is causing radical changes in groundwater recharge and modifying the existing mechanisms. Majority of the cities are sited on unconfined or semi confined aquifers depend upon river water and groundwater for most of their water supply and disposal of most of their liquid effluents and solid residues to the rivers and ground. There has also been an inevitable rise in waste production. Drainage of surface water has been disrupted as the small natural channels and low lying areas have been in filled, often with municipal waste. Total water potential of the Ganga basin including surface water potential and ground water potential is around 525.02 km$^3$ and 170.00 km$^3$ respectively. Basin supports approximately 42% of the total population in India. Water tables are declining at approximately an average of 0.20 m per year in many parts of the basin and there is a trend of deteriorating groundwater quality. The demand of water has been increased many folds and most of the areas are highly reliant upon the groundwater to meet this increasing demand for water, but unfortunately degradation of groundwater both in terms of quantity and quality has deteriorated the situation. Studies shows that change in climate may increase temperature by 2 to 6°C and can reduce precipitation up to 16%, which could reduce the groundwater recharge by 50%. In densely populated Ganga basin urban drainage consumes a high proportion of the investments into urban infrastructure and needs integrated approach for the sustainable development of water management, water education regarding conservation and pollution caused by urbanization.

**Keywords** Urbanization · Population growth · Ganga basin · Soil salinity · Water quality · Climate change · Urban infrastructure

A. K. Misra (✉)
Department of Civil Engineering, ITM University,
Sector 23A, Palam Vihar, HUDA, Gurgaon, Haryana, India
e-mail: anilgeology@gmail.com

## 1 Introduction

There are many direct and indirect links between urbanization and environmental degradation, because increasing number of people depend on the available fixed natural resources. The provision of water supply, sanitation and drainage are some of the important elements of urbanization processes and severely effect water resources and increases the pressure on urban hydrology. Urban impermeabilization leads not only to reduced infiltration rate but also increase direct runoff volumes, which frequently produces floods like those that frequently occurs in parts of Ganga basin.

Ganga basin has been considered an entity that determines both the range and reach of human activities with respect to water in both ancient and modern societies. It is considered as the part of composite Ganga-Brahmaputra-Meghna basin draining around 1,086,000 $km^2$ in China, Nepal, India and Bangladesh. The Ganga sub-basin drainage area lying in India is around 862,769 $km^2$, which is around 26.2% of the total geographical area of the country (CWC 2009). It is bounded on the north by the Himalaya mountain ranges; on the west the Ganga basin borders the Indus basin and then the Aravalli ridge, on the south by the Vindhyas and chhotanagpur plateaus and on the east by the Brahmaputra ridge. Ganga basin consists of hilly terrains of the Himalaya with dense forest, sparsely forested Shiwalik hills and the fertile Ganga Plains. The central Ganga Plain lies south of the Himalayan Mountains consist of mountains, hills and plateaus intersected by valleys and river plains. Majoriy of these areas are covered by forests and the soil types found in basin are sand, loam, clay and their combinations such as sandy loam, silty clay etc.

Ganga basin area lies in states of Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, West Bengal, Haryana, Himachal Pradesh and Delhi. The basin has a population of more than 500 million, making it the most populated river basin in the world. Table 1 shows the basins catchment area and population in different states in Ganga basin. The annual surface water potential of the basin has been assessed as 525.0 $km^3$ out of this 250.0 $km^3$ is utilizable water. Culturable area of the basin is about 58.0 M.Ha, which is 29.5% of the total culturable area of the country (GFCC 2009). Figure 1 shows the location and drainage of the Ganga basin.

In Ganga basin, the growing population pressure has severely affected the ability of the present water resources available to adequately provide water to the current

**Table 1** Shows the Ganga basin catchment area and population based on visual interpretation of satellite data pertaining to the period 1981–1991 and worked out the statistics of the catchment by Forest survey of India (MOEF 1995; Census of India 2001)

| State | Population (in lakh) | Total population of the state till 2001 (persons) | Catchment area ($km^2$) |
|---|---|---|---|
| Uttranchal and Uttar Pradesh | 1,391.12 | 174,532,421 | 294,411 |
| Himachal Pradesh | 4.61 | 6,077,248 | 6,201 |
| Haryana | 129.66 | 21,082,989 | 33,422 |
| Delhi | 94.21 | 13,782,976 | 1,483 |
| Rajasthan | 214.87 | 56,473,122 | 115,845 |
| Madhya Pradesh | 379.42 | 60,385,118 | 200,252 |
| Bihar | 803.26 | 82,878,796 | 136,925 |
| West Bengal | 547.93 | 80,221,171 | 63,136 |

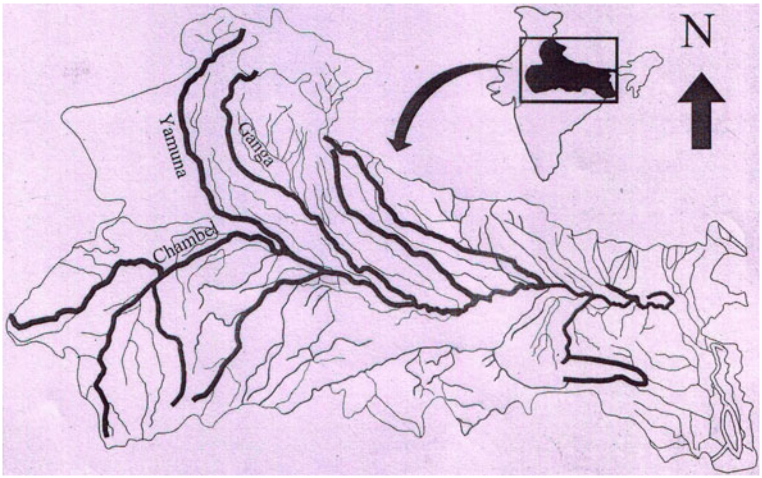


**Fig. 1** Shows the location of Ganga basin and drainage patterns

population at the prevailing level of technological development. This in turn also reinforces poverty and leads to further deterioration in socioeconomic conditions.

This study suggests actions that should be considered in the light of the linkages between growing population pressure and water resources. It identifies the key demographic and water resource concerns, and establishes the current state of understanding as to the linkages between population pressure and water use. Overall, it is important to understand the nature and strength of the linkages because of their implications for effective intervention.

## 2 Disturbances and Influences on Urban Hydrological Cycle

Urbanization not only creating obstructions for the hydrologic cycle by disturbing the processes of evaporation, transpiration and infiltration, it is also an important factor in polluting the natural resources. A common factor to most urbanization is that it results in impermeabilization of a significant proportion of land surface and major water imports from outside the urban limits (Lindh 1983). Urbanization also causes major changes in the frequency and volume of groundwater recharges (Foster 1999).

In Ganga basin hydrological cycle has suffered quantitatively and qualitatively changes with time as a result of changes in weather (temperature, humidity and wind velocity), evaporation and evapotranspiration, infiltration characteristics, land use and land cover, groundwater characteristics, physical and geological characteristics of the area and water quality. Excessive urbanization, industrialization and population growth has greatly modified the landscapes and carried out the major changes in the hydrological cycle such as large scale removal of natural vegetation drainage patterns, decrease in the natural depressions which store surface water, decrease in the rainfall absorbing capacity of soil, large scale formation of impervious areas (roads, concrete footpaths, rooftops and driveways) etc. Apart from that the human activities have changed the land cover of river basins and are regulating the water fluxes in nature can considerably change the hydrological cycle of the river basins also.

Ganga Basin is a striking example of such changes in the present-day situation where large scale deforestation in the local mountainous regions and changes in land use and land cover pattern have change the scale and frequency of flooding and drought. Deforestation especially in northern India due to escalation in population has increasing flooding because of more erosion of soil as root no longer hold soil together. In Ganga basin the problem of flooding has increases from west to east and from south to north. The worst flood affected states are Bihar, Uttar Pradesh and Bengal. In these states the runoff volumes and peak flow in rivers are higher.

The hydrological cycle has become more transformed and regimented in the region. Due to the large scale construction of dams, check dams, dikes, barrages and levees in the basin the surface runoff (direct runoff) has been decreased and water accumulation has been increased, which has increased the evaporation rate and groundwater level in some parts.

The impact of irrigation activities in Ganga basin can also be noticed. The diversion of surface or groundwater resources through canal network has been considerably increased, which modifies the natural hydrological processes by increasing the runoff and evaporation. Changes in the land use of the Ganga river basin have also shown significant influence on the hydrological cycle of the region. Since the consequences of land use change are revealed gradually but can be realized by the changes in climate. Major human disturbance and influence on hydrological cycle can be observed in urban areas of basin. The removal of natural land cover by the concrete and impermeable surfaces causes large reductions in infiltration rate and evapo-transpiration. Which increases rainfall runoff in urbanized areas causes water logging and flooding.

## 2.1 Effects on Water Quality

In addition to hydrologic and geomorphologic changes urbanization directly or indirectly affects the quality of the receiving water. Some of the indicators of the impact of urbanization on water quality include increased stream temperature and pollutants and radical changes in the subsurface infiltration rate.

Approximately 40% of the population that is around 360 million people of India lives in Ganga river basin. Both surface and groundwater are used for the domestic, irrigational and industrial supply. There is sharp decline in the quality of water both in the surface and groundwater due to increasing level of pollution from urban and industrial areas. Surface water sources are more polluted especially the rivers like Ganga and Yamuan as compare to groundwater pollution due to the discharge of untreated urban wastes and industrial effluents from the drains of large and medium cities located along the course of these rivers and their tributaries. Large number of town and big cities are located in the Ganga basin, which generate and discharge huge amount of sewerages and wastes, majority of which eventually reaches the river through the natural drainage system. Most of the tributaries of Ganga and Yamuna become the channels of transport of sewerage waste water and industrial effluents of the cities.

**Table 2** Concentration of fluoride in groundwater of different states of Ganga basin

| Locations | Type of geological formation | Fluoride (mg/l) | References |
|---|---|---|---|
| Sonbhadra District, Uttar Pradesh | Archean granite and gneissic complex | 0.483–6.7 | Raju et al. (2009) |
| Mathura, Uttar Pradesh | Quaternary deposits | 0.1–2.5 | Misra et al. (2006), Misra and Mishra (2007) |
| Agra, Uttar Pradesh | Quaternary deposits | 0.1–17.5 | Gupta et al. (1999) |
| Varanasi, Uttar Pradesh | Quaternary deposits | 0.2–2.1 | Ray et al. (1983) |
| Delhi | Precambrian quartzite's | 0.2–32.5 | Susheela et al. (1996) |
| Bihar | Archean gneissic complex | 0.1–2.5 | Ray et al. (2000) |
| Chandidongri, Madhya Pradesh | Archean granite and gneissic complex | 1.5–4 | Chatterjee and Mohabey (1998) |
| Shivpuri, Madhya Pradesh | Archean granite and gneissic complex | 0.2–6.4 | Nawlakhe et al. (1995) |
| Unnao, Uttar Pradesh | Quaternary deposits | 0.8–13.9 | Jha et al. (2009) |
| Rajasthan | Calc-schist, amphibolites, calc-gneiss and biotite schist (all Precambrian) | 0.1–11.6 | Madhavan and Subramanian (2003) |
| West Bengal | Quaternary deposits | 0.1–1.8 | Kundu and Mandal (2009) |
| Punjab | Quaternary deposits | – | Pillai and Stanley (2002) |

Apart from the surface water groundwater quality of different urban areas of Ganga basin is also deteriorating. Different studies carried out in different parts of the Ganga basin revealed that the levels of fluoride, nitrate, salinity etc has been escalated. High fluoride concentration in ground waters of the Ganga Plain is a major problem. Fluoride occurs in almost all waters from trace to high concentrations (Gaciri and Davies 1993). The concentration of fluoride in natural water depends on various factors such as pH, temperature, solubility of fluoride bearing minerals, anion exchange capacity of aquifer materials ($OH^-$ for $F^-$) and the nature of geological formations detained by water and contact time of water with a particular formation (Raju et al. 2009). Fluoride concentration more than 1.5 mg/l may cause dental and skeletal fluorosis. In India approximately 62 million peoples, including 6 million children suffer from fluorosis due to the consumption of fluoride contaminated water.

In Ganga basin Uttar Pradesh, Bihar, Madhya Pradesh and West Bengal are the most affected states. Studies carried out by different researchers shown in Tables 2 and 3 shows the fluoride endemic habitations in Ganga basin states. Various

**Table 3** Fluoride endemic habitations in Ganga basin States (Dinesh 2001)

| States | No. of habitations with excess fluorides |
|---|---|
| Bihar | 12 |
| Madhya Pradesh | 201 |
| Haryana | 334 |
| Himachal Pradesh | 488 |
| Punjab | 700 |
| Rajasthan | 16,560 |
| Uttar Pradesh | 1,072 |
| West Bengal | 21 |

water quality parameters such as Cl, conductivity, TDS, hardness, Na, Mg, and $SO_4$, indicating contamination due to leaching of domestic and industrial pollutants (Sargaonkar et al. 2008) led by excessive urbanization processes. The part of the middle and upper Ganga plain are also affected by arsenic groundwater contamination (Saha 2009).

Studies shows that fluoride is mainly derived from weathering, and the atmospheric deposition from soil dust and industrial emissions can also be considerable. Das et al. (1981) reported 0.1 mg/l for monsoon rainwater at Bhopal in central India. Considerably higher concentrations, around 0.3 mg/l have been reported from two sites in Uttar Pradesh (Satsangi et al. 1998) and Madhya Pradesh (Singh et al. 2001). These researchers show that, a large fraction of the dissolved material in the rainwater in their investigations, including the $F^-$, may be derived from local soil dust.

## 2.2 Impact on Urban Infrastructure

As per the United Nations report, the level of urbanization is estimated to cross the 50% mark in 2005 and by 2025 more than three fifth of the world population will live in urban areas (United Nations 1993). One of the major factors for unprecedented rate of urbanization is population growth, unemployment and more opportunities in urban areas. Table 4 shows the urban growth in some states of the Ganga basin. In Ganga basin majority of urban areas are more developed and industrialized than the rural areas and this attracts people to the urban areas and increase urbanization, which is increasing pressure on urban infrastructures, such as transport facilities, housing, water & sanitation and drainage facilities. Moreover to satisfy the need of more people more production is required, which in turn results in the release of large amount of wastes and pollutants. Many cities of the basin with already inadequate infrastructure facilities are facing congested population problems coupled with illegal settlements due to migration from the rural areas. Urban agglomeration is also decreasing the vegetation cover, which decreases the rate of soil erosion and sedimentation in the watershed and thereby helps in water resource management (Butt et al. 2010).

Urbanization has shown a severe effect on water resources in Ganga basin. Large scale construction has resulted in land surface impermeabilization, which has reduced the infiltration of excess rainfall and increase the surface runoff. To satisfy the needs of water over drafting of groundwater is carried without taking care of recharge, because of this the water level in many parts of the Ganga basin is depleting approximately .20 m per year. In many cities large portion is unsewered due to this large

**Table 4** Urban growths in some states of Ganga basin (Census of India 1991, 2001)

| States | Urban growths % | | | |
|---|---|---|---|---|
| | 1961–1971 | 1971–1981 | 1981–1991 | 1991–2001 |
| Punjab | 25.3 | 44.5 | 29.1 | 19.76 |
| Haryana | 35.6 | 59.5 | 43.1 | 28.06 |
| Bihar | 43.9 | 54.8 | 30.4 | 28.43 |
| Rajasthan | 38.5 | 58.7 | 39.2 | 28.33 |
| Uttar Pradesh | 30.1 | 60.6 | 38.9 | 25.74 |

proportion of urban drainage and wastewater is directed to surface watercourses. Because of reduced infiltration and storage capacity of the ground, frequently water logging occurs (especially rainy seasons) which causes waterborne diseases and pollute both surface and groundwater sources. In small towns majority of the area has incomplete coverage by mains sewerage. The seepage from unsewered sanitation systems such as septic tanks, cesspits and latrines, probably represent the most widespread and serious diffuse pollution source and for groundwater the immediate concern from onsite sanitation systems is a risk of direct migration of pathogenic bacteria and viruses to underlying aquifers and neighbouring groundwater sources (Lewis et al. 1982). In Ganga basin rapid urbanization has shown a profound effect on groundwater recharge and marked impact on groundwater quality.

## 3 Soil Salinity in Ganga Basin

Soil salinity is a very serious environmental hazard. It refers to the presence in soil and water of various electrolytic mineral solutes in concentrations that are harmful to many agricultural crops (Hillel 2000). The development of saline soil is a dynamic phenomenon that needs to be monitored regularly in order to secure up to date knowledge of their extent, spatial distribution, nature, and magnitude (Ghassemi et al. 1995). According to the Postel (1999) worldwide 1 in 5 ha of irrigated land suffers from a buildup of salts in the soil and vast areas in China, India, Pakistan, Central Asia and the United States are losing productivity. It is predicted that the global climate change due to increasing concentration of greenhouse gases will result in increasing temperature by 2 to 6°C and a possible reduction of precipitation of up to 16%. This could reduce the groundwater recharge by 50% (Mizyed 2009). If it happens then the rate of soil salinity will increase by 20 to 25% and agricultural growth will reduce by 10 to 15%.

Ganga basin states are facing the problem of soil salinity which is continuously increasing and urbanization is one of the contributing factors. The soil salinity occurs naturally from the long term influence of natural processes. While the soil salinity increased by human activities is the secondary salinization, which is salt stored in the soil profile due to the extra water provided by the human activities such as, canal network and its extension, flooding, irrigation, increased water logging problems and high evaporation rate due to increase in temperature. In India approximately $7 \times 10^6$ ha of agricultural soils are salt-affected, out of which $2.5 \times 10^6$ ha are sodic (Dahiya and Anlauf 1990; Chhabra 1995). In 1979, the alkaline soils occupied only $0.6 \times 10^6$ ha in India (El-Swaify et al. 1983).

Geologically most of the area of the Ganga basin is represented by the Quaternary sediments differentiated into older alluvium and younger alluvium. The soils in the Ganga basin are micaceous and have illitic mineralogy; the deep black soils have smectitic mineralogy. Soils which have illitic mineralogy have very high pH, often in the vicinity of 10 in the surface horizon, which decreases with depth. The sodium saturation is almost absolute in the surface horizon and tapers with depth. These soils are calcareous all through the profile depth with a thick layer of calcium carbonate concretions at around 1 m depth. In states like Uttar Pradesh, Madhya Pradesh and Rajasthan soils are calcareous in vast areas. The calcareous nature of the soil and the fact that the irrigation water in the area contains NaCl as the soluble salt are also one

**Table 5** Area (projected) under water logging and soil salinity in irrigation commands (modified from CSSRI 1997)

| Year | Area irrigated by canal (million ha) | Area affected by water logging/soil salinity (million ha) | | Increase in area (%/annum) |
|---|---|---|---|---|
| | | Actual | Projected | |
| Haryana | | | | |
| 1955 | 2.4 | 0.01 | | |
| 1977 | 3.2 | 0.46 | | 0.06 |
| 2025 (projected) | 3.2 | | 2.0 | 1.10 |
| India | | | | |
| 1992 | 17.3 | 3.47 | | |
| 2020 | 45.0 | | $9.0^{a} + 2.7^{b} = 11.7$ | |
| 2025 | 50.0 | | $10.0^{a} + 3.0^{b} = 13.0$ | |

[a] Assuming 20% of the area would be affected at any time
[b] Assuming the area affected would increase at the rate 0.06% per annum in the existing command

of the major reasons behind the continuous escalation in the soil salinity. Beside that low precipitation and high evaporation rate are aggravating the problem. A total of 5.3637 million ha alkali/sodic soils occur in the country, out of which 4.0992 million ha occur in the Indo-Gangetic alluvial plain and 1.2645 million ha in the deep black soil or vertisol region. Tables 5 and 6 shows the extent of saline/sodic soils in different states of the Ganga basin.

Salinity and alkalinity have become major problems in Haryana state due to water-logging, with about 60% of the cropped area facing soil degradation (Datta 2000; Singh 2000) And about $2 \times 10^{6}$ ha are in the process of being degraded. Studies carried out in the irrigated area of the lower Ganga canal in Uttar Pradesh by Umar and Sami Ahmad (2000) shows that groundwater's in this area have a residual alkalinity ($Ca^{2+} < HCO_3^-$) and 50% of the samples have a pH in excess of 8.2. Further the study carried out by, Jacks et al. (2005), Jaglan (1996) and Kumar (1996) shows that soil pH and alkalinity in Rajasthan has been increased. Moreover the area irrigated by the Indira Gandhi Canal has rapidly rising groundwater levels and low-lying parts show rising pH due to water logging (Jaglan and Qureshi 1996). Studies also show that soil alkalinity increases due to excess irrigation in combination with poor or absent drainage (Meena 2001). In Rajasthan the soil contain hardened/cemented horizons. These horizons not only affect infiltration and salinization depending upon their thickness and depth of formation but are also act as obstacle to groundwater recharge and root penetration for vegetation.

**Table 6** The extent of saline/sodic soils in some of the states of Ganga basin

| State | Saline | Sodic | Total |
|---|---|---|---|
| Haryana | 175.2 | 255.7 | 430.9 |
| Rajasthan | 490.4 | 9.5 | 499.9 |
| Delhi | 21.2 | Nil | 21.2 |
| Uttar Pradesh | 128.9 | 3,394.1 | 3,523.0 |
| Bihar | – | 229 | 229 |
| West Bengal | 377.7 | – | 377.7 |
| Madhya Pradesh | 1,743.4 | 26.6 | 1,770.0 |

Slightly saline areas are not accounted in these states (Bhargava 2007)

The determination of the effect of impervious area is very important because it increases the volume of runoff and increases the velocity of the water, both of which tend to increase the peak flows. No accurate data of total impervious area of Ganga basin is available till date. The effect of increased impervious area depends upon its location in the basin and the "connectedness" of the impervious area to the channel. This nature of studies is needed to be conducted in the Ganga basin.

## 4 Available Water Resources

The availability of water resources in Ganga Basin differs with place and time. The major source of water is glaciers and precipitation in the region. Majority of the rainfall is restricted to a brief period of 3 to 4 months. Due to asymmetrical distribution of rainfall the region faces plight of flood and drought in some part of the country every year. The total water potential of the basin including surface water and groundwater potential is around 525.02 $km^3$ and 170.00 $km^3$ respectively. It supports approximately 42% of total population of India.

In Uttar Pradesh major source of surface water are rivers. Major rivers are Ganga, Yamuna, Ghagra, Gomti, Gandak, Sone and Sarda flowing from southeast to southwest direction. During the rainy season, these rivers cause flooding of large, areas, particularly in eastern Uttar Pradesh, resulting considerable loss of crops, life and property. The average annual rainfall in the state is around 1,279 mm. Hydrogeologically area has been divided into five units namely Bahbar, Tarai, Central Alluvial Plain, Marginal Alluvial Plain and the Southern Peninsular Zone (CGWB 2009). State has plenty of water resources but due to groundwater quality problems (concentration above the acceptable limits of salinity, fluoride, chloride, Iron, Nitrate and Arsenic) and surface water pollution it's become difficult to satisfy the growing needs.

Another major state belongs to Ganga basin is Madhya Pradesh, has a diversity of topographical, geological and hydrogeological conditions. Majority of the landmass is plateau from which various rivers originate. Approximately 188,824 $km^2$ area of Madhya Pradesh belongs to Ganga basin. The average annual rainfall of the state is around 917 mm. Due to limited water resources, erratic and low rainfall Madhya Pradesh often faces the severe water scarcity problems. Most of the north east and south east part of the Rajasthan belongs to Ganga basin. Rajasthan has the poor water availability and the driest states of India. Rajasthan contribution in the water resources of India for surface water and groundwater is around 1.16% and 1.70% respectively (Government of Rajasthan 2005). The population growth rate in the state is among the highest in the country. The primary source of water is scanty and erratic rainfall confined to just 2 months of the year, having total average annual rainfall around 504 mm. Approximately two-third of the state suffers from severe water scarcity and quality problems.

Haryana is another small important state having 34,341 $km^2$ of area belongs to Ganga basin (North east and south east portion). An area of 1,553 $km^2$ of Haryana is covered by forest with four geographic features namely Shivalik hills, Ghaggar Yamuna Plain, semi-desert plain and Aravalli hills. The Siwalik hill region in the Haryana is the wettest and the Aravalli hill region is the driest. The average annual rainfall in the state is 615 mm. The sources of water resource in state are the rivers and rainfall. River Yamuna which flows along the eastern boundary of the state is a major source of surface water. River Ghaggar and Markanda are the seasonal rivers. Almost all the district of Haryana is facing water scarcity and quality problem due unexpected rate of urbanization. Next Ganga basin state is Punjab, situated just above the Haryana and is mainly underlain by quaternary alluvium of considerable thickness. The average annual rainfall in Punjab is around 780 mm. Punjab is also called state of lakes and rivers. There are five rivers namely Beas, Sutlej, Ravi, Chenab and Jhelum in Punjab that drains the fertile lands. Although plenty of water resources are available in Punjab but whenever monsoon fails state is unable to satisfy the growing demand.

Bihar is one of major states belong to Ganga basin. Topographically it is a fertile alluvial plain which extends from the foothills of the Himalayan in the north to the south. Bihar is considered as the richest states in water resources of India both in the surface and groundwater resources. River Ganga and its tributaries (Saryu, Gandak, Budhi Gandak, Bagmati, Kamla-balan, Mahananda, Sone, Uttari Koyal, Punpun, Panchane and Karmnasha) in Bihar make the water availability for irrigational, industrial and domestic purposes. Like Bihar, West Bengal is also rich in water resources. The average annual rainfall of the state is around 2,074 mm highest among all the states of the Ganga basin. Hydrogeologically state can be divided into two units namely porous alluvial formations deposited by Ganga and Brahmaputra rivers and fissured hard rocks. In majority of the portion of West Bengal availability of water is good, but quality wise it is not fit for domestic uses in some parts of states. Many thousands of people in several districts are drinking groundwater with arsenic concentration far above acceptable levels. The origin of the arsenic pollution seems to be geological.

Most of the area of the Ganga basin falls in the semiarid climatic conditions characterized by the seasonal rainfall confined for 3 to 4 months from June to

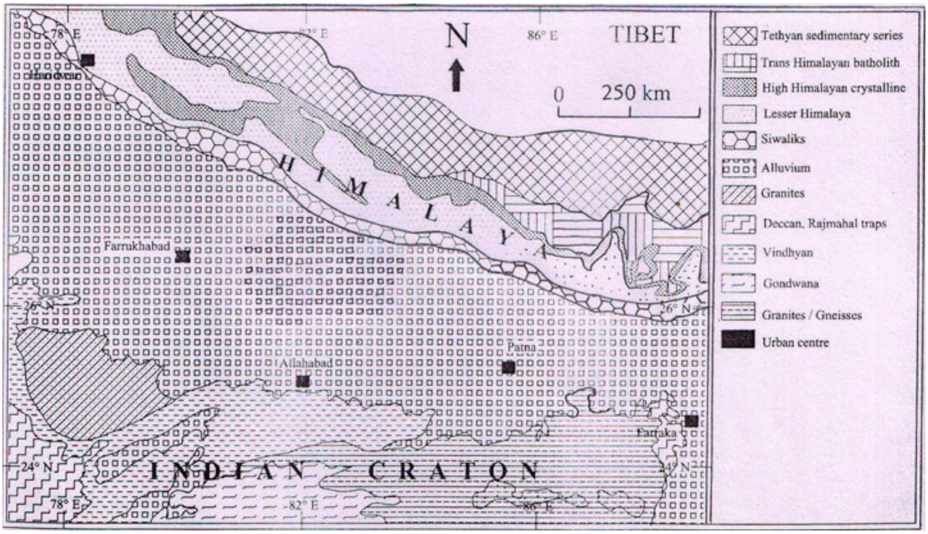


**Fig. 2** Shows the geology of the Ganga river basin (modified after Munendra Singh et al. 2007)

September. The average temperature in Ganga basin during winter season from November to February is between 5°C to 30°C. It sharply rises from March to May from 30°C to 45°C. In Ganga basin groundwater occurs everywhere but the yield of wells in various hydrogeological units shows a large variation due to heterogeneity in subsurface lithology. Figure 2 shows the geology of Ganga river basin.

## 5 Discussion and Conclusion

In the Ganga basin rapid urbanization has shown a potential effect on environment, water resources & its quality, soil salinity and urban infrastructures. The water resources are steadily degrading and could potentially form an environmental hazard. The impact of urbanization on the aquifer complexes is very varied. Over-exploitation of Quaternary aquifer in the basin becomes a common phenomenon in almost every urban area, which has caused the depletion of water levels. The greatest hydrogeological impacts of urbanization are found on the flat surfaces of the high terraces and the interfluves. The frequency of extreme hydrological events especially in Central Ganga Plain has been increased due to increase runoff causes more intense local flooding, while droughts during dry weather are deeper and longer. These changes have started showing their impact in Ganga basin on water habitats, exports high concentration of pollution into the rivers, wetlands and reservoirs, destabilizes ecological processes, handicap ecological stability of ecosystems.

As a result the findings of this study demonstrated that:

❖ There is growing imbalance between demand and supply of water.
❖ Both surface and groundwater quality is deteriorating due to urbanization.
❖ Urbanization has led to the lowering of water levels in many urban localities due to abstraction. This has shown a major impact on the surface environment.
❖ Poorly developed drainage systems/no drainage systems in cities causes frequent flooding led to the spreading of viral and epidemic diseases.
❖ Groundwater run-off, infiltration rate and recharge have reduced and water storage is much lower.
❖ Over drafting of groundwater is leading to diminished agricultural yields in the Ganga basin.
❖ Frequency of surface runoff has increased.
❖ Ganga basin has high density of population. This dense population coupled with high growth rate, which is generating huge demand for additional water in Ganga basin.

The following measures are proposed to be undertaken as a part of better water and urban management.

1. Water Management Programme in Urban Areas:

Most of the urban areas in Ganga basin are facing severe water scarcity. The available groundwater exploitation is unplanned and unregulated, causing ecological degradation. Therefore it is necessary to start water conservation/management plans such as rainwater harvesting schemes followed by formation of artificial recharge structures. The existing buildings and the under construction building can be equipped with roof-top harvesting structures. Emphasis should be given on urban watershed management and development programmes. Studies shows (Mohapatra and Mitchell 2009) that the implementation of conservation measures would decrease the volume of water use and also exert less pressure on the water distribution systems as well as wastewater treatment system.

2. Soil Erosion and its Prevention:

Soil erosion which is continuously increasing in the Ganga Basin needs immediate action to prevent it. As soil erodes, valuable moisture and nutrients are lost, which ultimately decline the yields. Soil erosion prevention should begin with soil erosion controlling methods. Prevention methods should be determined by the depth and severity of soil erosion. Prevention methods will help keep soil healthy and also increase the productivity, which will help in satisfying the demand of growing population.

3. Urban/Landuse Planning

One of the biggest problems of most of the urban areas of Ganga basin is the unplanned urban expansions and land use patterns, which have triggered conflicts between urban and peri-urban interest. By using remote sensing and GIS techniques, urban planning of the cities should be carried out. Emphasis should be given on the use of open and abandoned areas for the plantation and formation of water recharge structures. Areas with natural vegetation covers are the most important part of the urban planning with higher infiltration and reduced runoff rates. Therefore as much as possible these areas are protected for any construction to maintain the groundwater level and improve the water quality.

4. Improve Drainage and Sewerage Network

Almost every city of Ganga basin required up gradation of drainage and sewerage network. In majority of the cities there is a complete mismatch between drains inside a colony and their outfalls. Further almost all the drainage and sewerage systems in the cities are faulty and there is no chance for the rainwater and domestic water of findings its way to their designed outfalls. It causes stagnation of water and choking of drainage and sewerage systems especially during rainy seasons and become a potential health hazard leading to many epidemic diseases and pollutes surface and groundwater resources. Now it is urgently required to upgrade the existing systems along with creating new facilities for the sewerage waste treatment so that without primary treatment it is not allowed to dump in the rivers.

5. Promote Recycling & Reuse of Wastewater

Ganga basin is experiencing perhaps the fastest urban development putting great stress on the natural water cycle. This can be minimize by promoting the reuse of wastewater for water-demanding activities, which consumed limited freshwater resources. Many developed and developing countries have adopted the option of recycling and reuse of wastewater for agricultural and non-potable purposes. Same practices must be encouraged and facilities for recycling of wastewater should be built to minimize the pressure on groundwater resources.

6. Water Education for Sustainable Development

Water is the element most essential to sustain human life, therefore it is necessary to create better understanding of water resources and foster public understanding through water education. Water education should not be only about water types, sources, uses, treatment, management and its associated problems, etc. It must include people's perceptions of water, the level of their consciousness towards water usage, awareness of their civic responsibilities towards water, cultural beliefs and practices in relation to water. Awareness should also be raised among the people by taking the help of media and NGO's regarding conservation of water. Formation of new policies for sustainable development of water resources, regulating water prices for water conservation, conservation education, pollution prevention as well as effective information management will help in satisfying the demand.

7. Prevent Rural to Urban Migration

Planner and the decision makers should create opportunities in the rural areas in order to prevent the migration of people. Now days due to the lack of education, health, employment facilities in rural areas people are migrating from rural to urban areas. If more facilities of education (graduate/technical level) and employment are generated within the rural areas; large scale migration of people can be prevented.

8. Promote Population Control Education/Schemes/Benefits

Problem of urbanization is directly and indirectly related to population growth therefore effective measure should be taken to minimize the growth rate. Almost all census reports indicate the higher growth rate of population from rural areas and the major reason behind this is the lack of population control education/schemes and their benefits. Rural population should be given proper educations regarding importance of small family, better opportunities and related benefits.

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