International Scholars Journals

African Journal of Geography and Regional Planning ISSN 3627-8945 Vol. 6 (10), pp. 001-022, October, 2019. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Urban sprawl and water stress with respect to changing landscape: Study from Lucknow, India

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Accepted 12 May, 2019

Lucknow is the capital city of India's most populous state Uttar Pradesh. Urban growth currently is largely on par with other cities of similar size, and is anticipated to be slightly faster in the immediate future. The better economic prospect has lead to an increase in the urban population of the city during last few years. It has lead to large-scale urban sprawl and the inherent distinctiveness of hydrological environment is being neglected in urban planning. With the expansion of the urban sprawl and the increasing population, there has been a surmounting pressure on a) natural and built drainage systems b) surface/subsurface hydrological storage units, of Lucknow. The anthropogenic factors have also contributed to the presence of heavy metals in the hydrological units of the city. Upto now the regeneration of water by nature kept the surface and subsurface water ecosystem pure, satisfying the urban and peri-urban requirements. But during last few years, increasing demands from new urban extensions as well as intense agriculture and irrigation practices in surrounding rural areas have stressed the hydrological cycle considerably, raising questions over the sustainability of the water resources in the city. This paper attempts to highlight some important environmental criteria and propose methodology to achieve it, during the design of master plan with a focus on surface and subsurface water integrity of Lucknow building upon city's natural and built environments. Changes in land use and land cover are estimated with respect to urban sprawl from year 1973 and 2005 based upon Survey of India toposheets and satellite data of IRS -1D LISS III PAN Sharpened. Drainage network map is overlaid with land use patterns drawing implications on water environment.

Key words: Urban sprawl, water, master plan, land use, drainage.

INTRODUCTION

Lucknow is the capital city of the state of Uttar Pradesh in India. Like most of the urban scenarios in the world, the increasing population and urban sprawl in the city has stressed the water resources of the city (Figures 1 and 2). Unavailability of residential areas to the population below a certain wage has lead to the encroachment of wetlands and lakes in the city. The encroachment of these drains and lakes has caused a) frequent floods in the low lying residential areas of the city b) depletion of main hydrological features in terms of wetlands and lakes which were earlier the main recharge source to the underlying aquifer. Also as the River Gomti is a plane fed river (Jain and Sinha, 2003) the main recharge to the river is lost once the aquifers are not recharged. The precipitation during monsoon fed the lakes and wetlands thus recharging the aquifers and the river. But now cubic millions of water is lost due to absence of water resource management. The lack of sewage treatment plants in the city has also lead to a considerable amount of pollution in the river and in the phreatic aquifer in terms of degradation of water quality (Singh et al., 2005). For management of sewage water, storm water, and existing water resources, a master plan is needed which requires efforts by the environmental agencies, public works department, city administration, financial department and never the less individual effort of residents in the city. This paper attempts to highlight some important

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Figure 1. Lucknow city as viewed by IRS I C – LISS III + PAN merged data acquired in January, 2001.

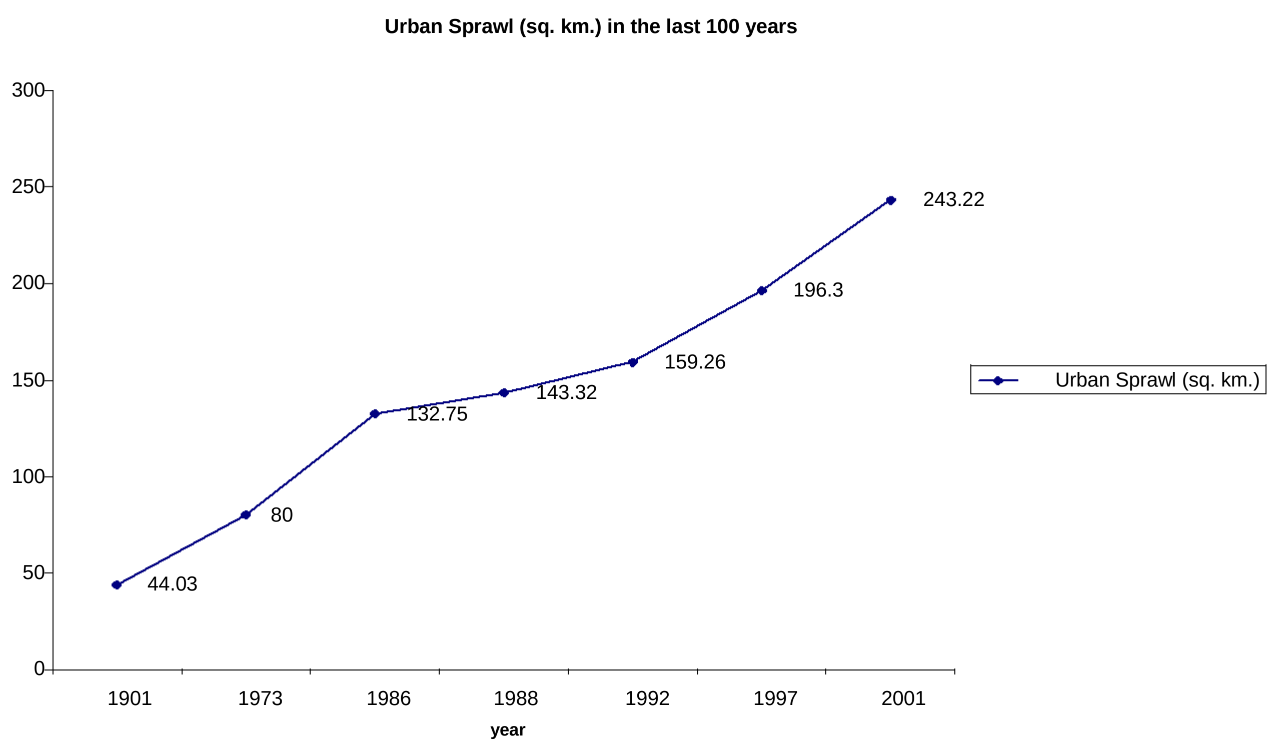

Figure 2. Year wise urban sprawl in Lucknow from 1901 - 2001.

Table 1. Settlements on both sides of the Gomti River in Lucknow.

S. no.	Cis-Gomti area	Trans-Gomti area
1	Hazratganj	Nirala Nagar
2	Aminabad	Aliganj
3	Hussainganj	Daliganj
4	Lalbagh	Old and New Hyderabad
5	Gologanj	Mahanagar
6	Wazirganj	Nishatganj
7	Rajendra Nagar	Indira Nagar
8	Malviya Nagar	Gomti Nagar
9	Sarojni Nagar	Vikas Nagar
10	Aishbagh	Jankipuram
11	Rajajipuram	
12	Chowk	
13	Saadatganj	

environmental criteria and propose methodology to achieve it, during the design of master plan with a focus on surface and subsurface water integrity of Lucknow. Changes in land use and land cover are estimated with respect to urban sprawl from year 1973 and 2005 based upon Survey of India toposheets and satellite data of IRS-1D LISS III (PAN sharpened) (Fox, 1991; Taragi and Pundir, 1997; Raghavswamy et al., 1996). Drainage network map is overlaid with land use patterns drawing implications on water environment.

GEOGRAPHICAL LOCATION AND BACKGROUND

Lucknow is situated in the central Gangetic plain and forms a part of Sai-Gomti sub-basin bound by Sitapur, Rae Bareily, Barabanki and Unnao on North, EAST and west, respectively. The total geographical area of Lucknow district is around 253 km^2 with four tehsils namely Malihabad, Bakshi ka Talab, Lucknow and Mohanlalganj. There are about 918 villages of which about 900 are inhabited. Besides Lucknow urban agglomeration, there are 7 towns namely Malihabad, Kakori, Nagram, Amethi, Gosainganj, Mohana and Itaunja. Gomti and Sai rivers and their tributaries viz. Behta, Kukrail and Loni rivers constitute the prominent natural drainage system of Lucknow. River Gomti originates from Fulhar Lake, near Madho Tanda, Pilibhit and extends 900 km through Uttar Pradesh and meets the Ganga River near Saidpur in Ghazipur. The river is a thin stream until it reaches Mohamadi (about 100 km from its origin) where it is joined by Sarayu River a prominent tributary. From here the river is well defined. Another major tributary is the Sai River, which joins near Jaunpur. After 240 km river Gomti enters Lucknow, through which it meanders for about 12 km. At the entrance point, water is lifted from the river for the city's water supply at the Aishbagh Water Works. 26 big drains in the Lucknow area discharge untreated sewage into Gomti River. At the downstream end, the Gomti barrage impounds the river converting it into a lake. The cities of Lucknow, Lakhimpur Kheri, Sultanpur and Jaunpur are located on the banks of the Gomti and are the most prominent of the 15 towns located in its catchment area. A highly meandering river in history, Gomti cuts deeply starting at the upstream on the Northwest, leaving a highland. Every year during monsoon the river swells up and floods its banks. As the river frequently changed its course, almost through the entire area, it left deposits of sand and clay layer by layer. The nature continued to deposit layers after layers of alluvium through the river for the past 0.2 million years. The alluvium deposited through river Gomti is today's vault of groundwater aquifers. The changing course also left remnants of cut off meanders of the river as ox-bow lakes locally called as 'tals'. A look at the older maps prepared by Survey of India shows that the entire city was occupied with several tals. The urban sprawl is spread equally on both sides of River Gomti. The colony and residential settlements are divided in two zones, that is, Cis-Gomti and Trans-Gomti (Table 1). The expansion of the city's spatial limit has lead to a surmounting pressure on both natural and built drainage systems. Very low proportion of the sewage generated within the city enters the main sewage systems. Either directly or indirectly a large proportion of the sewage water enters the surface drainage system, through damaged or blocked sewers. Moreover, pollution due to discharge of untreated sewage into the river adversely affects its urban usage (Singh et al., 2005). It also has a negative impact on the aesthetic appeal of the riverfront and poses substantial health risks on its usage (Tables 2 and 3).

Drainage modifications and land use changes have lead to alterations in the regional hydrology, that is, the natural pattern of drainage has been modified by the changed land use. Lucknow has contained fewer and fewer water bodies and natural wetlands over time. Restoration of these converted wetlands is quite difficult once these sites are occupied for non-wetland uses. The changes in hydrology include either the removal of water from wetlands or raising the land-surface elevation, such that it no longer floods. The changes in these wetlands and the hydrological features which existed before has changed the appearance and the functionality of water bodies. Maintenance and appropriate action for conservation of these hydrological features is very important for sustainable drainage systems. Immediate actions are required to conserve these natural lakes, streams and other hydrological features in order to have sustainable water resources in the cities. There is no doubt that in the past these small/large hydrological features have helped upto a considerable amount in groundwater augmentation. It could also have helped in the recharge of River Gomti since it is a plain fed river (Jain and Sinha, 2003). Also depending upon the condition of the land that is whether it is under vegetation cover or is barren regulates the run-off and will influence the character and hydrologic regime of the downstream areas. As example agriculture, deforestation or overgrazing removes the water- holding

Table 2. Distribution of different land use/land cover classes of Lucknow (based upon 2001 IRS - 1D/LISS III data).

Land use/land cover classes	Area (ha)	% of total area
Built up area	26865.76	10.65
Double cropped land	121971.29	48.36
Rabi cropped land	17644.95	7.0
Kharif cropped land	20336.56	8.06
Fallow land	6175.96	2.45
Plantation/Orchard	22317.42	8.85
Scrub land	17312.89	6.86
Salt affected wasteland	7802.44	3.09
Marshy/swampy land	5683.87	2.25
Waterlogged land	782.77	0.31
Dense forest	1001.43	0.40
Open forest	668.20	0.26
Scrub/degraded forest	467.35	0.19
Water bodies	3185.62	1.26

Table 3. Land transformation of Lucknow in the last 25 years.

Categories of land transformation	Area	
	(km Sq.)	%
Agriculture to built up land	76.37	62.98
Plantation to built up land	1.69	1.4
Wetlands to built up area	1.45	1.19
Watsteland to built up area	1.17	0.96
Rural to built up area	2.93	2.42
Forest area to built up area	0.39	0.32
Water body to built up area	0.74	0.61
Land under transformation	36.52	30.12
Total	121.26	100

capacity of the soil and hence causing soil erosion.

TOPOGRAPHICAL ELEMENTS IN RELATION TO DRAINAGE

Lucknow's terrain is almost flat with a depression in north-eastern part. The general slope of the area is from north and North-west to south and south-east. The highest elevation is 123.5 m, above mean sea level (amsl) and lowest elevation is 110 m amsl in the east in flood plain of Gomti river. Gomti flows in the heart of the city from north-west (Gaughat) to south east (Piprahghat). The drainage of Gomti river is mainly through Haidar canal and Kukrail nala. Kukrail nala meets the river near Piprahghat whereas the Haidar canal meets it after Gomti barrage. The Gomti river continues to be the main source of water supply to the city though a number of tube-wells have been bored to exploit groundwater. However, the available discharge in the River Gomti as per CWPC at Lucknow during lean period is around 500 MLD, while in the monsoons the discharge is around 55,000 MLD. For most of the period the discharge on an average is around 1,500 MLD only.

Hence during monsoons the river helps in recharge of the aquifer while in the low discharge season it is re-charged from the same aquifer. Considering that several towns like Jaunpur and other habitations also draw water from the River Gomti, it is not feasible to tap all the river water in Lucknow. Hence maintaining the river discharge is not only required for Lucknow city but also for other cities which rely on it. Also during the dry season, the river water level goes down to such an extent that there is need to request the State Irrigation Department to augment supplies to meet the drinking water needs.

FLOODS IN THE PAST

In 1960 Lucknow recorded its highest flood level at 113.2 m with large parts of the city being inundated. To protect the habitations earthen embankments were constructed all along the bank of the river as well as on Kukrail to a top level of 114.4 m. The sluice gates on the embankments were installed for discharge of drains during normal weather and stopping back flow during floods. But due to heavy monsoon in 1960 the back-flow of water through these drains into large parts of the city caused flood. Usually when river water level rises to the drain invert levels, these gates are closed so that no back flow occurs. In case of heavy rain and floods, the pumping stations pump storm water across the embankment into the river so as to prevent water logging in the city. The embankment and the flood pumping station are almost 25 - 30 years old and in this period one recent flooding occurred last year in 2008.

The flood-water of Gomti river inundated several parts of Lucknow in 2008, including the Gomti Nagar area of the city owing to incessant rainfall in the state. The spate in Gomti has not even spared Vipul Khand, the posh locality of Gomti Nagar area, where many bureaucrats and VIPs reside. Besides, the river water has inundated its nearby localities and posed hardships for the denizens. Gomti has also hit the lives of the people in Patelpuram and Guvari colonies situated at the backside of Vipul Khand. According to Central Water Commission, Gomti was only 69 cm below the danger level and flowing two cm above its normal level in the city. Gomti was towards an upward trend and rising at the rate of one cm/hour in Lucknow. The river was 74 cm above the red mark in Sultanpur and 88 cm below the danger level in Jaunpur. Earlier in 1985, the flood-water of river Gomti had engulfed several areas, including the main Hazratganj and Chowk area of the city. Meanwhile, the spate in Gomti river has caused reverse flow at Kukrail's nullah, which has posed danger to the Badshahnagar barrage. The water has also entered into Akbar Nagar colony and dislpaced several families. The river also flooded various ghats, including Pipraghat, Gaughat, Lallumal and Kuriyaghat and swamped various temples in city.

HYDROGEOLOGY IN RELATION TO DEPTH TO WATER AND GROUNDWATER FLOW

The area can be divided into two geological units, namely, younger and older alluvium of Quaternary age. The younger alluvial plain lies all along the river Gomti and forms a wide flood plain. The older alluvial plain occupies higher elevation than the younger alluvial plain and is underlain by thick alluvial deposits of quaternary age comprising of clay, kankar and sand. Subsurface geology is revealed by correlation based on the boreholes drilled by Central Ground Water Board (CGWB) and U. P. Jal Nigam. The CGWB and U. P. Jal Nigam have drilled a number of boreholes in the city which are located at (1) Mahanagar (2) Badshahnagar (3) Rajendra Nagar (4) Hevelock Road Victoria Hospital (5) IISR (6) Charbagh Station (7) Chandra Nagar (8) Mohanta Purwa (9) Chaupati (10) Sahdrara (11) Daliganj (12) Lucknow University and (13) Patang Park. The available data down to depth of 753 m reveal existence of three tier aquifer systems:

(a) The upper or first aquifer extends down to depth of 100 mbgl and is unconfined in nature. It comprises of sand and normally yields good quality water.

(b) The second aquifer lies in a depth range of 130 – 185 m to 165 - 235 m. It comprises of grained material and contains brackish water. Thus, this second aquifer is unsuitable.

(c) The third aquifer is fine grained and less productive than the first aquifer. It ranges from 300 - 477 m and are semi-confined to confine in nature.

The exploratory drilling results of CGWB reveal that aquifer groups below 450 m depth have autoflow conditions in Lucknow city area. The free flow discharge from deposit well at Badshah Nagar Railway Station is found to be 270 lpm. The discharge rate of tubewells screened up to 460 m depth varies from 1000 - 2000 lpm with draw down ranging between 20 and 35 m. It is found that tubewells constructed in the third aquifer (200 – 460 depth) group give comparatively low yield than the first aquifer due to low transmissibility. The main sources of recharge are:

1. Rainfall.
2. Seepage from canal network (Haider canal flowing from West to East in the city).
3. Seepage from natural stormwater drains (Pata drain, Sarkata drain, Kukrail drain etc.).
4. Seepage from return irrigation flow.

Out of the above four, the main source of aquifer recharge in the city is rainfall. The quantum of recharge relates directly to the intensity of rainfall, nature of soil and its textural characteristics, local vegetation and land utilization pattern. Groundwater resource evaluation has been made as per the GEC norms by the CGWB. Table 4 shows the groundwater recharge, ground water draft, level of development and category of the city on the basis of the development.

The above table indicates that the net annual recharge in the area is 41.90 MCM and the net annual draft is 42.66 MCM and balance is negative leaving no scope for further development in the central part of the city. The groundwater draft has been calculated from the existing shallow private and deep state tube wells in the city area. There are 270 number of tubewells constructed within depth of 160 m while there is no data about the private groundwater extraction wells which extract water from the first aquifer. The yield of tubewells ranges from 1000-2000 lpm with drawdown ranging between 20 and 35 m.

Table 4. Recharge sources and their contribution in Lucknow

Recharge source	Monsoon recharge (MCM)	Non monsoon recharge (MCM)	Total recharge (MCM)
Rainfall	1.61	0.076	1.68
Canal seepage	13.68	27.37	41.05
Seepage from surface	0.878	1.12	1.99
Seepage from tanks	-	0.007	0.007
Potential ground water resources from shallow water table areas	-	4.57	4.57
Total	16.16	33.14	49.30
Gross recharge	49.30 MCM		
Cross draft	60.95 MCM		
Net utilizable resource	41.90 MCM		
Net annual draft	42.66 MC		
Balance	(-)0.76 MCM		
Level of development	101.8%		
Category	Over exploited		

Source: Report on hydrogeology of Lucknow city, CGWB (2007).

The depth of water level ranges from 3 - 18 mbgl in the pre monsoon. There is a general rise of 0.5 - 2.5 m during the post monsoon. The figures reveals that shallow ground water is restricted to the flood plain of the river Gomti and deeper in the Central Part of Lucknow which may be attributed to higher elevation of topography and heavy withdrawal of groundwater. Long term fluctuation in depth to water level of Aminabad National Hydrograph station in the Central part of the city indicates that the water level has gone down from 6 m - 17 mbgl during the last 20 years. The rate of decline of water level is 0.56 m/year. However recent data have shown faster rate of declination of water levels especially during premonsoon of up to 1.50 m/year. This data has raised questions over the sustainability of the water resources.

There were less monsoon showers in the present year 2009, leaving the aquifers more stressed than before. Data for year 2009 is still not available but is expected to show decreased water levels of groundwater due to less monsoon (Figure 3).

Water table elevation contours have been shown in the groundwater level map of Lucknow city (Figure 4). The map has been prepared on the basis of the kriged data of the various piezometeric heights provided by the CGWB (central groundwater board) in July 2004 and shows that there are extremely low groundwater levels in the area extensively covered by the city (shown in green in the map) which gives another proof that there is extensive groundwater extraction from the first aquifer. Also it can be seen that the urban area acts as a sink for the groundwater due to heavy extraction. The direction of groundwater flow is towards the river Gomti, and the river is effluent in nature (Report of Gomti Action Plant, 2000). Also the sustainability of this water supply will be of question unless there are strict measures taken in order to replenish the groundwater. The increased sealed surface of the city due to urban development has left less space for groundwater to infiltrate and the extensive groundwater extraction has raised more concerns. It has raised more questions about the sustainability of the water resources and immediate concerns are needed for sustainability of groundwater for urban requirements.

The lateral expansion of the city in all the four directions has caused increasing pressure on existing natural drainage as well as built environments. The urban area is spread equally on both sides of the River Gomti. The commercial and residential areas on cis-Gomti side are Hazratganj, Alambagh, RDSO Colony, Charbagh, Aishbagh, Kaiserbagh, Aminabad, Husainganj, Model Houses, Lal Bagh, Golaganj, Wazirganj, Rajendra Nagar, Malviya Nagar, Sarojini Nagar, Aishbagh, Rajajipuram, Haiderganj, Thakurganj, Chowk and Saadatganj. The residential settlements in the trans-Gomti area are Nirala Nagar, Aliganj, Daliganj, Mahanagar, Old and New Hyderabad, Nishatganj, Indira Nagar, Manas Enclave near Kukrail, Gomti Nagar and Gomti Nagar Extn., Nilmatha cantt. Vikas Nagar, Khurram Nagar and Janakipuram. The natural water resources of the city were enough few decades back in order to meet the urban water demands. But in the last three decades the population of the city has grown two folds, stressing the natural water resources of the city. Also, the intensive agricultural practice in the nearby villages has overburdened the existing aquifers (Figure 4 - 10). The practice of private groundwater extraction pumps have to be stopped. Also social awareness has to be spread in the urban and rural areas as a part of water sustainability measures.

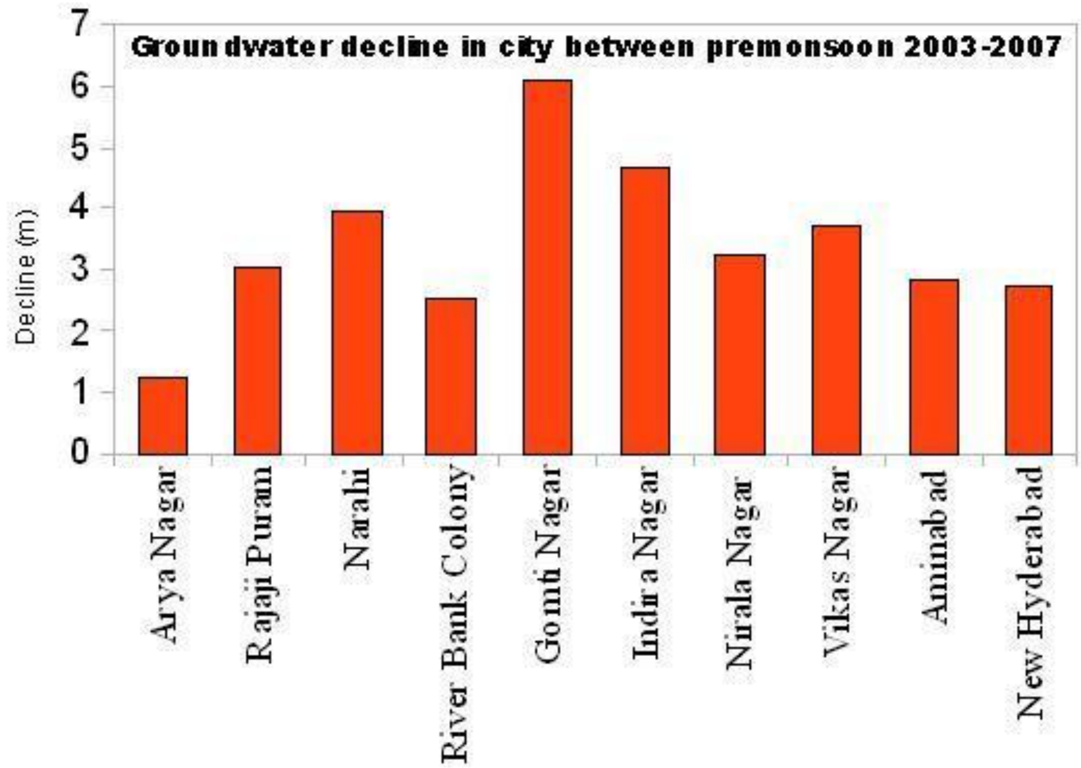

Figure 3. Groundwater decline in Lucknow between premonsoon 2003 – 2007 (Source: Central Groundwater Board, 2008).

ENVIRONMENTAL CONCERNS IN DRAINAGE PLAN

Integrity of wetlands and water bodies

Freshwater ecosystems such as lakes and wetlands in the city's built environment are among the most threatened of all the environmental resources. Wetlands are the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems and are integral to a healthy environment. They help to retain water during dry periods, thus keeping the water table high and relatively stable. During periods of flooding, they act to reduce flood levels and trap suspended solids and nutrients to the lakes. The removal of such wetland systems because of urbanization or other factors typically causes lake water quality to worsen. In addition, wetlands are important feeding and breeding areas for freshwater biodiversity (Table 5).

Crude sectoral approaches adopted in regional planning have led to breakdown of lake-watershed systems. In the past, there were large ponds that received storm water and helped manage the problem of water logging in the city. However, at present, most of these ponds have been encroached. In Lucknow plenty of water bodies which used to be seasonally inundated during monsoon were reclaimed for various purposes such as - residential settlements and commercial establishments due to high premium on land for its commercial purposes. It has lead to the loss of natural water storage, decrease in catchments yield, water storage capacity, wetland area and flora diversity in the city. Draining and filling of wetlands and water bodies has depleted the groundwater sources. Exotic species like water hyacinth (Eichornia crassipes) and Salvinia (Salvinia molesta) have threatened the wetlands and clogged the water bodies competing with the native vegetation due to excessive nutrients from the wastewater.

Wetlands are more valuable economic resources when retained in their natural or semi-natural state. Development projects have often stimulated wetland conversion largely because of lack of information and ignorance of planners about wetland functions and their role in sustainable drainage. The rapidly expanding populations, large scale changes in land use and land cover and burgeoning housing and development projects and improper use of watersheds have all caused a substantial decline of wetland resources of the region.

Wetlands in Lucknow have long suffered significant losses and continue to face an on-going conversion threat from industrial, agricultural and residential developments as well as hydrological perturbation, pollution and pollution-related effects. Conversion or degradation of wetlands during city's expansion should not be encouraged in the interest of city's natural environmental integrity.

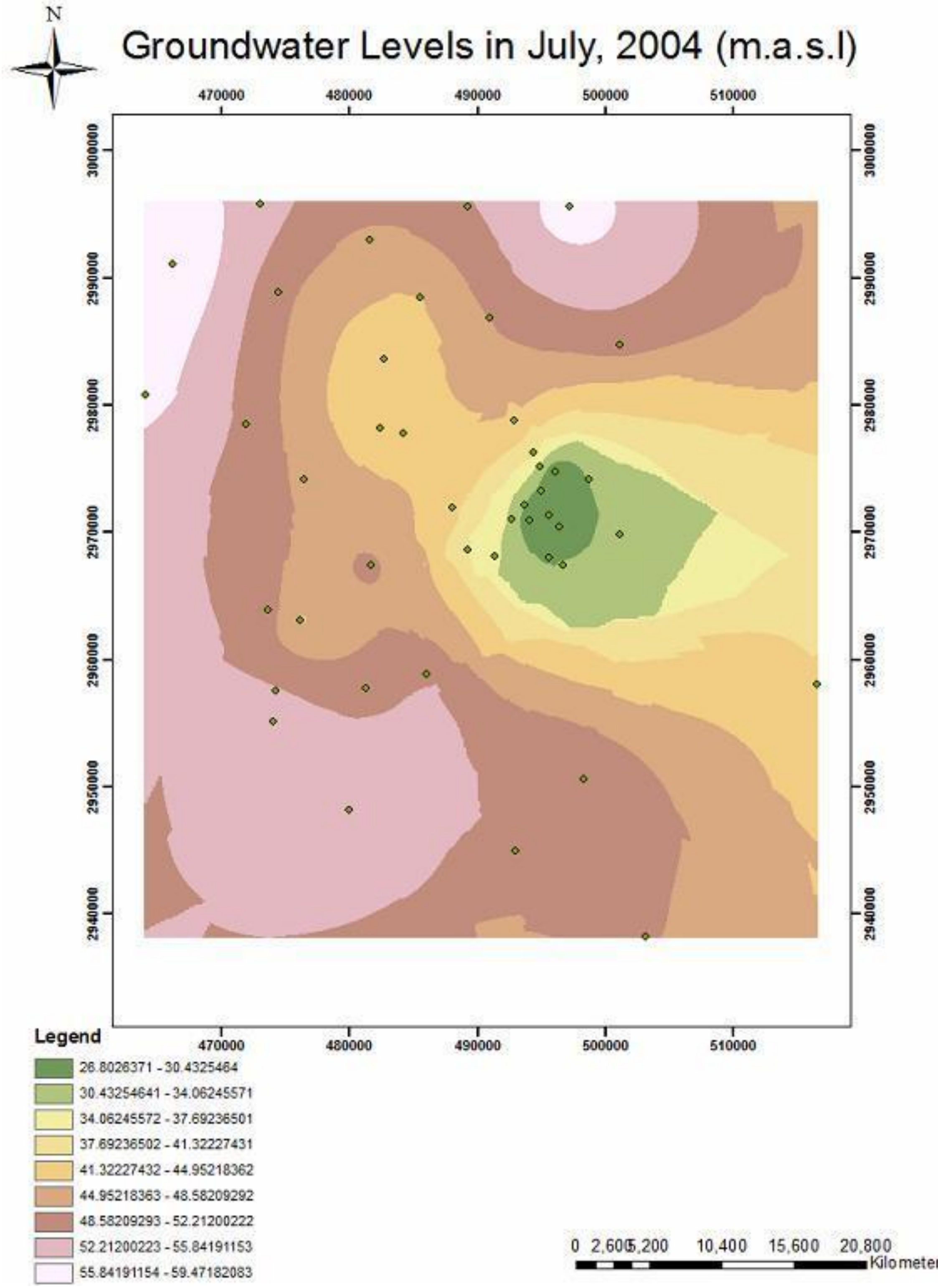

Figure 4. Groundwater decline in Lucknow in July 2004 (m.a.s.l.).

Encroachments, denudation of catchment area leading to siltation, and deterioration of water quality have remained critical areas for immediate attention. Survey and demarcation of water bodies, removal of encroachments around the recharge areas, fencing and trenching, gully control of water harvesting structures,

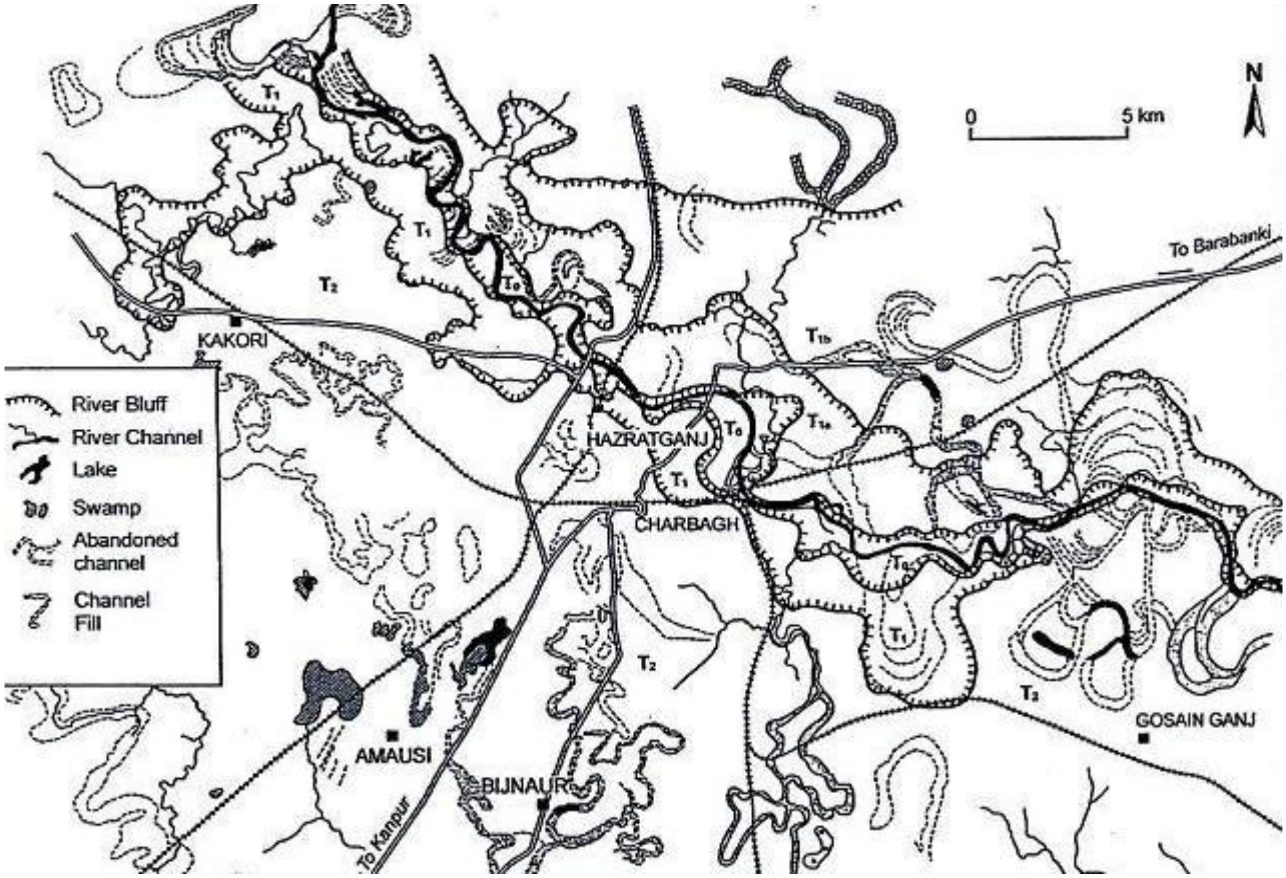

Figure 5. Geomorphological map of Lucknow area based upon SoI sheets and satellite imageries (Source: CGWB).

afforestation in the catchment area, stream bank erosion control are some of the protection measures to be adopted in the city's DMP. Action plan should bring out a detailed work plan for a period of five years with a long term vision for implementation of management action plan to achieve the conservation objectives (Figures 11 - 13 and Table 6). In this action plan measures should be taken to protect the existing wetlands as well as more emphasis would be laid upon creating artificial reservoirs for the city. These artificial reservoirs can be created based on surface gradient driven flow for different parts of the city. In other case an artificial reservoir can be created on the banks of river Gomti using sluice gates. These sluice gates should be able to control the flow of water in river Gomti and can store water for the dry season during high discharge period.

Haibatmau Lake is situated at south side of Lucknow near SGPGI on the Rae Baereli Road. The increasing pollutant influx load of domestic wastewater, agricultural washouts from neighboring crop fields and encroachments from the urban settlements have threatened the very existence of this water body. Butler Lake is situated in the middle of Lucknow city having no prominent vegetation except some algal species, though there is no direct visible source of pollution. Chinahat Lake is situated in the north eastern side of Lucknow. The water level during summer's become less. Prominent vegetation in and around the lake is present. This lake is maximally threatened by encroachments and illegal mining for sand and soil. This causes a great damage to aquatic life of lake (Table 7). The data on physio-chemical characteristics of different water bodies are presented in table above which represents the general water quality (APHA, 2000). The higher value of free CO2 at site S1 is due to mixing of sewage water directly in the water of the lake. Many workers have reported higher free CO2 levels in polluted water of water bodies. The DO value is minimum at site S2 due to least vegetation and microbial activity. The value of phosphate and nitrate is maximum at site S1 due to discharge of sewage water into lake without any treatment of sewage water. The eutrophication at Haibutmau Lake has lead to the loss of freshwater biodiversity. Soil erosion has resulted in increased run off which decreases area and depth of water bodies thus increasing sedimentation. This also decreases the total aesthetic value of that area. The reduction in quality of water is mainly contributed by discharge of wastewater through various point and non-point sources. The dumping of untreated sewage water should be stopped.

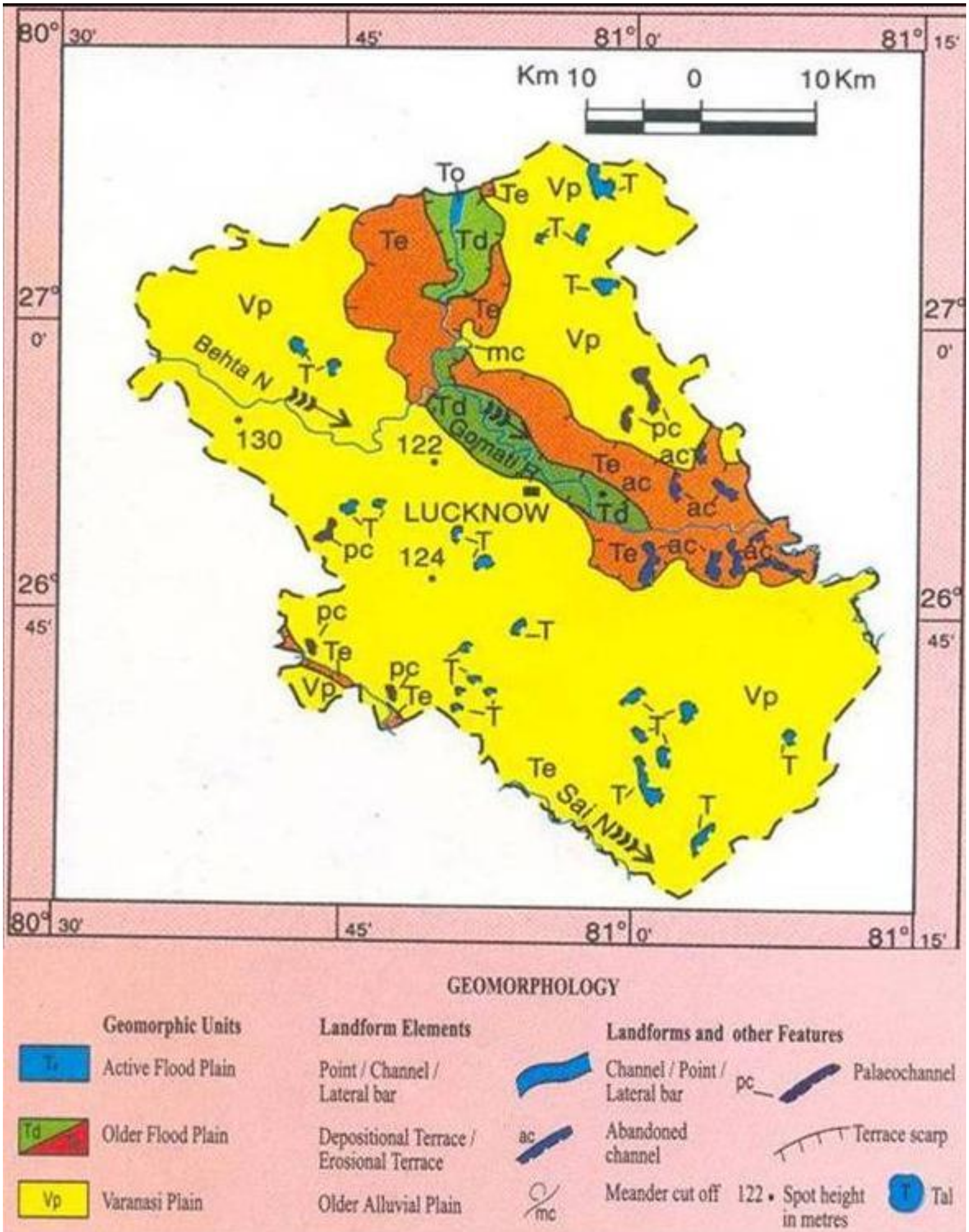

Figure 6. Geomorphology of Lucknow showing landform elements and paleochannels

Pollution in Gomti river

Lucknow was inhabited due to the presence of river Gomti like most of the other cities which have grown close to a freshwater source. River Gomti is the only natural surface water source for Lucknow and has been polluted upto larger extents due to mismanagement of wastewater. Large amounts of wastewater is dumped into

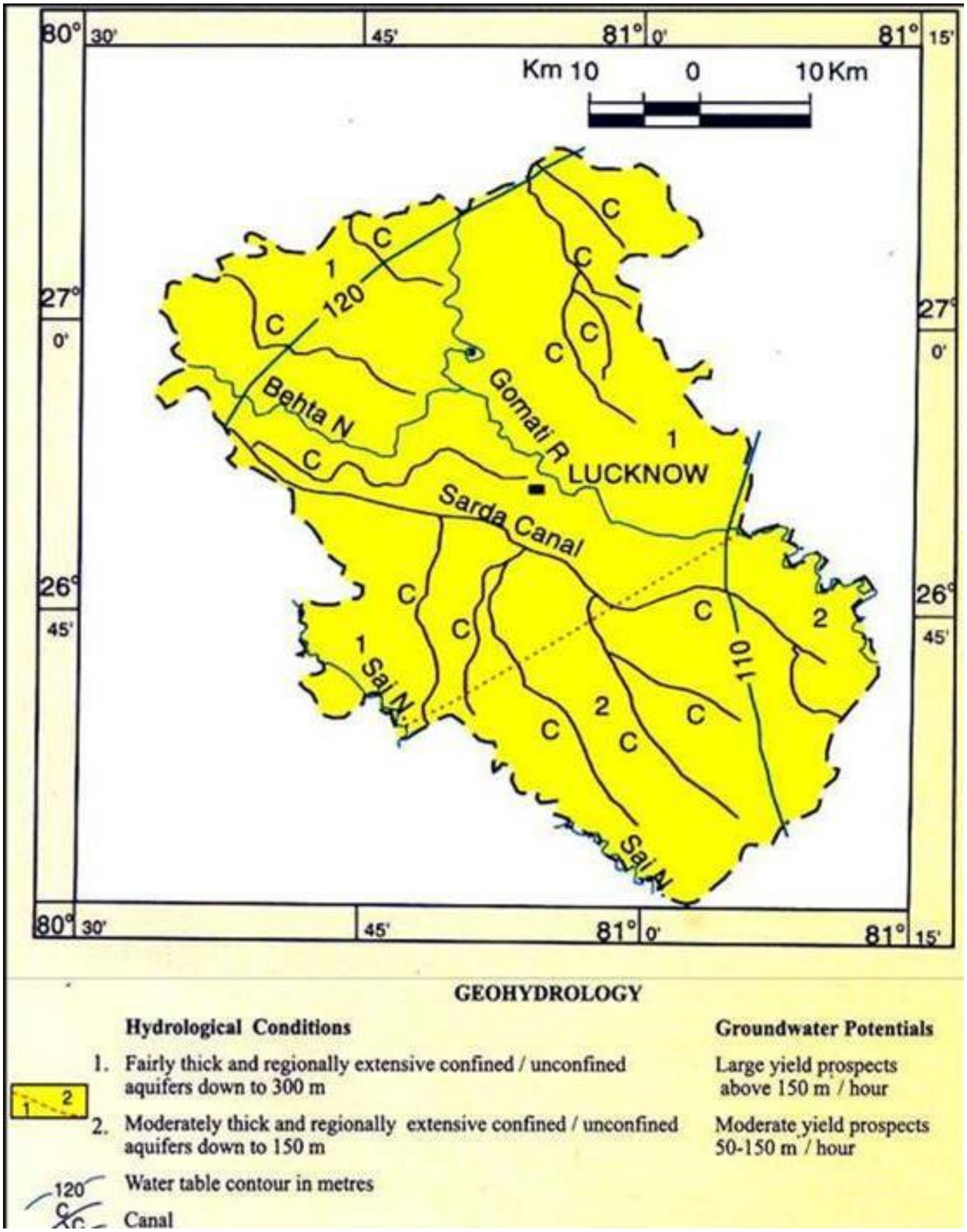

Figure 7. Geohydrology of Lucknow region showing confined and unconfined aquifers (Source: CGWB).

the river every day (Table 9), sapping it of oxygen and killing fishes and ecosystem and has lead to low D.O. levels in the river 25 nallahs discharge about 315 MLD sewage directly into the river, only 42 MLD sewage is treated from the current sewage treatment plant that is, only 12 percent of the sewage is being treated presently and the rest 88 percent flows directly to the river without treatment contributing heavily to the pollution load of the river. Sewages and drains are blocked due to encroachment along the drainage systems and due to disposal of solid wastes. New areas are inhabited in the trans and cis-Gomti side without any proper planning of wastewater management. These areas should come up with their own sewage treatment plants and should dispose the

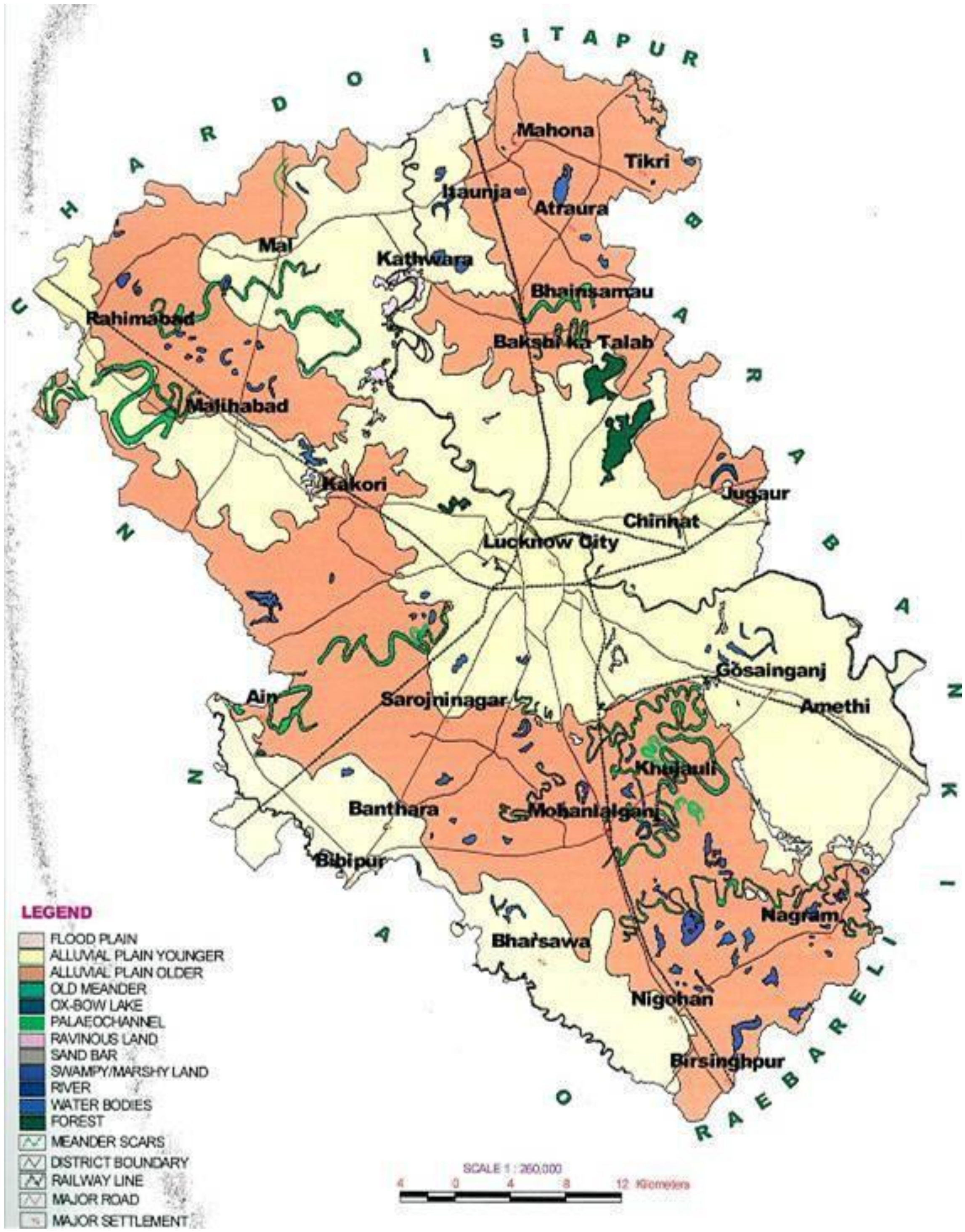

Figure 8. Hydrogeomorphological map of Lucknow based upon NRDMS report for Lucknow

treated water into the river Gomti with careful observation (Figure 14).

The main city area has over 20 nallahs (drains). On the eastern side there is Haider canal that was built for connecting the River Ganga to Gomti during the rule of the Nawabs. This canal runs from the Southeastern side of city towards the northeast, and drains into the river downstream of the newly constructed barrage. This canal now carries most of the storm water run off during the rains and in the dry weather, the sullage and sewage of the area around it. On the trans-Gomti side there used to be a small rivulet known as Kukrail, which now carries the

Table 5. Wetlands type and their area during pre and post monsoon periods in Lucknow (based upon Wetlands of India Report, Space Applications Centre (ISRO), 1998 and IRS - 1 D/LISS III imagery, 2001).

Wetlands type	No.	Area (ha)	
		Pre monsoon	Post monsoon
Lakes/ponds	6	667.02	2153
Marsh/Swamps	8	881.58	1533.72
Water logged	7	756.17	816.67
Total	21	2304.77	4503.39

Table 6. Characteristics of the three lakes under investigation

Water bodies	Types of water bodies	Annual range of water level (m)	Vegetation type	Vegetation density
1. Haibatmau Lake	Natural /Stagnant	3 - 4	SR , EM ,.FF	Dense (fully covered zone)
2. Butler Lake	Natural /Stagnant	2 - 3	SR,UN	Rare
3. Chinhat Lake	Natural /Stagnant	2-2.5	FF, EM	Sparse

(EM = Emergent; SR = Rooted in Sediment; FF = Free Floating; UN = UN vegetated).

storm water of this area and discharges into the river upstream of the barrage. At present during the dry weather, most of the sullage of the trans-Gomti area is carried by it. The Kukrail drain having the catchment area of the fastest developing Kursi Road, Indiranagar, Mahanagar Colony and Faizabad Road contributes over 80 MLD during rainy seasons, which is set to multiply at much faster pace than share of any other culvert. High capacity water treatment plans are needed to be installed for both the sides which carry the storm water drainage as it carries huge amounts of effluents.

Sewerage network and treatment infrastructure

The sewerage treatment infrastructure has not grown at the same pace as the city has grown. The sewer network extends across the main city areas on the cis-Gomti side as well as newly developed colonies on the cis-Gomti and trans-Gomti sides. The existing network of sewerage is broadly described below:

Cis-Gomti trunk sewer: This sewer runs along the Southern bank of the river Gomti starting from the Chotta Imambara to cis-Gomti sewage pumping station located at the edge of NBRI Garden. It is 7 km long and at its head is a 750 mm diameter circular RCC sewer increasing to 2100 mm. diameter brick sewer at the tail end. The main sewer has several branches - the Sarkata A - diameter 750 mm, Sarkata B - diameter 1050 mm, Pata Nala Sewer- diameter 900 mm, Shahmina Road Sewer - diameter 450 mm and the Ghasiyari Mandi, Chamberlane, Ashok Marg sewers that join the main trunk sewer near the tail end.

Trans-Gomti trunk sewer: This sewer runs along the north bank of the river Gomti and is 3 km long from Daliganj to the trans-Gomti sewage pumping station. For most of its length, it is of 900 mm diameter except at the tail end when it discharges into the pumping station here it is 1100 mm in diameter. This sewer carries load that is pumped from Daliganj pumping station as well as that flows from the Mukarram Nagar and University Road area.

The eastern intercepting sewer: Starting from Golaganj, this sewer is oval shaped with a size of 600 x 900 mm. The sewer discharges into the cis-Gomti sewage pumping station. Additionally, the 600 mm Butler Palace sewer also discharges at the cis-Gomti sewage pumping station. The installed capacity of the various sewage pumping stations are as shown in Table 8.

The 1200 mm diameter rising main from the cis-Gomti pumping station crosses the river through a road bridge and in the trans side is joined by the 450 mm diameter rising main from the trans-Gomti pumping station where after its size increases to 1350 mm. Earlier the sewage from the rising main used to discharge into a 1.25 x 30 m brick channel leading to a 600 acre sewage farm. This farm has now been reclaimed to construct the Gomti Nagar Colony. In the absence of any disposal arrangements, the sewage is discharged directly into the river thus aggravating the pollution problem since the sewage is discharged upstream of the Gomti barrage. The sewage network has not been augmented from time to time in order to keep in pace with the development of the city. About 70 - 80% of population in old-Lucknow is covered by sewer lines, but a major portion of it is blocked or broken leading to the over flow of sewage into

Figure 11. Arial extent of algal growth and eutrophication inside Haibatmau Lake (note the encroachment from both the sides).

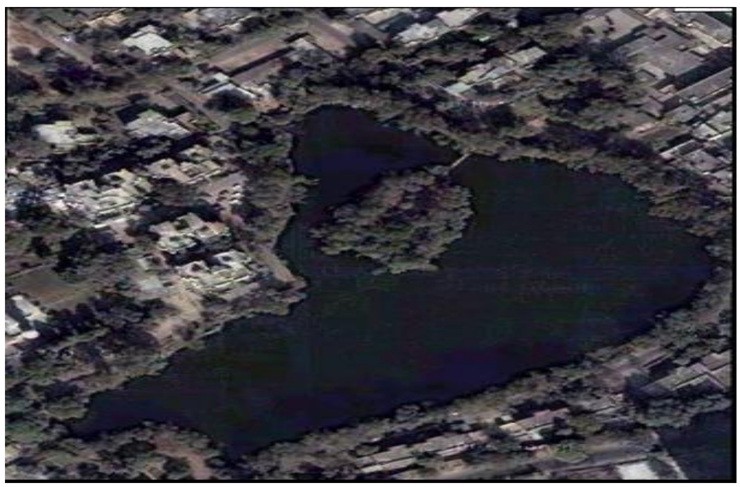

Figure 12. Vegetation and settlement around Buttler palace lake.

Figure 13. Connection of Buttler palace lake with the city's settlements and its river environment.

Table 7. Comparison of water quality of three water bodies of Lucknow (based upon average of three samples at each site).

Parameter	Unit	Haibatmau lake	Butler lake	Chinhat lake
Temp water	°C	29.6	29.6	26.66
pH	---	8.7	8.8	7.3
EC	µ s/ cm	9.0	9.6	9.3
Colour	Hz	30	55	40
Alkalinity	mg/lt	256.6	401	275
Acidity	mg/lt	86.6	48.6	90
Free CO_2	mg/lt	93.86	23.3	116
DO	mg/lt	6	2.6	3.3
BOD	mg/lt	4	1.93	2.5
NO_3	mg/lt	32.83	21.63	11.06
PO_4	mg/lt	38.06	21.26	12.16
Hardness	mg/lt	85.26	74.83	63.83
TDS	mg/lt	4.52	489	452
T SS	mg/lt	1.40	1.28	1.0
TS	mg/lt	453.4	490.28	453.

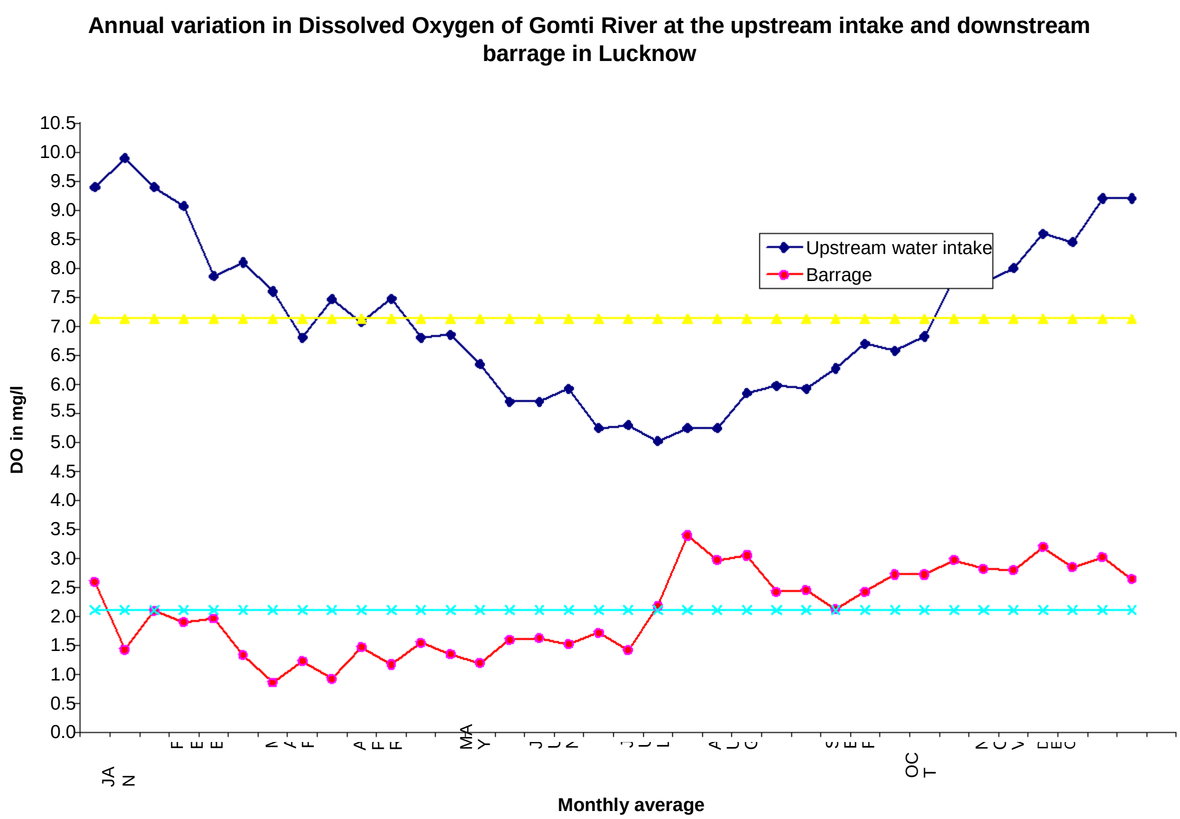

Figure 14. Variation in DO content (mg/l) measured at Gaughat and Barrage (based upon 2004 to 2007 data).

natural storm water drains which are supposed to carry rain water. In the upstream of the city the quality of river water is better. Due to discharge of Nagariya drain into the river, the deterioration starts which continues with the addition of discharges of other city drains. The river receives industrial as well as domestic wastes from various drains of Lucknow city. In the process the water and sediment of the river Gomti get contaminated with heavy metals and other pollutants (Tripathi and Bhargava, 2004). Because in rainy season runoff from open contaminated sites, agricultural field and industries, directly comes into the river without any treatment. Since 125 years river water is extracted at the Aishbagh Water works from the river Gomti at Gaughat pumping station. The second waterworks at Balaganj got commissioned after a gap of 100 years, and the water source for this new waterworks remained Gaughat. While the Balaganj waterworks was being constructed, a study was taken up by using remote sensing technique, and it was found that the course of Gomti River is stable at Balaganj and water quality is also good, so it was recommended to lift water for the new waterworks from Balalganj. But, at that time since it was preferred to lift the water for the second waterworks from the Gaughat, there was no change in the plan. At the Gaughat pumping station, the Nagaria Nala is very close to the suction canal of the pumping station which poses threat to water quality. The Gaughat water pumping station for the city gets direct sewage discharge from Nalas especially Nagaria Nala as well from cattle discharge from Cattle Colony. About 75 years ago, a water ware (channel) was built across the river at Paper Mill for diverting the excess water towards open flood plan (now Gomti Nagar). This water ware maintained the water level high during dry seasons, but because of meandering river course at this site, the water ware was abandoned and later settlements (Paper Mill Colony) came up. The need to maintain water level of the river during summer season prompted the decision to build a barrage. Bhainsakund the cremation ground was selected as the site for a new barrage. In between Gaughat and barrage there are 10 major drains on cis-Gomti side and another 12 drains on trans-Gomti side directly discharging in the river.

Consequently water retained by barrage for supply to city gets highly contaminated and unfit for consumption (Table 9).

In the newly developed localities, the developers are responsible for the maintenance of sewers and drains until the colonies are handed over to the corporation and it is observed that levels of maintenance are poor. In most of the newer colonies, the sewer network has been provided but no disposal arrangements made since the Lucknow Jal Sansthan has not taken over the system for maintenance. The city has a significant number of septic tanks that together with overflowing leach pits usually discharge into roadside drains. Taking into consideration the household sewage, existing public toilets and open defecation about 40% of the population do not have access to adequate sanitation. Informal sewers connecting a few households and discharging into nearby open drains are also seen. For the most part, the existing network is either completely blocked or its capacity severely reduced due to disposal of silt and solid waste - the problem is aggravated by the absence of regular sewer maintenance. This has increased the prevalence of pour flush toilets discharging into a single leach pit and on site disposal of sewage.

Table 8. Installed capacity of sewage pumping stations.

Name of pumping station	Capacity
Cis-Gomti Sewage Pumping Station	250 MLD
Trans Gomti Sewage Pumping Station	40 MLD
Daliganj Intermediate Pumping Station	40 MLD
Mahanagar Intermediate Pumping Station	7 MLD
Paper Mill Sub Pumping Station	3 MLD
Total	303 MLD

Source: UP Jal Nigam.

The Lucknow Jal Sansthan is responsible for the maintenance of the STPs and the sewer network, while the maintenance of drains is the responsibility of the Lucknow Nagar Nigam. The two agencies function as discrete entities and at times it is observed that in case of blockage in a sewer, the sewer is broken and connected to the nearby storm water drain. The problem of poor maintenance of the sewers and drains is further aggravated by the practice of disposal of solid waste into the drain or the sewer manholes. This compartmentalisation of approach to systems maintenance as well as individual interventions has resulted in intermixing of the sewerage and drainage system aggravating the pollution load and flooding during the monsoons. Since the sewage at the pumping stations is bypassed into the sewer in most cases, their maintenance is totally ignored and the large installations of pumping machinery are deteriorating daily. The Lucknow Jal Sansthan accords low priority towards maintenance of the sewerage system since income from it is very low.

Subsurface pollution

The rapid growth in urban sprawl neglected water environments which has resulted in gradual deterioration of environment and the impact can also be seen on the groundwater bodies. The effect has been identified and studies have revealed that in certain areas the contamination is present in concentrations higher than recommended limits. Also there exists all possibility of further deterioration in groundwater quality unless proper corrective measures are taken (Shukla and Ray, 1989). The incidence of groundwater pollution is highest in the areas having large volume of waste. It is concentrated and discharged into relatively small areas. The contamination of groundwater is only detected later since the contaminated plume advances slowly due to absence of inertial forces. This plume can remain in the aquifer depending upon the fractionation properties of the contaminant as well as the hydrogeological characteristics of the aquifer. Many years may be required to rehabilitate the contaminated aquifers, once the source of pollution is eliminated (Ellis, 2008). These sources can be

Table 9. Drains and their discharge.

Cis-Gomti drains (13 Nos.)	Average dry weather flow in MLD
Gaughat drain	1.0
Sarkata	18.0
Pata	18.0
NER Upstream	0.3
NER downstream	0.5
Wazirganj	13.0
Ghasyari Mandi	10.0
China Bazar	2.0
La-Place	1.0
Jopling road	1.0
G. H. Canal	78.0
Jiamau	--
La-Martiniere	0.5
Trans-Gomti side (12 drains)	**Average dry weather flow in MLD**
Mahesh Ganj	--
Rooppur Khadra	0.5
Dyer Meakin	3.0
Daliganj No. 1	8.0
Daliganj No. 2	1.0
Arts College	0.5
Hanuman Setu	0.5
TGPS	1.0
Kedar Nath	2.0
Weshatganj	1.0
Kukrail	20.0
Baba ka purwa	--

Source: Lucknow Nagar Nigam.

point or line sources and the contamination can be sometimes above lethal levels. Many small scale industries and shops such as the dry cleaning industry, the automobile repair shops, gas stations etc., can leave the aquifer lethal for coming generations. This has been observed worldwide where the aquifers have been characterized as unfit for any household purpose.

The urban population needs to be aware of such problems related to groundwater contamination and should not repeat the same mistakes done by most of the developed nations. The problem of groundwater contamination can still be solved but may become impossible in the coming years if sooner no action is taken. In case of industrial units, the effluent in most cases is discharged into pits, open ground or open unlined drains near factories, thus allowing it to move to the subsurface, which leads to ground water pollution. Depending on the effluent released in the subsurface, the groundwater from the respective aquifer can be characterized to be harmful for drinking purpose. The tube wells in the vicinity of these areas can increase the mobility of the respective plume which can further deteriorate the usability of the aquifer. In order to protect the quality of water it is necessary to prevent its contamination. Not only this, an integrated approach is required to undertake groundwater pollution monitoring and abatement programmes so that suitable measures are taken to further restrict, if not eliminate the threat. Various attenuation studies can be done on the aquifer in order to make the groundwater reusable.

The movement of pollutants in the subsurface, towards the saturated zone follows mostly the same laws that control ground water movement. The pollutants can enter the aquifer by percolation through zone of aeration; and by infiltration and migration into the zone of saturation depending on its chemical properties. Its entry and movement, however is influenced by large number of geological conditions prevailing in the affected area. Usually under favorable conditions shallow aquifers are most susceptible to contamination since these are directly in contact with the sources of pollution i.e. with the surface. Reaction in the top soil, vadose and saturated zones; are certain factors which control groundwater pollution. During the movement pollutants may undergo changes due to various physical, chemical and biological processes. These processes may cause attenuation of pollutants to some extent depending on extent of reaction that have taken place and the local condition prevailing in the area. But recently scientists have found out that these processes can also increase the toxicity of these pollutants (IITR, 2008). A simple example is of TCE (trychloroethylene) which changes to vinyl chloride (a more toxic substance than TCE) due to microbial processes in the subsurface. Hence depending upon the type of subsurface pollution the concerned authorities have to be really careful of dealing with it.

The pollutants may take considerable time to reach the saturated zone. But once pollutants reach the saturated zone they spread out laterally, and move in the direction of groundwater flow. There exist some techniques for site remediation like soil vapor extraction, funnel and gate system, etc. (depending upon the site characterization and the contamination), but all of these techniques are very expensive to use and do not guarantee any solution yet. Usually under favorable conditions shallow aquifers are most susceptible to contamination since these are directly in contact with the sources of pollution, that is, with the surface. Reaction in the top soil, vadose and saturated zones; are certain factors which control groundwater pollution. During the movement pollutants may undergo changes due to various physical, chemical and biological processes. These processes may cause attenuation of pollutants to some extent depending on extent of reaction that have taken place and the local condition prevailing in the area. But recently scientists have found out that these processes can also increase the toxicity of these pollutants (IITR, 2008). A simple example is of TCE (trychloroethylene) which changes to vinyl chloride (a more toxic substance than TCE) due to microbial processes in the subsurface. Hence depending upon the type of subsurface pollution the concerned authorities have to be really careful of dealing with it. The pollutants may take considerable time to reach the saturated zone. But once pollutants reach the saturated zone they spread out laterally, and move in the direction of groundwater flow. There exist some techniques for site remediation like soil vapor extraction, funnel and gate system, etc. (depending upon the site characterization and the contamination), but all of these techniques are very expensive to use and do not guarantee any solution yet.

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Six different sites all over Lucknow were chosen in all the four directions for monitoring the quality of groundwater, out of which two sites belong to central Lucknow. These sites are:

1. Mahanagar (Mahanagar Police Stations that is North Lucknow).
2. Chinahat (Near Amity University that is East Lucknow).
3. Charbagh (Central Lucknow).
4. Hazratganj (Behind Prince complex, Nawal Kishore Road that is Central Lucknow).
5. Rajajipuram (Sec-C that is West Lucknow).
6. SGPGI (South Lucknow).

The suitability of ground water for drinking purposes has been assessed according to guidelines laid down by BIS (1991) for various parameters viz. pH, total dissolved solids, alkalinity, chloride, hardness, nitrate, fluoride, and total hardness.

The various parameters observed during study are presented in Table 10 and are described here. Electrical conductivity is the measure of mineralization of water and indicative of the degree of salinity of ground water. Variation of conductivity in the city ranges from 582 µs/cm (Rajajipuram) to 934 µs/cm (Charbagh). The values show that the groundwater is generally fresh. The tolerance limit for total dissolved solids for drinking purposes is 500 mg/l. The TDS value ranges from max. 778 mg/l (Hazratganj) to minimum 564 mg/l (Rajajipuram), thus showing that the water is unpalatable and may cause gastrointestinal irritation. The highest value of free CO_2 is seen in S6 VI sample 70.4 mg/l (SGPGI) and the lowest values are seen in the Site-II sample 62 mg/l (Chinahat). Alkanity of water is a measure of its capacity is neutralizing acids. The calculated values show the highest reading Site-I 185.70 mg/l (Mahanagar) and the lowest at Site-IV 146.82 mg/l (Hazratganj) which are well below the permissible limits that is 200 mg/l as laid down by BIS (1991). Acidity is maximum at Site-III 232.50 mg/l (Charbagh) and

Table 10. Groundwater quality parameters at 6 locations in Lucknow.

Parameter	Unit	Mahanagar (North)	Chinhat (East)	Charbagh (Central)	Hazratganj (Central)	Rajajipuram (West)	SGPGI (South)
pH	mg/l	7.37	7.52	7.24	7.53	7.30	7.04
Electrical conductivity	µ s/ cm	920	802	974	888	.82	635
TDS	mg/l	758	704	698	778	564	576
TSS	mg/l	0.046	0.034	0.024	0.106	0.028	0.038
TS	mg/l	758.2	704.1	698.0	778.1	564.0	576.0
Free CO_2	mg/l	66	62	68.2	66.4	69.3	70.4
Alkalinity	mg/l	185.7	160.4	172.5	146.8	166.4	178.3
Acidity	mg/l	224	1.93	232.5	176.5	231.5	196.5
Hardness	mg/l	150	180	220	175	190	128
Chloride	mg/l	71	85	46	68	35	57
Fluoride	mg/l	0.24	0.32	1.2	0.56	0.94	0.86
Nitrate	mg/l	20	16	20	25	18	21
Phosphate	mg/lt	0.12	0.06	0.10	0.15	0.12	0.06
Presence of *E. coli*	mg/l	Nil	Nil	Nil	Nil	Nil	Nil

minimum at Site-IV 176.50 mg/l (Hazratganj). No standards are laid by BIS for acidity. The total hardness of ground water ranges from 128 mg/l at Site-VI (SGPGI) to 220 mg/l at Site-III (Charbagh), thus showing that water at Site-VI (SGPGI) is moderately hard and the water at other sites is hard. The values for nitrate are well under the max. permissible limits as laid down by BIS of45 mg/l. Maximum value of nitrate reaches in sampling site-III is 38 mg/l at Charbagh. The fluoride vale of 1.2 mg/l at Charbagh seems to be high as per the standards. The biological parameter i.e. the presence if *E. coli* is tested in various water samples, but this can not be traced in any of the water samples.

CONCLUSION AND RECOMMENDATIONS OF THE STUDY

Drainage modifications and land use changes are associated with alteration in the regional hydrology which can change the surface and subsurface water integrity including their character such as functions, values and the appearance. The metropolitan environment comprises mainly two components viz. (i) natural environment, and (ii) the built habitat. The natural environment *per se* relates to natural features and resources including the air, water and land (open spaces, forests etc.). The built habitat is related to built environment and infrastructures such as water supply, sewerage, and solid waste disposal. Environmental deterioration is not a necessary or inescapable result of urban sprawl; what needs to be done is striking a right balance - in making development in such a way that they are more effectively attuned to environmental opportunities and constraints.

A master drainage plan addresses the current and future drainage needs of a given community. The boundary of the plan usually follows regional watershed limits. The proposed facilities may include channels, storm drains, check dams, wetlands or any other conveyance capable of economically relieving flooding problems within the plan area. The drainage master plan should be related with the Master Plan of 2021 which ensures drainage as per the proposed land use taking into account land suitability, topography, geomorphology and hydrogeology. The purpose of the Drainage Master Plan is to consider various maintenance, repair and design alternatives in order to maximize the capability of the system at the lowest cost, within the context of environmental resource-management policies. The goal is to provide realistic technical solutions that are economically, socially, environmentally and institutionally acceptable to the community and the planners. In order to achieve this goal it is necessary to first identify the existing storm water drainage and discharge system to evaluate known problems.

The storm water drainage can be calculated using integrated GIS programs and numerical simulations which are used nowadays by most of urban planners. This will help in prevention of floods in the coming future. Integrating GIS with drainage and sewage database can help in generating maps of new sewage and drainage lines in an effective manner. For example depending upon the population of a certain locality the sewage produced can be calculated and hence the diameter of the concerning sewage line can be calculated automatically. It also helps in creating good databases of the work done in the city.

Also a numerical watershed model can be integrated into the same in order to simulate the flow and storage of collected storm water for aquifer recharge during the low rainfall period. The watershed model can also serve the purpose of studying the complete hydrological cycle and anthropogenic factors that contribute to the water crisis. The climate changes can be simulated before hand once these tools are ready. In advance study we can also know the effect of climate change on the hydrological cycle. Studying different scenarios in terms of low rainfall or increasing urban sprawl can help us plan for any upcoming water crisis. The least harmful locations for industrial use can also be identified using these watershed models. Also these watershed models are used to simulate the flow and transport of contaminants, nutrients and soils during erosion. Numerical models can also be developed in order to decide the fate of contaminants in the city and for site remediation. The evaluation of existing capacity compared with the projected increased drainage capacity requirements based upon future growth should be carried out. Changing conditions such as the availability of land, new urban planning strategies, enhanced lifestyle with high density settlements and opportunities for natural resource enhancement should be considered in the DMP. The following key points and methodologies should be taken into account while implementing the integrated modeling and GIS based approach for creation of the Master

Sewage water management

Due to water supply augmentation schemes and urban expansion sewage flow is expected to increase in the future. In order to prevent the overflow of sewage into the city waterways, investments for providing additional sewage interceptor pipe lines, replacing sewer mains which are worn out, and enlarging the capacities of pumping stations are required. It is better to isolate the system of collection, transmission and disposal of sewage in each zone in order to obviate the difficulties of the relay system. It is recommended for extension of sewerage system to unsewered areas and use of low cost sanitation wherever appropriate.

Methodology

The GIS map integrated with residential population data will be used to simulate the amount of sewage from each block. A proposal to create small sewage plants of capacity 3-5 MLPD (limit) will be made in each block once the amount of sewage approaches the specified limit. The treated sewage will follow the environmental criteria from World Health Organization (WHO) in terms of chemical oxygen demand (COD) and biological oxygen demand (BOD) etc. This treated water will be diverted to the secondary sewage lines in the city. The primary or main sewage lines will divert the sewage from all the secondary sewage lines to the river. During the whole course of work it will be made sure that no untreated sewage is discharged into the river.

Storm-water management

(a) The natural drains of Lucknow are not perennial in nature and receive flood discharge only during monsoon season; in the rest of the year it acts as a carrier of wastewater, construction materials, debris and solid waste, though they were originally natural flood discharge channels. The addition of untreated wastewater has led to a very high level of pollutants. Also, the disposal of solid wastes severely reduces flows particularly during monsoon periods. The contamination of water ways and anaerobic digestion of wastewater flowing in the natural drains leads to the accumulation of sludge causing hindrance to the hydraulic functioning of the waterways and also causing severe contamination in the ecosystem.

(b) The treatment of wastewater generated from Lucknow city is to be taken on priority to improve water quality of river Gomti. There should be a separate STP at Daulatganj near Gaughat for Nagariya Nala, Gaughat Nala, Sarkata Nala and Pata Nala. The wastewater from these drains should be treated before discharging into Gomti. This will improve considerably the quality of river water in the core area of the city.

(c) As the capacity of existing sewers is limited, during rainy days they became surcharged due to ingress of storm water. Any surplus of sewage in excess of pumping stations capacity is drained into the nearby natural water courses. This practice must be discouraged.

(d) For the urban storm water system, existing coverage of drainage provision is less than 50%. The present drainage system is generally found to be in a poor state, with many blockages due to solid waste and services (water pipes, cables etc.) and repairs needed. The main interventions envisaged are the repairs/rehabilitation of existing systems and improved maintenance.

(e) One of the specific issues around drainage concerns regulation in newly developed areas. The common practice is to make the developer responsible for the provision of surface water drainage, but little attention is paid to linking these drains to the larger local drains.

Small nallahs in colonies should not be neglected, which may cause severe problems of water logging. In many colonies, the common practice is to desilt the small drains through private workers and dump near the edge of the drains to dry out before lifting. At many places, part of the sludge gets blown away while the remaining finds its way back into the open drains.

Methodology

The surface elevation data will be used to mark the natural flow of water using integrated GIS approach. Existing drainage system will be used with a new drainage system where needed to simulate flow of water under natural conditions, to make it cost effective. Separate pipelines for storm-water drainage need to be installed throughout the city in addition to the existing drainage system depending upon the storm-water discharge from a certain area. It should be the sole responsibility of the house owner to keep the drainage channel in front of the house unblocked so that proper flow of the surface runoff can be maintained in the street. Fine should be imposed on the house owner in case of negligence. The discharge from a certain block will be calculated using integrated GIS, surface elevation data and numerical watershed modeling in each area and hence the design of the drainage system in every block will depend upon the drainage simulated in the model. The drainage pipes will be completely covered so that it carries only the storm-water drainage and not any public waste. This storm-water will be diverted to the main nallahs like the Gaughat, Nagariya Nala, Sarkata Nala and Pata Nala. We calculate the amount of discharge from various blocks of the city using integrated GIS model as described in the paragraph before. Then a wastewater treatment plant is installed close to the point of discharge into the river. The storm-water contaminants are usually associated with solids which will be treated according to the environmental criteria of WHO and will be released into the river.

Separate drainage lines in addition to the existing ones will have to be considered in case new residential areas evolve in the coming future. It should be kept in mind that the storm water pulses in the urban areas are frequent and faster than in the rural areas. Hence the velocity of water can erode the bed of respective drains. These channels can be designed in a special way by creating jumps in order to break the energy of the water and reduce erosion. These jumps can be designed by public works department or by irrigation department on receiving the design criteria. The discharge and velocity of the storm-water can be calculated by integrated GIS and numerical watershed modeling with high accuracy.

Water resources management

(a) Urban water bodies provide multiple values for suburban and city dwellers. The capacity of functional wetlands and lakes as well as the flood plain in flood control, aquatic life support, and as pollution sink implies a greater degree of protection in the DMP.

(b) In many places the nallahs and embankment have been encroached, restricting the flow in these drains and causing floods. These sites are predominantly housing the low income groups. In some stretches of large size drains, encroachment has meant that there is hardly any space left for desilting and as such these stretches remain unclean. The lakes/water bodies/drains should be protected from encroachments and existing encroachments should be evicted by the departments/agency concerned bringing the water bodies to its original state.

(c) In the peripheral areas, there are many water bodies which do not have a proper control and property rights. Such precious resources have typical problems of 'tragedy of commons'. There are other lakes which are vested with other departments/agencies (such as Revenue, Irrigation departments, etc). One dedicated agency should be in-charge of conservation, maintenance and continuous planning and management of these water bodies.

(d) Excess overland flows from local catchments constitute substantial portion of run off. There should be provisions of temporary storage of the overflow in form of storage basins. Such areas should be identified at the zonal levels where water bodies can hold excess run off during monsoon seasons. The lakes may be developed not only as a flood accommodator and for groundwater recharge, but also as open space with trees as wooded areas enhancing the aesthetic amenities for local people. These can be developed in existing parks, depressed lands and other suitable wastelands with proper environmental controls.

(e) Over a period of time, the quantum of available water supply for the city would get diminished, making it not possible to supply water as per the project design, mainly for the reasons of depletion of water potential of aquifers, failure of monsoons, inadequate recharge of groundwater etc. In order to sustain the water sources, studies have to be carried out and recharge structures like check dams, percolation ponds and other rainwater harvesting structures have to be constructed.

(f) A comprehensive study on water supply and sewerage system for Municipalities, town Panchayats and Village Panchayats in the peripherial areas (mainly peri-urban areas) should be conducted and the system planned and provided in a phased manner depending on the level of developments and need.

(g) The tubewells located in Lucknow city for water supply should be monitored regularly for their quality and quantity. Their water levels should be monitored regularly so that any deleterious effect due to over exploitation of the resource can be deciphered and appropriate measures taken for controlled withdrawal from the reservoir.

(h) Non-structural measures required to support these ideas include capacity building, with particular emphasis on adequate policy provision for master plan implementation; and public education (e.g. to prevent solid waste dumping in urban drains).

Methodologies

Planning and regulatory controls to prevent development in beds of old tanks, water bodies and paleo-channels should be undertaken. Planning and regulatory controls to prevent encroachment of squatter settlements in old tank beds and watercourses should be ensured. Directorate of Environment should identify the ecologically sensitive areas, which require protection/ conservation and take action for conserving the same with statutory provisions and should work with Irrigation department. It is important to give priority in the DMP to repairing those systems that would become degraded without any suitable intervention. Prioritizing systems for repair requires that a framework be developed categorizing the level of interventions. Numerical watershed models can play an important role in proving the importance of such channels and wetlands and can show a loss of groundwater recharge areas when they are encroached. Numerical watershed models can mark certain area which can be used as storage basins for a subwatershed. In case of absence of these storage basins much effort has to be put in order to prevent floods in the city. Hence these storage basins should be freed from encroachments in order to preserve the natural beauty of the city and to collect local runoff. The amount of recharge in the city can be improved once these lakes are freed from encroachments. This can be modeled also using numerical simulation tools. Also in order to create new residential areas it will be made sure that least harm is provided to these major recharge areas. Different residential areas can be compared later to see the effect on groundwater recharge. It is also critically important to create awareness among people regarding environment and water resource management and sustain the level of awareness to conservation at the household level. People can be advised to harvest rainwater or in worst cases a rule should be made for residential colonies to harvest rain water.

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