WATER HARVESTING, POLLUTION AND MANAGEMENT IN URBAN AREAS

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ABSTRACT

Due to rapid urbanization and industrialization, urban population of the country is increasing year after year posing a challenge to the planners, engineers and administrators to cope up with the problems providing the basic amenities such as availability of safe drinking water, sanitation, drainage, solid waste management etc. In order to achieve the said targets, suitable strategy and policy framework has to be evolved giving due consideration to the important aspects such as the development of water resources, adoption of appropriate technology for water harvesting and conservation, and effective operation and maintenance. Also, to plan for a better future and to stimulate visions for a better future, conventional approaches to urban water management must be challenged.

In the present study an attempt has been made to look into the surface and ground water resources scenario in India with special reference to urban development. The effects of urbanization and Industrialization have been demonstrated with some case studies. The potentialities for systematic planning of urban water harvesting, its conservation and management practices with safe water supply (quantity and quality wise) have been discussed.

1.0 INTRODUCTION

The water resources are very important part of natural resources in India. Their optimal development, conservation and management are crucial for providing a reasonable quality of life to all the citizens. The available water resources can be used for a variety of purposes e.g. drinking, domestic, irrigation, hydropower generation etc. Urban areas often develop near the river bank an aquifer or near a lake. In ancient times many water supplies for cities come from within, or close-by, and clever ways were developed to capture and to use water. In India, water has been harvested since antiquity i.e. from rainwater to groundwater, stream to river water and floodwater. Evidence of water harvesting can be found in ancient texts, inscriptions, local traditions and archaeological remains. There is some evidence of advanced water harvesting systems even from prehistoric times (Agrawal & Narain, 1999):

1. Iltutmish built the tank at Hauz Khas in Delhi in the 14th century.
2. The 12th century (1148-1150 AD) account of Kashmir, *Rajatarangini* by Kalhana, describes a well-maintained irrigation system, in which notable structures existed around the Dal and Anchar lakes and the Nandi canal.

3. Recent archaeological excavations near Allahabad have brought to light an extraordinary example of early Indian hydraulic engineering, dating back to the end of the 1st century BC. One of the tanks is not only the longest of its kind discovered so far (more than 250 m long) but is fed by the waters of the Ganga. Other contemporary or near contemporary tanks just collect rainwater.

4. The Bhopal lake, created in the 11th century, was one of the largest artificial lakes of the time, covering an area of over 65,000 hectares. The Bhopal king Bhoja created the lake by constructing an embankment across two hills. 365 streams fed it.

5. Some of the settlements of the Indus Valley Civilisation, dating back to 3000-1500 BC, had water harvesting and drainage systems. The most recent to come to light is the settlement at Dholavira, a major site of the Harappa or Indus Valley Civilisation. This ancient Harappan settlement, dating back to the third millennium BC, was laid out on a sloping terrain between two storms water channels. The gradient between the higher east and the lower west of Dholavira is 13 m, which is ideal for reservoirs. There is a series of water reservoirs, which almost entirely surround the city. The inhabitants of Dholavira, therefore, created several reservoirs to collect the monsoon runoff flowing in the flanking streams of the Manhar. Stone *bunds* were raised across them at suitable points in order to divert the flow of water through inlet channels into a series of reservoirs, which were dug out in the sloping areas between the inner and outer walls of the Harappan City. Water reservoirs were separated from each other by bund-cum-causeways, which facilitated access to different divisions of the city as well. Likewise, a network of drains criss-crossing the citadel was also laid out to collect rainwater.

6. Karnataka has been a forerunner in managing traditional water harvesting structures, like *arakere, volakere, devikere, katte, kunte and kola.* Some have the same structure and purpose but still carry different names. The most numerous were tanks - 40,000 tanks still exist today.

7. Kasaragod district of northern Malabar has a special water harvesting structure called *surangam,* a tunnel dug through a laterite hillock from the periphery of which water or moisture seeps out.

8. The eagerness of the early rulers to maintain dams is also reflected in the Kuntagani plates which state that the Kadamba king Ravivarman ordered a tank-bund to be constructed in the village of Variyaka (the Kadambas ruled an area northwest of Mysore city between 4th and 6th century AD).

9. Kautilya (321-297 BC) wrote his *Arthasastra* in Patliputra. There is enough evidence in the book to indicate that the people knew about rainfall regimes, soil types and appropriate irrigation techniques in specific micro-ecological contexts. Both natural resources like rivers, springs and lakes, and human made systems like tanks, reservoirs and wells were tapped for irrigation.

10. The 2nd century rock inscriptions at Junagadh describe the repairs of embankments on Lake Sudarsana, which was destroyed during a flood. The lake had originally been constructed during the reign of Chandragupta Maurya by his viceroy Pushyagupta and was later improved under the reign of Ashoka, when the Yavana king, Tushaspha, excavated irrigation canals from the lake.

11. Feroz Shah Tughlaq (1351-1388 AD) perceiving that there was a great scarcity of water in the city of Hisar and resolved to bring a supply there. He, accordingly, conducted two streams into the city from two rivers: one from the river Yamuna, the other from the Sutlej.

12. *Kunds,* found in the sandier tracts of the Thar Desert, are covered underground tanks with an artificially prepared catchment area to increase runoff. It was developed to supply drinking *water. The Paliwal Brahmins of Jaisalmer developed Khadins, an example of runoff -farming,* around the 15th century.

The conventional water harvesting, conservation and management techniques used in early era are still being used in different parts of the country. The technology for urban water development has developed more slowly as compared with technologies for designing and managing hydroelectric power, irrigation, aqueducts, and other large-scale water systems. On the contrary, in recent years, water demand in urban areas has increased manifolds. There is a trend that the people move to the urban fringe zones and their agricultural surroundings. Consequently, a population decline in rural areas can be observed. With economic liberalization and expected higher economic growth, the growth rate of urbanization in India in coming decades is likely to increase (Table 1). India has 6 mega cities and 23 metropolitan cities, which are expected to increase to 40 by 2001 A.D. By the year 2021 it is expected that as many people will live in urban areas, the urban population will reach 41 percent mark of the total population of India.

Table 1 : Urban Population 1951-2021 (Source: Indian National Report for Second United Nations Conference on Human Settlements: Habitat II) (in million)

Year	Total Population	Urban Population	% of Urban to Total Population
1951	361	62	17.30
1961	439	79	18.00
1971	548	109	19.90
1981	683	160	23.34
1991	846	218	25.72
2001	1006	307	30.50
2011	1164	426	36.50
2021	1545	618	40.00

Increasing demands of water for agriculture, industrial and other urban usage and deterioration of the surface water quality have created a tremendous pressure on natural water resources.

2.0 URBAN WATER RESOURCES- PRESENT SCENARIO

Surface water has been the dominant source of water supply followed by ground water in metropolitan cities and towns in the country. The "demand and supply" scenario of these surface and ground waters in urban area for different uses are shown in Table 2.

Table 2: Water Demand for Various Uses (Source: Theme Paper on Water Conservation prepared by Central Water Commission, 1991)

Purpose	**Demand in the year (Cu.Km)**		
	1990	**2000**	**2025**
Domestic use	25 (4.5)	33 (4.4)	52 (5.0)
Irrigation	460 (83.3)	630 (84.0)	770 (73.3)
Energy	19 (3.5)	27 (3.6)	71 (6.8)
Industrial use	15 (2.7)	30 (4.0)	120 (11.4)
Others	33 (6.0)	30 (4.0)	37 (3.5)
Total	**552 (100.00)**	**750 (100.00)**	**1050 (100.00)**
Supply in the year			
Surface Water	362 (65.6)	500 (66.7)	700 (66.7)
Ground Water	190 (34.4)	250 (33.3)	350 (33.3)

It can be seen from the Table 2 that in absolute terms there could be no shortage of water in the country but in actual practice, the functioning of water supply for various beneficial uses is difficult. There are large variations in rainfall from region to region, season to season and year to year. The spatial and temporal variations in precipitation have led to complex situations such as the distinctly different monsoon and non-monsoon seasons, the high and low rainfall areas and drought-flood-drought syndrome due to numerous factors. Only 84 % of the urban population of India is provided with protected water (Suresh, 1999). Also, due to over exploitation of groundwater, the water table has gone down tremendously in some regions of the country.

Moreover, water pollution has emerged as a very serious problem in urban areas. With increasing population the large cities resulted with severe health impacts. Water pollution is mainly due to lack of proper storm water drainage and sewerage system, improper and inadequate garbage collection and disposal system, haphazard siting of industries/processes, transportation, storage and handling of toxic or hazardous chemicals, and lack of adequate open spaces and green areas *etc.*

Conventionally, the water pollution problems are solved by introducing environmental management techniques such as control of pollution at source, providing of sewage treatment facilities etc. However, in large urban agglomerations, the problems can not merely be solved by these conventional pollution control measures. The measures taken for pollution control in individual sectors *viz.* municipal waste disposal, industry, transport *etc.* are not solving the problems, due to ever increasing gap between 'demand' and 'supply'. Table 3 indicates the wastewater management in the mega cities of the country.

Table 3: Wastewater Management in Mega Cities (Source: Shukla, 1999)

Sl.No.	Name of the City	Wastewater Generated (mld)	Wastewater Treated (mld)
1.	Bangalore	496	286
2.	Calcutta	690	690*
3.	Chennai	276	173
4.	Delhi	2160	973
5.	Hyderabad	350	115
6.	Mumbai	2400	1800*

** Primary Treatment only*

In can be seen from the Table 3 that the waste water generated from Maga cities are not treated prior to the disposal in surface water as well as groundwater.

3.0 SOME CASE STUDIES FOR URBAN WATER POLLUTION

Most of the cities in India are located at the bank rivers. Unfortunately, the municipal and industrial wastes are continuously disposed into the rivers without prior treatment, which in turn deteriorates the river water quality. To establish the increasing level of pollution in rivers and ground water due to urbanization and industrialization, some studies carried out earlier by different researchers have been demonstrated in brief. They include pollution load in river Kali at Muzaffarnagar (Jha and Bhatia, 2000), pollution load in river Yamuna at Delhi (< biblio >), pollution load in groundwater at Delhi (CGWB, 2000) and pollution load in river Ganges at Varanasi (Choudhary, 1998).

3.1 Pollution Load in River Kali at Muzaffarnagar

Water quality surveys of the river Kali in Western Uttar Pradesh were carried out at the dawn of new millennium (March'99 to December'99) to evaluate the impact of point and non-point source contaminants discharged into the river (Jha and Bhatia, 2000). Some of the main contaminants which may have negative impacts on the aqueous environment in a river such as temperature, pH, TDS, Total suspended solids, Turbidity, DO, BOD, COD, Phosphate, Ammonia-Nitrogen, Nitrate-Nitrogen, Potassium, colour and odour along with flow were monitored. The results indicate marked increase in the river pollution due to continuous disposal of effluents by the municipal, industrial and sugar mill drains of Muzaffarnagar town, U.P., India without prior treatment (Fig.1). The sudden drop of DO to zero and rise in BOD after the disposal of wastewater from drains in the river indicates presence of settleable solids, dissolved solids, organic matter, and nutrients. It appears that for nearly half a decade the quality of river Kali has been deteriorated tremendously. The river water is not found suitable for domestic purposes as well as for bathing at the downstream of Muzaffarnagar city. One treatment plant has been established in Muzaffarnagar city under Ganga Action Plan Phase II (Yamuna Action Plan) and is proposed to be commissioned for wastewater treatment.

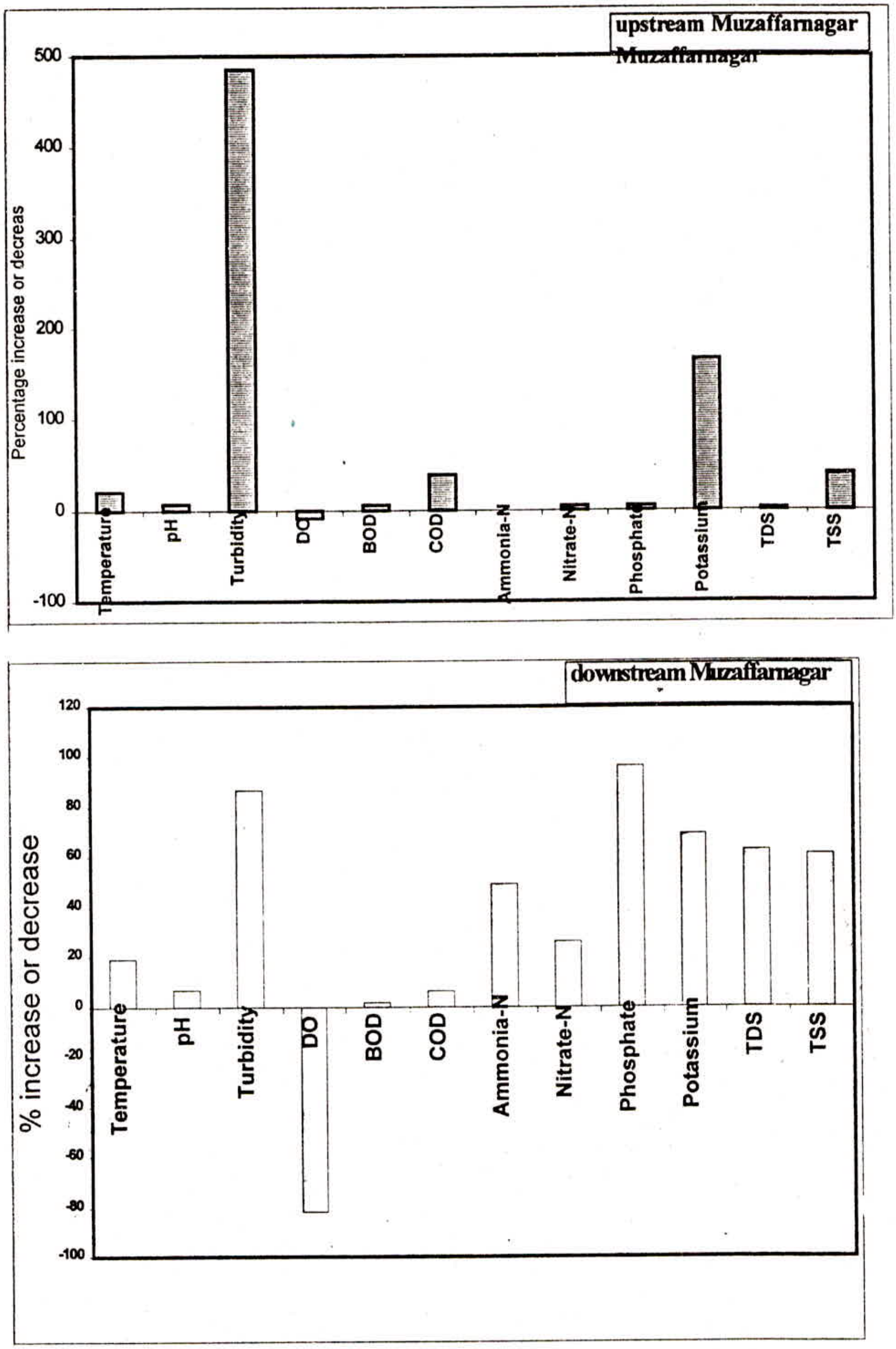

Fig. 1 : Percentage Variation of Water Quality Variables in River Kali at Muzaffarnagar, U.P.

3.2 Pollution Load in River Yamuna at Delhi

The small and medium scale industries located in several pockets in the city are rapidly expanding every day. River Yamuna receives pollutants in large quantity from municipal and industrial wastes (Central Board for Prevention and Control of Water Pollution, 1982). The Najafgarh drain is the largest drain contributing about 60 % of total wastewater and 45 % of total BOD load into river Yamuna. Delhi generates 1900 MLD of sewage against installed capacity of about 1270 MLD of sewage treatment (CGWB, 2000). The balance untreated sewage along with significant quantity of partially treated sewage is discharged into Yamuna River continuously. From the data of Central Water Commission (1991-96), it can be seen that the DO is around zero for low flow conditions. The BOD is as high as 80-90 mg/l mainly attributed by the extremely low flow and constant organic load to the river (Fig.2). The overall conditions are better only in monsoon months from July to October due to the large dilution owing to high flows.

3.3 Pollution Load in Groundwater of Delhi

The overall probable causes of ground water deterioration in Delhi are due to natural hydrogeological conditions, over population of Delhi, over exploitation of ground water, lack of harvesting of rainfall for recharge of ground water, improper disposal of sewage and industrial waste water, improper disposal of municipal and industrial solid waste and the lack of public awareness. About 45 % ground water samples out of 303 samples tested by CGWB (2000), have been found unsuitable for drinking purpose based on overall impact of physio-chemical characteristics including heavy metals, total dissolved solids, nitrate, fluoride, trace metals or due to synergistic effects of some or all of these, The block wise sequence of overall deterioration of ground water quality has been observed by CGWB as Kanjhawala block > Najafgarh block > City block > Alipur block > Mehrauli block > Shahdara block.

3.4 Pollution Load in River Ganges at Varanasi

Varanasi is known for its religious harmony. People coming from distant places go for holy dips in river Ganges at different ghats of Varanasi located on the concave bank. However, due to disposal of wastewater through many drains in river Ganges at Varanasi near the ghats, the water quality has been deteriorated tremendously in recent years. A total of 300 MLD pollutants are being discharged into the river. Choudhary (1988) carried out an extensive survey of river Ganges at Varanasi to see the affect of different effluent drains falling into the river Ganges and rate of increase in pollution level at Varanasi. Fig. 3 shows the location of pollution load sources near different ghats of river Ganages at Varanasi. It is interesting to see that due to curvilinear nature of river at Varanasi and typical flow conditions in different ghats (low flow and higher depth), the pollutants disposed into the river are spread near the ghats and resulted in unhygienic condition. Choudhary and Jha (1997) found that the pollutants discharged on the concave bank (near ghats) takes longer duration for dilution and dispersion that may be due to low velocity, higer depth, formation of secondary circulation etc..

4.0 CHALLENGES FOR URBAN WATER DEVELOPMENT

In the process of urban water development, the issues confronting today are achieving desired development for economic or social reasons on one hand and safe guarding the environment and

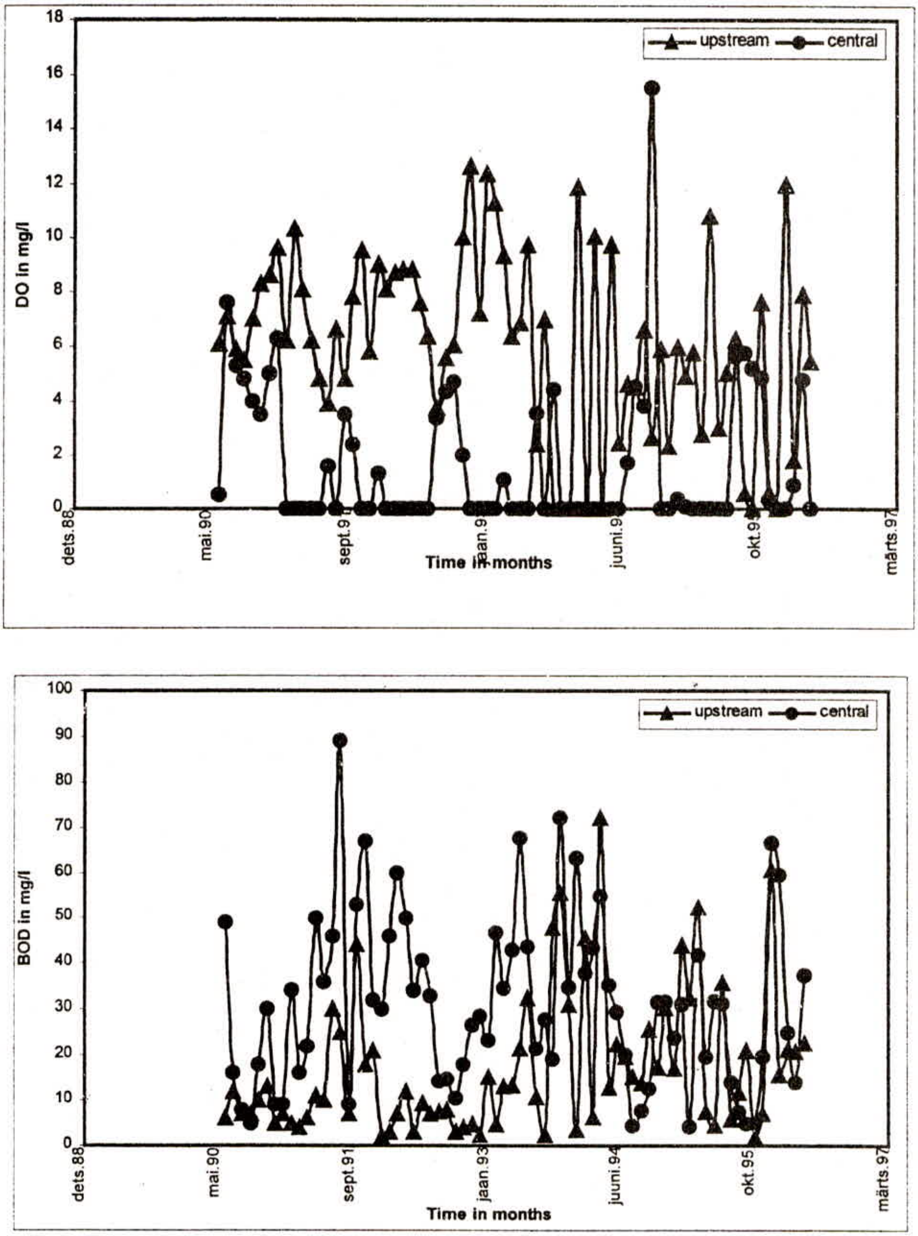

Fig. 2 : Variation of DO and BOD in Yamuna at Delhi

maintaining good quality living conditions on the other. Lack of legal framework for spatial planning, dearth of financial resources, inadequate of environmental awareness, inadequate water supply, poor water quality, shortage of manpower and limitations in technical competence are among the constraints in integration development process.

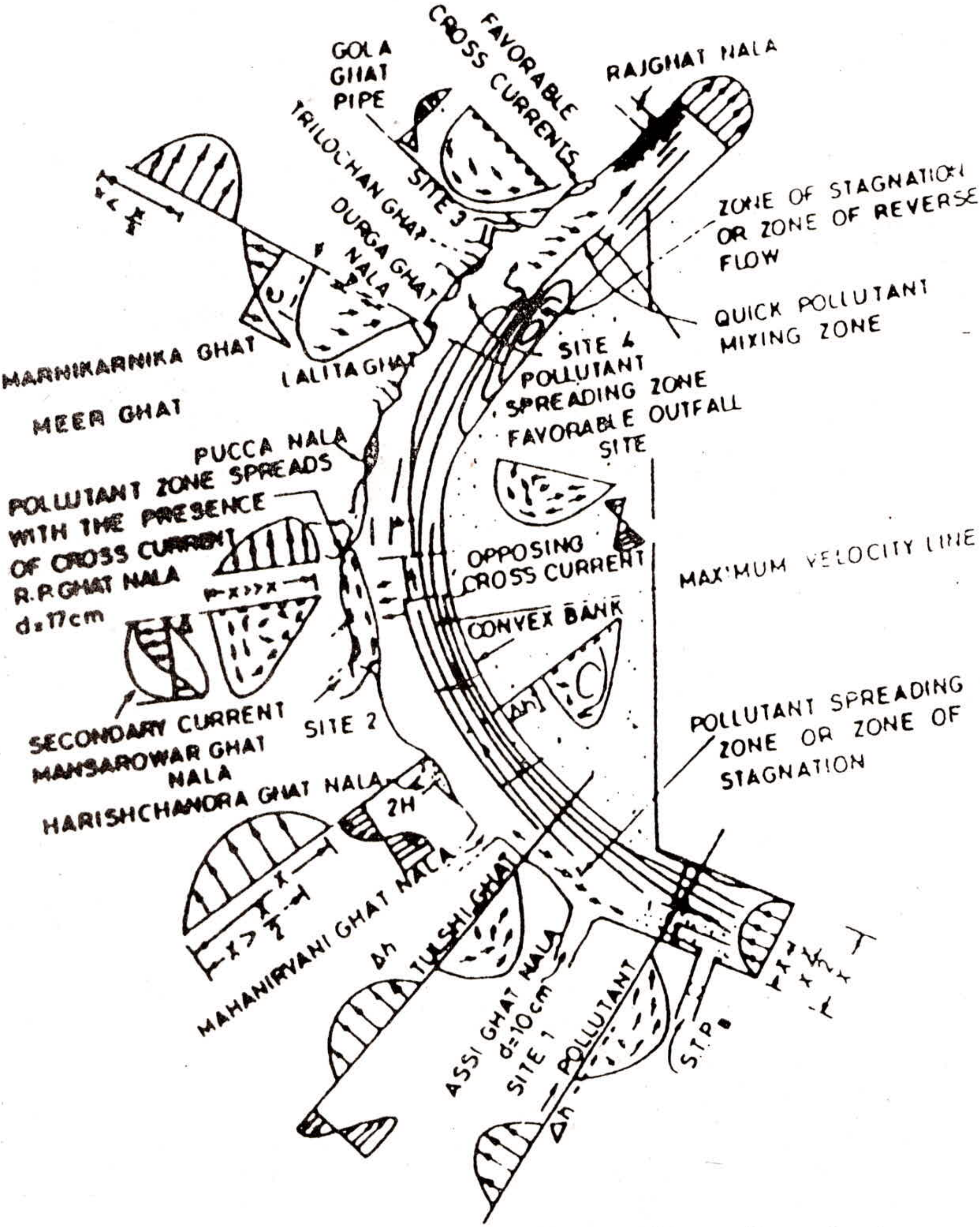

Fig. 3 : Ganga River Flow and Pollutant Outfall Sites at Varanasi

Urban water systems for tomorrow's cities will see the introduction of new management policies and structures, and also innovative technologies. New technologies will come into practice quickly as the opportunities are identified by more progressive utilities. There is an urgent need to introduce different views of the urban water harvesting, its conservation and management issues, which are not trapped in the traditional way of doing things. Several issues that future engineers /planners must deal with are the described in the following sections.

4.1 Water Harvesting

The average annual utilizable water resources through conventional schemes of all the major river basins taking into account the uneven nature of distribution of water resources and the topographic constraints is estimated to be 35 % of the total surface water resources. This indicates that vast amount of runoff is going as waste to sea. Conversely, the over exploitation of ground water resources more than its annual replenishment has caused the continuous declining of water levels, declining of well yield, drying of shallow wells, deterioration of ground water quality, sea water intrusion into the coastal aquifers.

Urban development adds impervious surfaces, increases runoff, and decreases infiltration and groundwater recharge. Urban runoff is viewed as a nuisance, to be removed as quickly as possible, but it can be a resource (Carmon et. al.1997). On the other hand, most of the cities are increasingly forced to depend on distant sources, as the nearby sources have either been tied up for the various beneficial uses or exhausted. Following Table 4 shows the scenario of the present status of new sources of water supply in few of the metro cities in the country.

Table 4: Distance to New Sources of Water Supply (Source: Shukla, 1999)

City	Local Source	New Source	Distance to New Source (Total Cost in Million)
Ahmedabad	Water level going down by 4-5 meters per year	River Sabarmati	150km. (Rs. 4900)
Bangalore	Exhausted	Cauvery River	100km. (Rs. 2800)
Chennai	Local source highly inadequate and overused	Krishna River Water from Andhra Pradesh Telugu Ganga	100 km. 400 km
Delhi	Yamuna water reduced flow, pollution, depletion of ground water and contamination	Tehri Dam (Bhagirathi River) Renuka Dam Krishna Dam	250 km (Planning Stage)
Hyderabad	Exhausted, Polluted	River Godavari, Nagarjuna Sagar Reservoir	160km. (Rs. 9170)
Mumbai	Local source functioning weak (mostly lakes)	Bhatsai Dam	60-80km. (Rs.3956)

Since the huge quantity of rainwater finds its way ultimately to the rivers and joins the sea, the only alternative left is to harness and conserved rainwater through "rainwater harvesting". Capturing and infiltrating runoff on-site reduces both the cost of drainage systems and the loading on the aquatic environment (Ferguson, 1990; Harbor, 1994; Bettes, 1996; Kronveter et. al, 2000). Rainfall harvested for use should be captured close to where it falls, before its quality becomes impaired. It can be seen that the rainwater conservation is possible in surface as well as sub-surface reservoirs depending upon the hydrological and climatic conditions. Conservation of rainwater on the surface is not feasible in urban areas due to obvious reasons. Rainwater can, however be stored in underground natural and manmade reservoirs that have tremendous potential to store water for long period.

Use of rainfall and runoff, directly or after storage, should be evaluated jointly with the options provided by dual distribution systems and point-of-use treatment. Capturing runoff in the ground, in detention and retention basin, reduces pollution of the receiving environment and the cost of drainage systems. This knowledge is now well established by urban storm water management programs.

There are various methods of rainwater harvesting (Gablier, 2000; Raju and Umapathi, 2000; Sethuraman and Shukla, 2000) in Indian context. They include; Percolation Pit Method, Broken Brick Bed Method, Well cum Canal cum Percolation Pit Method, Through Open Wells, Through Defunct Bore-wells, Through Ponds, Through Ridge and Furrow Storage, Through Recharge wells, Through Service well cum Recharge well, Rooftop water collection and Recharge, Storm water Drains with Percolation Pit, etc.

4.2 Control of Water Pollution

In general, the aim of making cities healthier is possible through proper plans. Seeing the present scenario, the execution of different measures to control water quality of rivers and groundwater and its reuse is a need. The important measures are (a) Point-of use treatment, and (b) recycling of water. In addition to that, there is an urgent need to introduce different issues that are not trapped in the traditional way of doing things. Several issues that future engineers / scientists must deal with are the following:

1. New hydraulic hardware for efficient water use and waste reduction. (http://www.waterwiser.org)

2. New materials coming into use for pipes and appurtenances.

3. Efficient and cost-effective high-level treatment technologies (e.g. **membranes**) that will be more widely used, with less emphasis on centralized control.

4. Several technologies that will be used for control and communication in water and sewerage systems, including smart local communications objects, distributed automatic control, and centralized decision support systems for emergencies. Advanced water and waste treatment technologies should be continuously evaluated to identify opportunities

for using distributed treatment of water and of wastewater, and the proper geographic scales at which this should be done. This includes point-of source treatment for potable water and in-home and neighborhood treatment of sewage.

5. Moderate approaches for monitoring of point and non point sources of pollution from urban areas (using curves).

6. Probabilistic mathematical model to determine least cost storage -treatment combinations for various levels of control over both runoff quantity and quality.

7. Urban runoff pollution control by means of optimal combinations of storage and treatment.

8. Numerical Models for analysis and simulation of sewer systems: to characterize the flow of waste water through various components of sewer systems, to minimize the leakage of wastewater from the systems, to determine economically optimal systems, a wastewater and storm water runoff model for sewer networks, a sludge treatment plant model and an overall model for the economics of a system 9using optimization technique).

Point of use Treatment

Point-of use treatment of water is a technically, feasible option for potable water supply. With economies of scale from mass production and utility level maintenance, it is also potentially economical. In most modern cities, there is no indication that point-of-use treatment, like bottled water, is required as a health precaution, but many are convinced that it results in a superior product. There are also some dangers in using point-of use treatment, since poor maintenance of devices will result in more harms than good. Large-scale, widespread point-of-use treatment deserves a thorough study and evaluation to identify site specific opportunities. Point-of-use treatment increases water management flexibility and opens up undeveloped sources. Point-of-use treatments will also probably result in overall cost savings, since not all the water distributed within the city needs to be treated to the highest standards. Like dual distribution systems, which already have their place, the technical, health, social, economic, institutional, and legal aspects of point-of-use treatment need to be evaluated in holistic manner.

Recycling and Reuse of Water

Recycling and reuse of gray water in the home from the sink, shower, and bathtub is not a new idea, but it too should be fully examined in the light of modern monitoring and control systems. Approximately 40 % of domestic water use are for toilet flushing, for which gray water can be used if the pipes are properly fitted. In addition to reduced consumptive use, there are economic savings to be captured through reduced treatment costs. Agricultural and garden reuse of water is common practices in many arid regions; urban uses are also possible with adequate attention to health hazards.

As recycling of water increases, there will be a need to develop methods that avoid accumulation of pollutants in water and soils. Use of gray water will recycle wastes and increase their ultimate concentration in the final effluent. Point-of use treatment of water produces waste materials. Accumulation of waste material (salt, heavy metals, nutrients) from urban areas can be used for irrigation, especially with highly efficient irrigation technologies, such as drip, which reduces return flows and flushing.

4.3 Spatial Planning

The spatial planning is an important concept for attaining balanced development of urban areas. For all developmental activities, a crucial input is land and depending on the activity a specific land use is decided. The environmentally related land uses are trade and commerce, housing construction, transport facilities (road, rail and water), utilities (water - surface and ground etc.), refuse/hazardous waste disposal facilities, wastewater installations, quarrying and mining, power generation, forestry, inland and coastal fisheries, recreation and tourism etc. These land uses are likely to have some impact on the envircnment. The best use of the land needs to be assessed in terms of not only the economic aspects but also the environmental aspects and the land uses are accordingly to be allocated so that the natural environment and ecological balance is not disturbed.

Presently spatial planning approach is limited to some urban areas only. Earlier, the spatial planning concept could not be implemented in many cities due to the following constraints (Ramaseshan, 1979);

- in view of the existing social and living conditions, economic interests may tend to over-ride the environmental aspects.
- ecosystems are already over-used in some areas.
- introduction of spatial planning which involves highly complex nature of planning activities is a daunting task particularly in a large country like ours.

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This is resulting in unbalanced development leading to increased influx of people to urban areas forming uneconomic agglomerations, over exploitation of resources thereby forming degraded ecological areas etc. However, with the advent of computers and satellite era, the spatial planning concept can be implemented to its fullest strength and to the extent possible.

5.0 CONCLUSIONS

The urban areas in India are growing into bigger agglomeration with ever increasing influx of people. The over exploitation of surface and ground resources, deterioration in safe water quality for various purposes and demand for support services are demanding the need of a defined urban planning. For urban planning, It is essential to involve individual peoples of the city, NGO's, State and Central Govt. agencies, Different Institutions and accept the challenges for innovation. Continuous efforts and technology support to water harvesting, control over water pollution and effective planning and management at initial stages of urban development are essential.

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