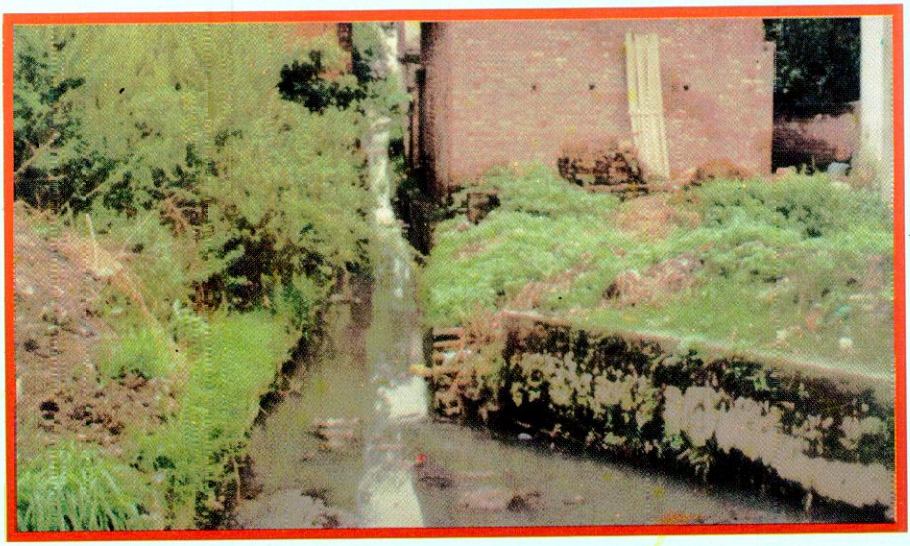
URBAN HYDROLOGY



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HYDROLOGICAL ISSUES AND CHALLENGES OF URBANISATION

HYDROLOGICAL ISSUES

- Disruption of the natural hydrological cycle due to reduction of infiltration and groundwater recharge, increase in surface runoff and flooding
- Decline in water levels and possible land subsidence due to groundwater mining
- Determination of surface and groundwater quality
- Increase pollutant loads from runoff discharges and sewage outfalls of poor quality
- Leakage to groundwater from old and poorly maintained sewers
- Extensive soil and groundwater contamination from industrial leakage, or spills of hazardous chemicals or poorly planned solid and liquid waste disposal practices
- Increased artificial surface water infiltration and recharge from source control device leading to poor groundwater quality
- Reduction in ecological habitat and species diversity of the receiving water body
- Need for integrated land use and catchment planning.

CHALLENGES IN URBAN WATER MANAGEMENT

- Delivery of drinking water supply for growing cities
- Water for sanitation versus sanitation without water
- Recycling of wastewater nutrients
- Wastewater irrigation
- Storm water management and drainage
- Rain water harvesting
- Artificial recharge of depleted aquifers
- Urban agriculture
- Recovery of resources present in solid and fluid wastes
- Paradigm shift from water disposal and treatment to conservation and recycling of resources
- New programs like dry sanitation
- Major changes in life style and societal structures as well as educational and research programs
- Transfer of knowledge and technology.

Preface

Urban hydrology is that part of the comprehensive field of hydrology, which deals with effects and phenomena in human settlements. The growth of urban settlements during the past years has put tremendous pressure on urban services like water supply, sanitation, drainage, and solid waste disposal. Urbanisation affects all phases of the water cycle in settlement areas, with far-reaching changes taking place in precipitation, evaporation, evapotranspiration, infiltration and runoff. In developing countries and especially in India the population growth is very fast. Water-related problems in metropolitan cities are quite complex, and further degradation is expected. Water shortage is a rapidly growing problem and delivery of safe drinking water cannot be ensured. In many places, municipal and industrial wastes are disposed of to the natural environment, generally without adequate treatment. The present situation with respect to pollution of air, land, and water, as well as lack of basic water and sanitation facilities in cities creates living conditions that are nothing less than a derision of human dignity. Solution of this problem requires efficient regulations and actions to properly regulate and manage further urban population growth and, in the water sector, to develop novel environmentally friendly and economically efficient methods of water conservation and treatment.

At present cities in India are booming. Internal growth and migration from rural to urban areas has been putting a colossal pressure on the administration and management. Therefore, the rapid increase of urbanisation is emerging out as a major challenge for administrators, planners and research workers. The main objective of this brochure is to present the status of urban hydrology and to highlight some of the hydrological problems related to urbanisation in India. This brochure includes the trends of urbanisation in World and in India, and discussion on urban hydrologic cycle, hydrological and related problems of India, impact of urbanisation on streamflow, and urban water management. Some information on available urban hydrologcal models and the recommendations for the management of urban areas is also included. The information included in this brochure has been collected and compiled by Dr. Vivekanand Singh, Scientist 'B', Dr. Pratap Singh, Scientist 'E'. and Mr. A. K. Lohani, Scientist 'C' of the Institute from available literature and various sources. This is duly acknowledged.

(S. M. Seth)
Director

1.0 INTRODUCTION

☞ "Urban hydrology is defined as the interdisciplinary science of water and its interrelationships with urban man (Jones, 1971). It is a relatively young science; the bulk of its knowledge has accumulated since the early 1960s. The beginnings of urban hydrology can be traced to the time shortly after the automobile became the major means of transportation in the United States. Roads were paved to facilitate travel, allowing the growth of the suburbs where the commuter escaped the congestion of inner-city life. The result was the rapid creation of large impervious areas, producing noticeable drainage problems. The science of urban hydrology was born out of the necessity to understand and control these problems (Lazaro, 1990)".

☞ "Urban hydrology is a special case of hydrology applied for cities i.e. area with very high level of human interference with natural processes. All hydrological sub processes in urban areas must be considered in much smaller temporal and spatial scales than those in rural area. Growth of urban areas brings significant changes in physical properties of land surface increasing integrated vulnerability of inhabitants, agricultural land and rural ecological life support systems (Hall, 1984)".

1.1 Urbanisation

Urbanisation is defined as the concentration of people in urban settlements and the process of change in land use occupancy resulting from the conversion of rural lands into urban, suburban and industrial communities (Davis, 1965; Savani and Kammerer, 1961). Urbanisation of a region includes the transformation of a rural region into an urban region, development of a suburban region to an urban region and rural-urban migration. The urban areas have developed in response to human social and economic needs. The important causes of urbanisation are advances in science and technology, industrialisation, advance in agriculture, better scope of employment, service-oriented business, better education, medical facilities and transportation. Economic development and urbanisation can be correlated. The forces of urbanisation are the product of man's genius, of his continuous quest for efficiency and of his need for the social and cultural milieu that an urban area can provide (Lazaro, 1990). Urbanisation represents a particular form of land use and surface cover. The micro-climate in an urban neighbourhood is modified by the form of urban structures, by changes in the heat balance, there is increased drawl from surface water and groundwater sources, reduced infiltration, increased peak flow, increased waste water with corresponding effect on water quality etc. The impact of highway development, and rail lines on soil erosion and water quality is significant. Channel straightening and narrowing, culvert sizing, drainage etc. affect the runoff timing significantly. Receiving waters have often become waste receptacles, ·subject to increasing flow volumes and effluents harmful to both quality and ecology.

1.2 Trends of Urbanisation in the World

The world growth of urbanisation over the years is logarithmic. In 1950 about one-third of the world's population lived in cities. In 35 years since 1950, the number of people living in cities has almost tripled, increasing by 1249 millions (734 to 1983 million). In more developed countries, about 75% of the population is concentrated in urban areas. On a worldwide scale, total population growth during this century has been accompanied by a continuous increase in the ratio of urban to rural dwellers (McPherson, 1974). The average populations increase between 1960 and 1990 was 75%, but in Asia where growth is fastest, the population increases by 158% and in Africa by about 135%. Urban growth in developed countries is linear, but exponential in less-developed countries, it can be seen from Figure 1. About half of the world's population live in cities today, and projections shows that by the year 2001 the number of city dwellers will be twice as large as the rural population. The number of cities in the world with population above five million inhabitants will increase to 60, as shown in Figure 2. In this figure values for the year 2000 and 2025 are the projected.

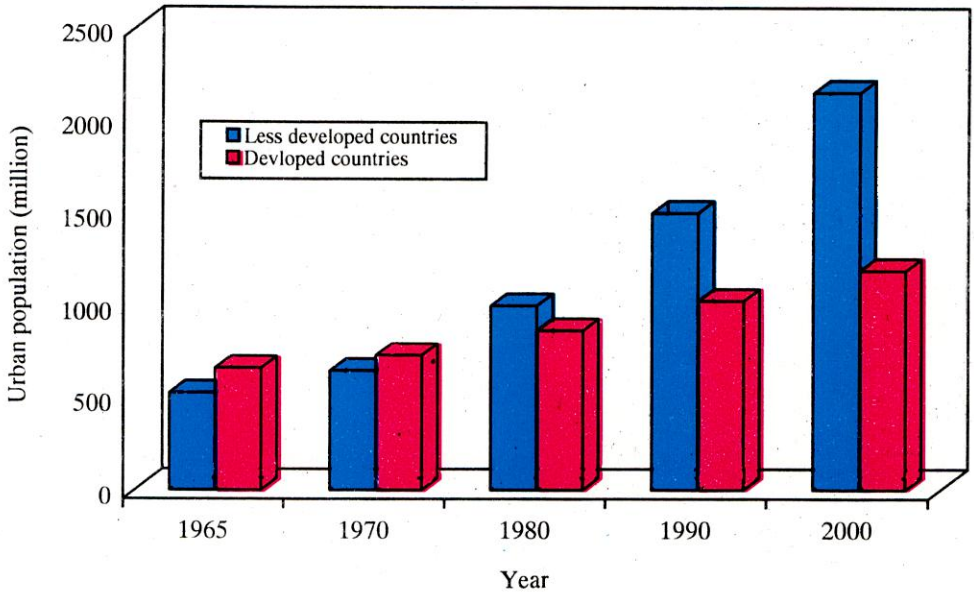

Figure 1: Urban population in world from 1965 to 2000 (Niemczynowicz, 1996)

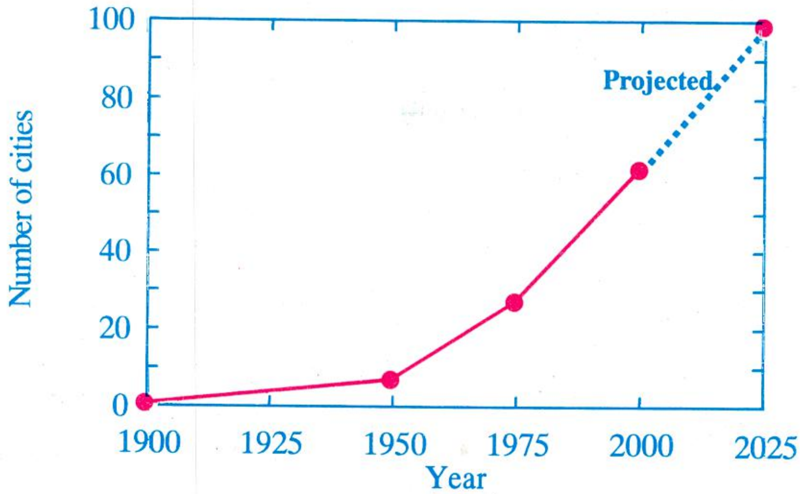

Figure 2: Number of cities greater than five million population in the world (Niemczynowicz, 1996)

1.3 Trends of Urbanisation in India

The rate of urban growth is especially high in developing countries like India. By year 2001, the urban population of India would be nearly 330 million, which is about 33% of the total population. It is expected to be about 405 million (35% of total population) by 2011 and 549 million (41% of total population) by 2021 to live in urban areas. Such increasing trends of urbanisation in India would change the age-old image of India as a rural nation. Urban population growth in India is shown in Figure 3. In this figure, population for the years

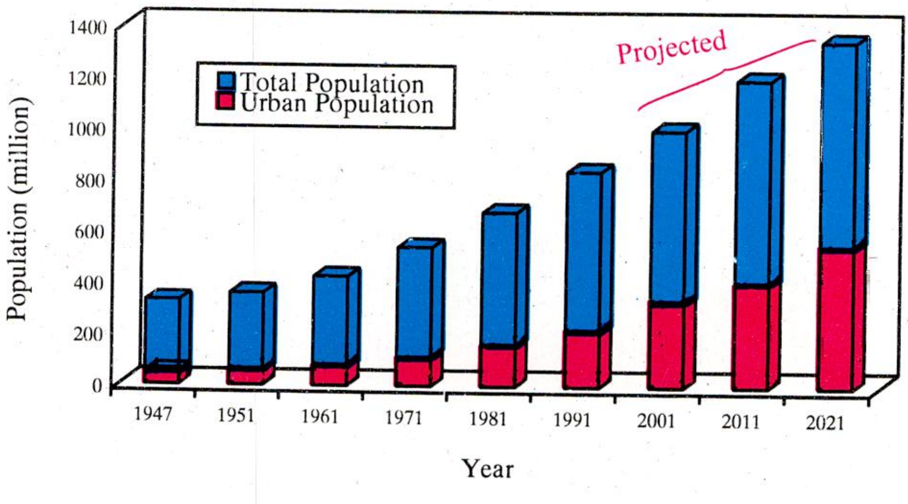

Figure 3: Urban population in India (Suresh, 2000)

2001, 2011 and 2021 are the projected. Among the urban areas, the small towns are somewhat stagnating while the 23 metropolitan cities (as per the 1991 census) stand out very prominently as they accommodate about one third of the total urban population, it can be seen in Figure 4.

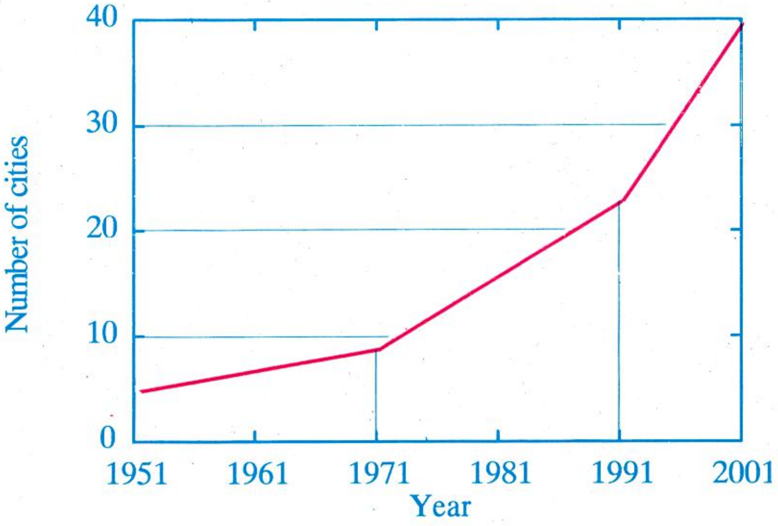

Figure 4: Number of Indian cities with more than 1 million population (Suresh, 2000)

The rapid process of urbanisation in India is a challenge for administrators and planners, as well as for technicians and research workers. Since 1970, urban hydrology has played an increasing role as a supporting activity to the design and the implementation of urban water resources systems. Figure 5 shows the physical urban water resources system. A further enlargement of these activities has to reckon emphatically with the scale and time horizon of the urbanisation process and its water related steps. These scale and time horizons will affect the approach and the particular actions to be taken. We may distinguish; industrialised countries, developing countries, geographical aspects and climate conditions. Similarities or differences in the hydrological behaviour of various urban areas might be based on their physical properties, such as topography and geological and soil condition. The factors limiting the expansion of urbanisation are topographic obstacles and geology.

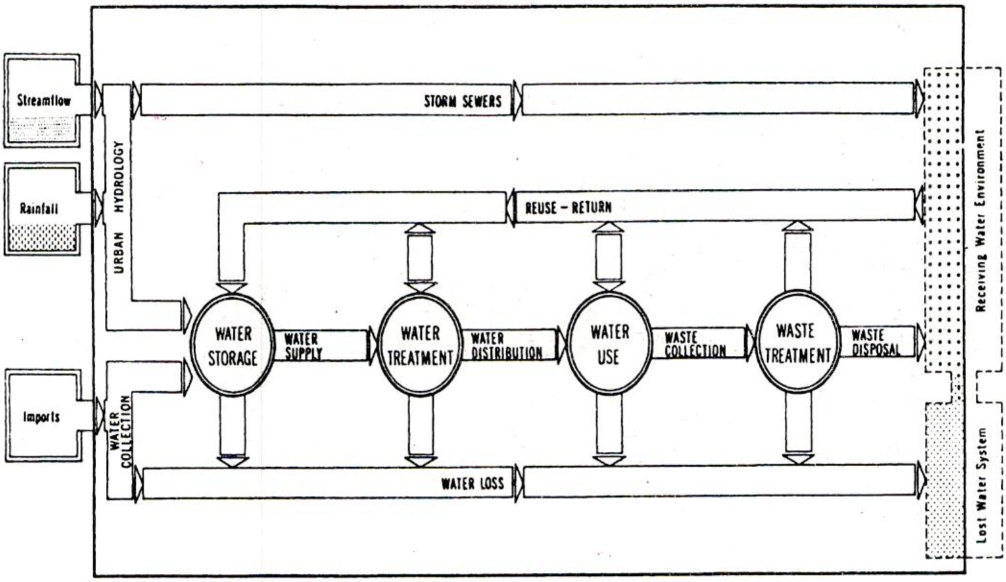

Figure 5: The physical urban water resources system (Zuidema, 1978)

2.0 URBAN HYDROLOGICAL CYCLE

The hydrological cycle describes different hydrological processes. Various paths by which water precipitated onto the land surface finds its way to the ocean and evaporation gives moisture, thus completing the cycle. Different components of a hydrologic cycle are evaporation, precipitation, infiltration, runoff, streamflow and groundwater. However, due to the effect of the urban environment, the hydrological processes are more complicated. Some of the differences are (Hall 1984),

- Natural drainage systems are altered and supplemented by sewerage systems.
- Effects of flooding are mitigated by different schemes.
- Wastewater disposal scheme exists.
- Water is supplied from remote location.

The system representation of the urban hydrologic cycle is presented in Figure 6.

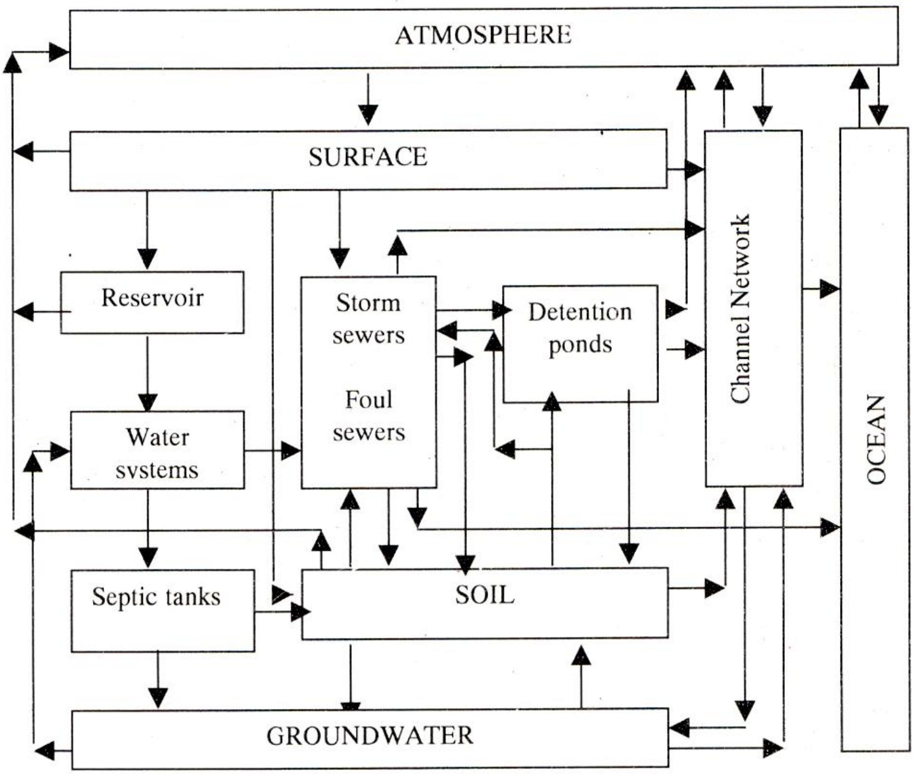

Figure 6: The urban hydrological cycle (Hall, 1984)

3.0 HYDROLOGICAL PROBLEMS OF URBAN AREAS

The following are the major hydrological and related problems of urban areas:

- Supply of clean pure drinking water
- Provision of adequate flows for the disposal of waterborne wastes
- Magnitude of the per capita domestic consumption of water
- Requirement of water for industrial processes, recreation, and amenity purposes
- Flood & pollution control problems
- Internal and external drainage problems
- Storm water management

- Heat production in urban area
- Sewerage system
- Water quality
- Recycling of waste water
- Sources of urban pollutants.

4.0 IMPACT OF URBANISATION

4.1 Climate

Rapid population growth and expanding economic activity are already putting enormous pressure on global water resources. The growing cities and towns alter surface of the ground. Therefore the radiation balance of the area is modified and resulting in the change in the aerodynamic roughness affects air motion. Broadly the industries, buildings and water borne pollution influence the urban climate.

Heat is added to the atmosphere by industrial heating processes and by motor vehicle. Thermal power stations and other industries use coal, diesel, wood, kerosine or other fuel as energy source. Air pollution occurs through coal and wood burning for fuel. Due to non-availability of regular electric supply, the residents have to install heavy generator sets run on diesel, kerosene or petrol. These generator sets are also installed in most of the business establishments. With electricity cut being so frequent, the use of generators create pollution by their exhaust emission containing carbon monooxide, sulpher dioxide, led, nitrogen dioxide, ozone and particulate matters. Dust particles in the climate along with sulpher dioxide and other gasses reduce the clarity of the atmosphere, thereby decreasing the amount of incoming radiation and sunshine.

Due to higher thermal conductivity and greater heat capacity of the buildings, compared with those of vegetated areas, the thermal properties of urban areas contrast strongly with those of their rural environment. Heat is also added to the atmosphere by industrial heating processes and by motor vehicle. The buildings induce mechanical turbulence in the air movement. When coupled with the thermal turbulence, which results from urban heat production, the structure of the city may be seen to exert a considerable influence on air movement. According to climate models, rising levels of greenhouse gases are likely to raise the global average surface temperature by 1.5 - 4.5°C over the next 100 years. Changes in temperature and in winds would clearly have profound effects on the water cycle.

4.2 Streamflow

The population density increases as urbanisation progresses. Therefore, the total demand of water increases. Due to the high standard of living, the per capita demand also increases. Thus, the demand of adequate water resources increases. The amount of water borne waste increases in response to the growth in the population. This result in an increased load entering the river systems and oceans downstream of urban areas with a resultant increased stress on the assimilative capacity of these aquatic environments.

Urban water supply scenario in India *(Suresh, 2000)*

Access to drinking water

- Within their houses : 58 %
- Within a distance of 0.5 km : 40 %

Water available in urban slums : 27 lpcd (litre per capita per day)

National targets

- Urban area where piped water supply and underground sewerage system available : 135 lpcd
- Urban area where piped water supply available but underground sewerage system not available : 70 - 100 lpcd
- Towns with spot sources or stand posts : 40 lpcd

Increasing water scarcity

- National average of water availability is estimated at 2464 cubic meters of water per capita per year.
- From as high as 18417 cubic metres in the Brahmaputra valley, per capita water availability comes down to a low of 411 cubic metres in the east flowing rivers between Pennar and Kanyakumari.

Figure 7 shows the general trend of declining availability of water per capita per year in India. The values for the year 2000 onward are the projected values. It has reduced from 6000 to 1200 per capita for the period of 100 years.

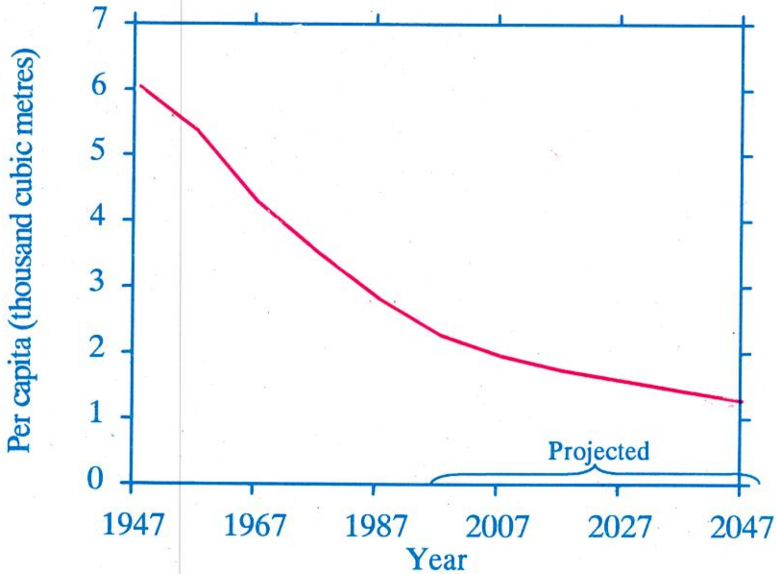

Figure 7: Declining availability of water per capita in India (Engelman and Roy, 1990)

Impervious area

Depending on the percentage of land use, urbanisation may be classified into 4 categories viz. 1. Rural; 2. Early urban; 3. Middle urban and 4. Late urban. The building density increases in the progresses of the urban environment from one category to the next. The surface is modified drastically due to the increased building density as a result of construction of roads and parking lots. Therefore, the extent of impervious area increases resulting in less infiltration and consequently, more runoff. Less infiltration results in less groundwater recharge and more surface runoff. Associated with impervious surfaces is a decrease in surface roughness and presence of constructed drainage systems which results in the runoff flowing with higher velocities compared to the natural condition. Thus, a higher volume of flow takes place within a shorter duration and peak rates of flow inevitably increased. This results in the problem of stream drainage and floods in the urbanised area. Figure 8 shows the change in the response of runoff due to urbanisation in a region.

Water quality

The rise in population density and increase in the extent of impervious areas affect the water quality aspects of the urban hydrological cycle. As the runoff volume is more, and the amount of soil moisture recharge is reduced, less water

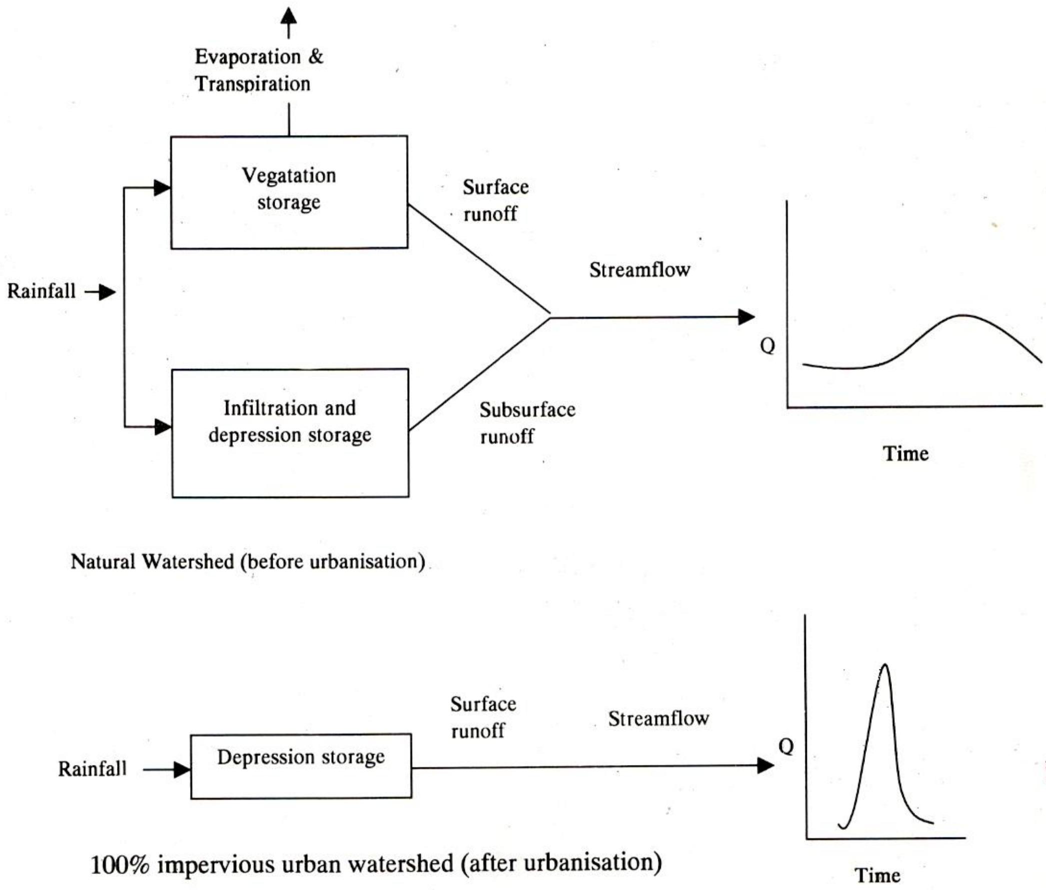

Figure 8: Comparison of stream flow patterns for natural and urban watersheds (Lazaro, 1990)

will percolate and low flow will decrease. In addition, the volume of waterborne wastes increases. Therefore, the quality of storm water runoff deteriorates. The factors, which influence the quality of water within an urban area, are shown in Figure 9. Contaminants are washed away from roofs, streets and roads. Soluble particles go into solution and particulate matters are dislodged. The processes of washing of surface contaminants are:

- Freeing the contaminants from the surface;
- Transporting the particles transversely across the surface to a gutter;

- Transporting the particles parallel to the curb line to the storm sewer;
- Carrying the particles through the storm sewer.

The disposals of solid and waterborne wastes also have an adverse effect on the ground water quality.

The entry of pollutants into a flowing stream sets off a progressive series of physical, chemical and biological events in the downstream waters. The character and quantity of polluting substance govern their nature. After entry into the stream waters, sewage acts as an excellent food source for bacteria, and logarithmically stimulates their growth. As they multiply, they require large amount of dissolved oxygen. They exert a high BOD value thereby decreasing the streams supply of

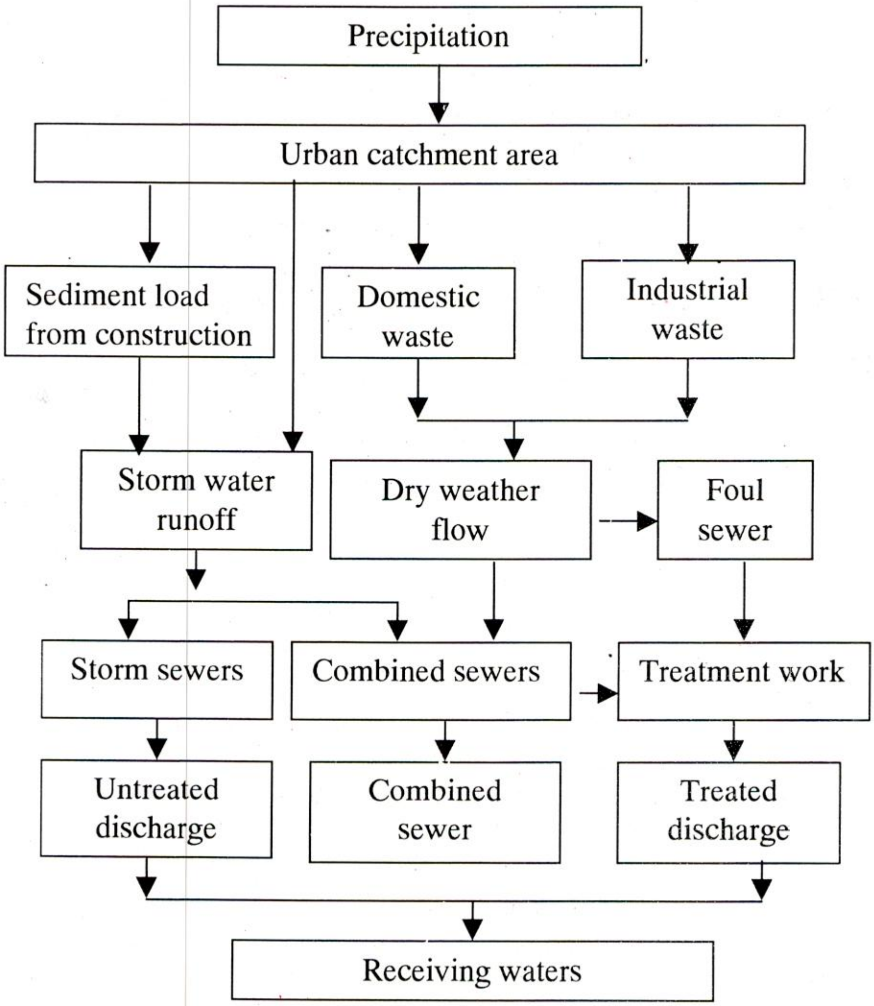

Figure 9: Water quality changes in urban areas (Hall, 1984)

DO with a resultant impact on the ecology of the stream. The resultant ecological impacts are as follows:

- Aquatic ecology upset;
- Earlier organisms die/move;
- Low in DO region is created;
- Septic region occupied by bacteria;
- A predatory relation exists between ciliated protozoa and bacteria;

4.3 Mountainous region

Population growth in the Himalayan region has led to an increased demand for food, which has been met by the increased use of fertilisers and the expansion of agricultural land. These changes modify the quality and quantity of river flows downstream from the affected areas and therefore have a regional as well as a local impact. In the Himalayas, nitrate and sulphate concentrations of similar magnitude to those observed in NW Europe have been reported in snow samples. In general, the waters from these catchments have high background concentrations of sulphate, calcium and bicarbonate, all derived from bedrock weathering sources.

5.0 URBAN WATER MANAGEMENT

In the previous section the adverse impacts of the quality and quantity of storm water due to urbanisation have been described. Therefore, urban storm water management (USM) is necessa ry to tackle these problems. Urban storm water management describes a group of techniques whose common aim is the mitigation of adverse effects to the quantity and quality of urban runoff. The common practices in urban storm water management are presented in Table 1. Hierarchy of the water resources management system is shown in Figure 10.

As previously discussed, the flow quantity is adversely affected by urbanisation with associated increase in the suspended sediment. This increase in suspended sediment may produce changes in the downstream channel network. Owing to the changing flow regime brought about by urbanisation, predevelopment bankful discharge will occur more frequently. Therefore, enlargement of channel will take place. The extent of the enlargement reduces the visual appeal and the recreational value of the stream. The costs for remedial work are also very high. The drainage engineer's response to the changes in the channel network brought about by urbanisation has often been eminently predictable. Attempts have been made to improve the capacity of the channel by adjustments to its alignment, slope and cross-section and to reduce bank erosion and bank instability by lining and the placement of riprap.

Table 1: Stormwater management practices (Hall, 1984)

Type of measure	Quantitative	Qualitative
Structural	-Channelisation -Balancing Ponds -Recharge Basins -Rooftop Storage -Porous Pavements	-Effluent treatment at source -Balancing Ponds -Recharge Basin
Non-structural	-Preservation of local landforms -Flood plain Zoning	-Street sweeping -Gully Cleaning -Anti-litter legislation -Control of de-icing

The most four important consequences of channelisation from the environmental viewpoint are as follows:

- vegetation removal
- channel deepening
- meander removal
- destruction of pools and riffles.

Most of the large cities are already facing acute shortage in water supply. Now a days rainwater harvesting is becoming very popular for this purpose. The rain water harvesting can be done through:

- Individual house
- Percolation pits (individual house)
- Pebble bed (building complexes)
- Ponds
- Ditches and furrow storage
- Recharge wells

The rapid increase in population and consequent increase in activities all round, has led to occupation of the flood plains resulting in increased flood damage. A flood storage pond represents an attempt to replace the natural storage capacity that has been lost through urbanisation. Since the flood storage pond is concentrated at a single site but the natural storage capacity was distributed through out the catchment area, a regional perspective is required in the design of such installations in order to ensure that ponds do not worsen rather than lessen downstream flooding problem.

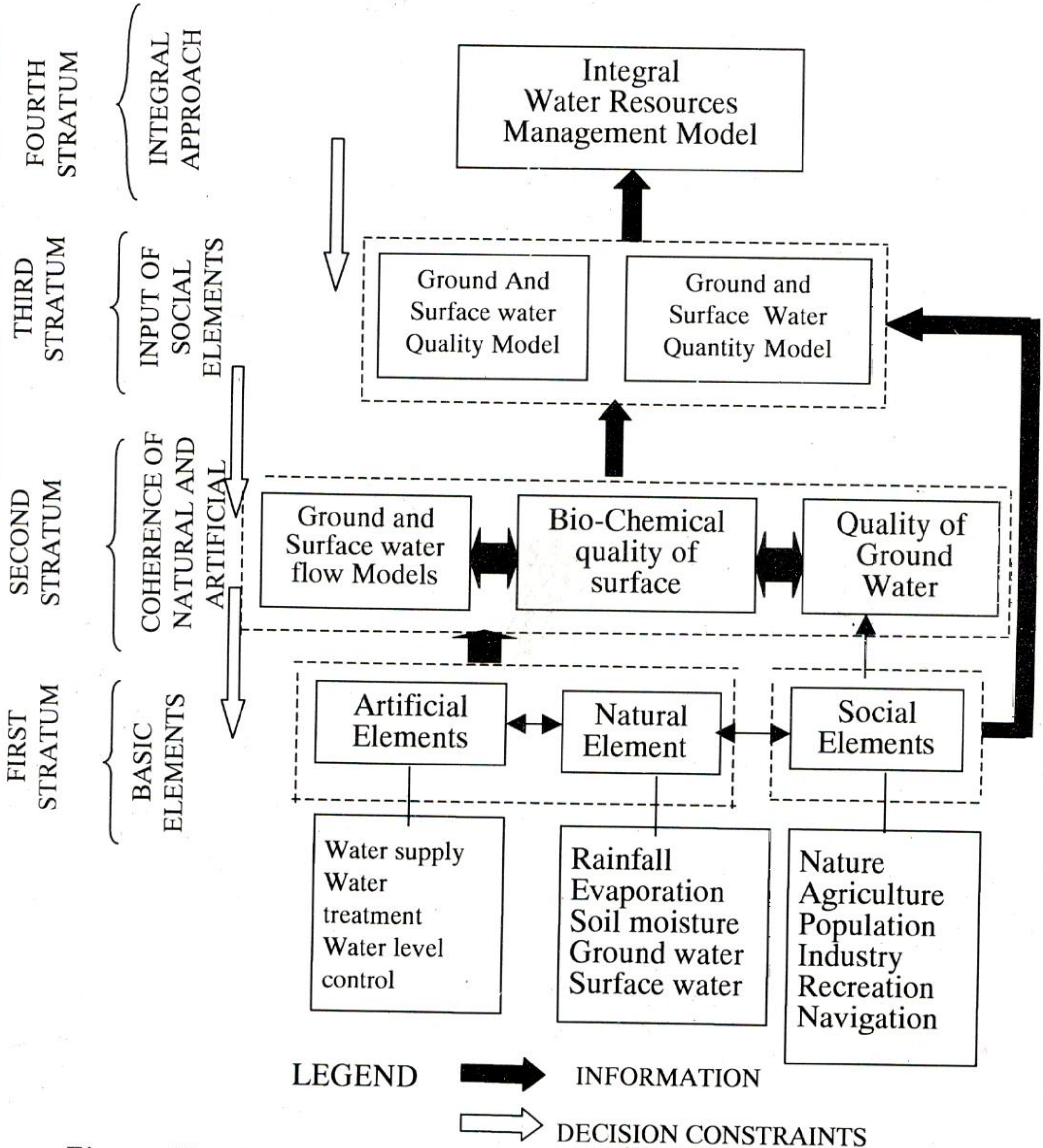

Figure 10: Hierarchy of the water resources management system (Zuidema, 1978)

Unlike channelisation, flood storage ponds may have a beneficial effect on the water quality by the removal of particulate matter by settlement. Unfortunately the bulk of the pollutant loading carried is liable to be carried by the large numbers of small and medium size storms, where as the major flood damages result from the larger, more infrequent events. In contrast to flood storage ponds, whose principal function is to reduce the peak rate of inflow and to redistribute the runoff volume overtime, recharge basins are intended to contain the whole of the storm hydrograph for subsequent recharge to underlying aquifers. Such basins are therefore confined to regions that have reasonable permeable surficial deposits and a water table that is sufficiently deep to remain below the floor level of the urban area. In addition to augmenting local ground water reserves, recharge basins may also effects considerable savings in the cost of outfall sewers. Of the structural methods, the uses of rooftop storage and porous pavement is largely confined to more localised applications.

In general, non-structural storm water management practices involve some element of either prior planning or continual maintenance. In an area with mature drainage network, the streams meander through natural flood plains located between spurs through out from the watershed. The hill slopes located between these ridges and the valley floors are well drained and provide choice sites for development. Encroachment of the flatter flood plains in the valley floors is thereby avoided, and the need to undertake costly flood alleviation works are greatly reduced.

For the management of urban water quality, that of effluent treatment at source is perhaps the most obvious structural method, but also the most inflexible because of its inability to cope with rapid changes as runoff changes. In contrast, balancing ponds and recharge basins can serve to control flood flows as well as provide an opportunity for the settlement of waterborne solids. The non-structural methods for water quality management are predominantly concerned with preventing the entry of dust and dirt into the drainage network. Street sweepers are relatively inefficient at removing the fine solids. Fraction of street dirt, which has been found to account for a significant proportion of the pollution potentials. Road gullies are similarly ineffective in retaining the finer solids for subsequent removal. As can be seen from preceding discussion. There are a wide variety of alternatives for the management of urban storm water. The selection of the best alternatives is achieved generally through the development of a catchment wide Storm Water Masterplan (Hall, 1984). Such a plan considers all impacts of Storm Water runoff and its management.

5.1 Storm Water Masterplan

The steps in the development of a storm water masterplan are as follows:

- Definition of Goals and Objectives

  This steps defines the stockholders in storm water management and their desired goals in the management;

- Definition of Principles

  Defined in this step are the responsibilities of authorities, organisation and people in storm water management;

- Constraints

  This step considers constraints on alternative management plans. These constraints may be hydrologic and hydraulic such as in the capacity of the drainage system, financial such as in the cost of the drainage system, legal such as in the legally defined requirements of a drainage system, or social such as the acceptability of the proposal;

- Strategies

  In this steps strategies for implementation of the management plans are outlined. It should be noted that these strategies are not prescriptive but rather are flexible and subject to constant review and change as necessary;

- Assessment Criteria

  This step defines how the success of the strategies can be assessed. Changes to the strategies are based on these criteria.

6.0 URBAN WASTE WATER MANAGEMENT

In most urban areas in India, the water is heavily polluted with domestic sewage, industrial effluents and solid wastes. The principal organic and inorganic contaminants are: acids, alkalis, carbohydrates, dyes, fats, soaps, waxes, gases, suspended matters, oils, toxic metals, and pesticides including radioactive materials and heated effluents that impose thermal loading on receiving waters. Only 209 of India's 3119 towns and cities have even partial sewage systems and treatment facilities (Mukherjee, 1999). Consequently many urban rivers have steadily deteriorated in quality although on a national scale ambitious projects have been started to reverse this trend. The status of urban sanitation at the end of the eighth five year plan is given in the Table 2.

Table 2. Status of urban sanitation (as on 31.03.97, Shukla, 1999)

Percentage population provided with sewerage and sanitation facilities		
Sewer (%)	On-site Sanitation (%)	Total (%)
28.21	21.11	49.32

Wastewater management is a serious problem in major cities of our country. The amount of water, which gets into an urban centre's system finally empties out as sewage and drainage water. These pollute both surface and subsurface water resources in the region. Figure 11 indicates the status of the wastewater generation and its treatment in 6 mega cities in million litre per day.

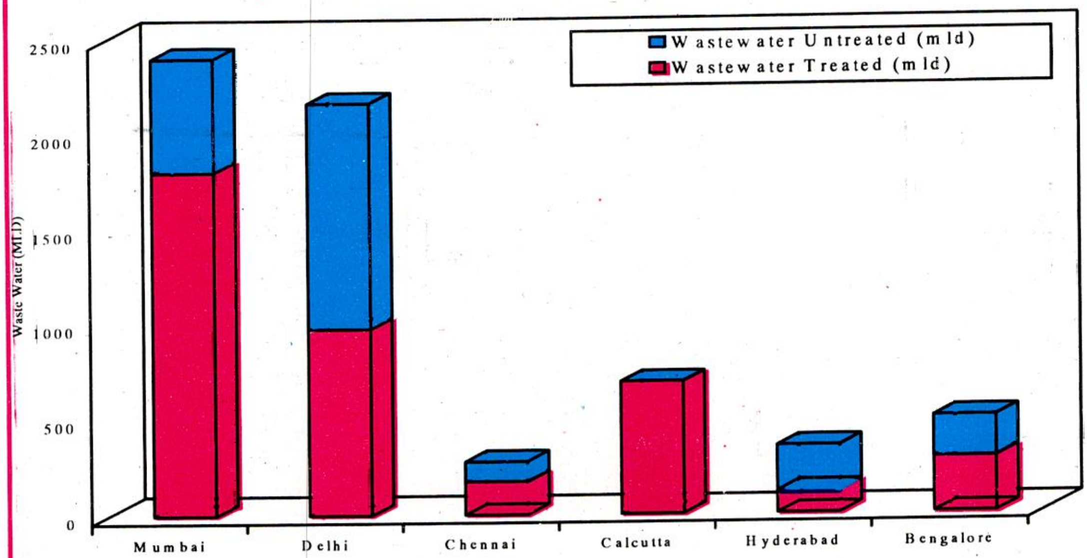

Figure 11: Wastewater management in the mega cities (Shukla, 1999)

A very huge quantity of solid waste is generated by the Indian cities and it is estimated that only sixty percent of it is collected. The uncollected solid waste fills open space, drains and roads and it is a major cause of the insanitary conditions and diseases. The scenario of solid waste management in 6 mega cities (in mt/day) is shown in Figure 12.

7.0 COMMON URBAN HYDROLOGY MODELS

Several researchers have proposed and developed mathematical model for estimation of runoff from non-linear reservoirs in an urban drainage basin. These models are as follows:

RRL : (Road Research Laboratory Method and Illinois Simulator) an urban runoff model that utilise the time -area runoff routing method. It was developed in England and described by Watkins 1962. The technique was developed specifically for the analysis of urban runoff and ignores completely all pervious areas and all impervious areas that are not directly connected to the storm drain system; hence estimates of peak flow rates and runoff volumes are likely to be low.

SWMM : (Storm Water Management Model) A very widely accepted and applied storm runoff simulation model was jointly prepared by Metcalf and Eddy 1971,

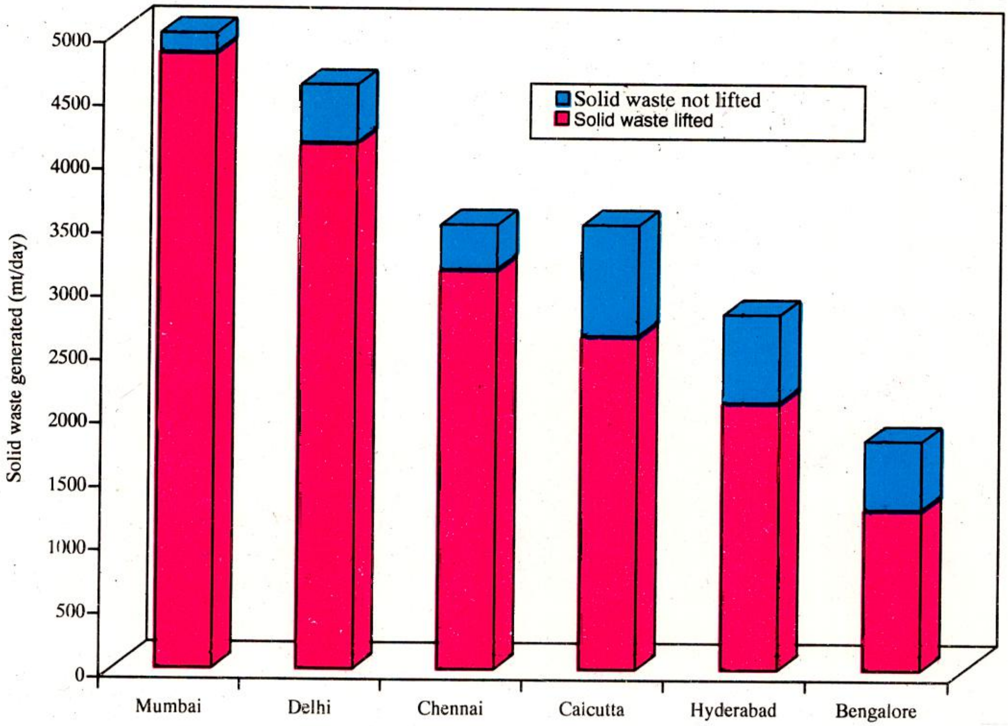

Figure 12: Solid waste management in mega cities (Shukla, 1999)

Inc., the University of Florida, and Water Resources Engineers for use by the U.S. Environmental Protection Agency (EPA). This model was designed to simulate the runoff of a drainage basin for any predescribed rainfall pattern. The total watershed is broken into a finite number of smaller units or subcatchments that can be readily described by their hydraulic properties.

ILLUDAS : (Illinios Urban Drainage Area Simulator) developed by Terstriep and Stall (1974). This model is an improved version of RRL that has a wider range of capabilities. It incorporates the impervious area neglected by RRL and is a demonstrated improvement over RRL.

UCURM : (University of Cincinnati Urban Runoff Model) This model is developed by the Division of Water Resources, the Department of Civil Engineering, of the University of Cincinnati in 1972. It is similar to EPA model and divides the drainage basin into subcatchments whose flows are routed overland into gutters and sewers pipes. Starting at the upstream inlet, the flows are calculated in successive segments of the sewer system, including discharges from inlets, to produce the total outflow.

EDI-QUAL-I : is developed by Willis, Anderson and Dracup (1975) and the modelling procedure consists of breaking up the riversystem into reach and routing the governing over each reach and finally determining initial concentration of conservative and nonconservative constituents for each reach.

HEC-1 : (Flood Hydrograph Package) is designed for the simulation of flood events in watersheds and river basins. Similar model has been developed by Kidd, (1978); Falk and Niemczynowicz (1979) to simulate rainfall-runoff, which are applicable on small, impermeable urban catchments.

HYROM : developed by the Institute of Hydrology (1989), is designed to produce hourly estimates of streamflows from hourly catchment rainfall and potential evapo-ration derived from meteorological data using the Penman formula.

GIUH : Gupta (1983) and Bhatacharya (1995) have developed similar numerical models for simulation of rainfall-runoff processes in urban catchments.

FLAPS : (1995) is developed for rainfall-runoff simulation that considers system both as a lumped or distributed system.

The above mentioned models have been practised by many researchers over the years and they are improving gradually by introducing one or more effective parameters.

8.0 INTEGRATED URBAN WATER MANAGEMENT PROGRAMME OF IHP-5

The International Hydrological Programme of UNESCO in the fifth phase (1996-2001) focussed on Hydrology and Water Resources Development in a vulnerable environment covering 8 themes. In theme 7, integrated urban water management covered with following aims:

- To improve the management of existing urban drainage system through an integrated approach;
- To disseminate knowledge on integrated urban water management;
- To analyse the effectiveness of non-structural flood control measures such as: flood warning systems, flood plain zoning, flood plain insurance and relocation in reducing damages as an alternative to structural measures (contribution to IDNDR through pilot projects);
- To identify the impact of urbanisation on surface and ground water quality through point and non-point pollution;

- To establish experimental urban catchments and to create a world-wide data base for comparative urban hydrology studies concerning megacities as an extension of the FRIEND approach;
- To create access to available technology for developing countries through the establishment of regional centres of excellence in different climatic zones;
- To study impacts of storm water (wastewater discharges) on ecosystem health of receiving water courses in all parts of the world;
- To assess feasibility of drainage source controls designed to replicate the natural hydrology of area as closely as possible;
- To consider the need of urban inhabitants for reasonable land use.

The proposed plan of the 6th phase (2002-2007) is focussed on water interaction - systems at risk and social challenges. The urban hydrology area is covered under theme 3 and it has the following main aims and activities:

- To address the processes and strengthen research into urban water systems interactions in particular climate regions;
- To develop and apply appropriate modelling tools for analysis of interactions;
- To create conditions for multidisciplinary interactions, appropriate transfer of knowledge and technology and for running training programmes for water managers, urban planners and sanitary specialists, in connection with Theme 5;
- To search for low cost technology for brackish water reclamation.

Activities:

- Efforts for urban water demand management under scarcity conditions;
- Acquisition of remotely sensed data-particular needs of urban areas in arid and semi-arid regions;
- Study of water re-use in human settlements;
- Study on urban groundwater problems;
- Consideration of urban sedimentation management-interaction of water, sediment and solid waste;
- Perspectives of urban runoff harvesting;
- Detailed water balance study in urban areas;
- Study of the aquatic habitats in urban areas of the humid tropics;

- Acquisition and processing of high resolution (terrain and land use) data for urban water needs and urban water data (reliability, robustness, availability);
- Hydrological, biological and chemical processes in urban water environment for sustaibnable cities of the future;
- Development of urban water amenities systems (urban ponds, enclosed water bodies, coastal areas);
- Development of innovative techniques for integrated urban water modelling;
- Hydrological processes (surface, underground and receiving water) in urban areas under wintry conditions;
- Interactions of urban water sub-systems under wintry conditions;
- Performance of source control, urban amenity and urban ecological habitats system under wintry conditions;
- Modelling of urban water interactions in cold climate regions.

GENERAL REMARKS

With the growth of the population and increase in industrial development activities, there is general tendency of shifting of population from rural to urban areas. The planning, development and management of urban settlements have to keep pace with this scenerio and take necessary measures for supplying water, sanitation and waste disposal facilities. As the gap between demand for services and availability is quite significant, there is rise in density of slums and squatter settlements, which have neither sewerage, nor adequate storm water drainage and often inadequate water supply. Such, often unplanned growth of urban townships and mega cities poses threats to both the availability and quality of surface water and groundwater resources.

The management and control of water quality within large urban catchments demands an integrated and interdisciplinary approach involving engineers, scientists, ecologists and planners. Forecasting environmental risks and the design of mitigating measures to reduce them is, however, prone to much uncertainty due to factors such as extreme spatial variability of land use, land cover, the heterogeneity of the geologic materials and difficulties associated with the description and parameterisation of the coupled flow, transport and chemical transformation processes involved. An interdisciplinary perspective with proper understanding of fundamental principles and ecological awareness, as well as changes in attitudes to water resource exploitation and pollution are necessary if sustainable urban development is to be achieved.

VS

There is need for increasing development and application of scientific modelling approaches for urban hydrology studies, to consider various present and future scenerios for ensuring proper, sustainable development and management of urban areas.

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