STATUS OF DEVELOPMENTS IN URBAN HYDROLOGY

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ABSTRACT

At present cities in India are booming. Internal growth and migration from rural to urban areas has been putting immense pressure on the administration and management. The rapid increase of urbanisation is emerging as a major challenge for all concerned with planning and development. The main objective of this paper is to present the status of urban hydrology and to highlight some of the hydrological problems related to urbanisation in India. This paper includes the trends of urbanisation, issues and challenges in urban hydrology and discussion on impact of urbanisation on climate, stream flow and urban water management. Some information on available urban hydrological models and the recommendations for the management of urban areas is also included.

1.0 INTRODUCTION

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). 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. 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 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 often become waste receptacles, subject to increasing flow volumes and effluents harmful to both quality and ecology.

1.1 Trends of urbanisation

The world growth of urbanisation over the years is logarithmic. In more developed countries, about 75% of the population is concentrated in urban areas. The average population increases between 1960 and 1990 was 75%, but in Asia where growth is fastest, the populations increased by 158% and in Africa by about 135%. Urban growth in developed countries is linear, but exponential in less-developed countries, as shown in Figure 1. About half of the world's population lives in cities today. Projection shows that by the year 2001 the number of city dwellers will be twice as large as the rural population.

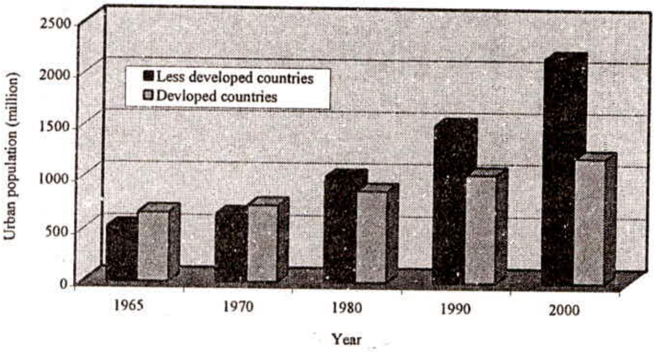

Fig. 1 : Urban population in world from 1965 to 2000 (Niemczynowicz, 1996)

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 are 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 predominantly rural nation. Urban population growth trend in India is shown in Figure 2, with projected figures of population for the years 2001, 2011 and 2021. 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.

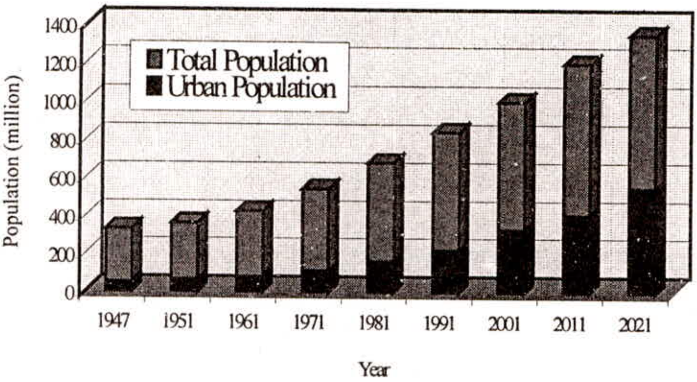

Fig. 2: Urban population in India (Suresh, 2000)

1.2 Issues and Challenges

Various authors have dwelt on major hydrological issues and challenges of urbanisation.

Major hydrological issues of urbanisation are as follows:

- 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
- Need for integrated land use and catchment planning.

Major hydrological Challenges in urban water management are as follows

- 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.

The rapid process of urbanisation in India is a challenge for administrators, planners 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. 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. Chances to solve these complex problems of urbanised cities depends on economic and social prerequisites of the host country. In developing countries, urban populations and accompanying problems grow fastest. A large part of the population lives in slum and squatter areas in bad sanitary conditions, poverty, and misery. In these countries, the priorities for economic development and investment are for food, shelter, clothing, health and education. Urban drainage is generally not taken into consideration except when it affects significantly any of the above factors, particularly as a part of the more general problem of flooding of urban areas. As many of the important cities of India are on the banks of rivers and are subject to flooding, drainage of urban areas and riverine flood control are generally interlinked. The proposals for urban drainage improvements such as in the Delhi Metropolitan area, Lucknow, Patna etc., can be attributed to such a linkage. Because of financial limitations and because urban drainage problems constitute "negative goods," very little attention has been paid in India to urban drainage.

Storm Water Management Model (SWMM), developed by the US Environmental Protection Agency, is a typical package of models linked together and divided into a number of blocks. It is a comprehensive model covering both quantity and quality aspects. However, it is unwieldy to apply in Indian hydrological conditions. Design of urban drainage system in India is based on rational formula, because of lack of adequate continuous records of precipitation and stream flow (UNESCO, 1978). Ramaseshan (1983) has also reported that the urban hydrological problems of India differ from those of developed countries in several important points such as lateral rather than vertical development, limited amounts of paved area, initial interaction between urban drainage and flood control, preference for open drains over closed ones, limited availability of continuous records of precipitation, stream flow and water quality, limited number of sewer connections and hence shifting of combined sewer, high cost of construction and modification and limited capacity of financial investment. The urban drainage index adopted in urban storm water runoff modelling of Rohini, Delhi was 3.5 cumec/sq. km with 35 mm/hr rainfall intensity with once in two years recurrence interval. Since the rate of urbanisation in Rohini is expected to increase from 55 % to 84 %, the urban drainage index needs to be modified to 5.5 cumec/sq. km (Chakraborti, 1989).

2.0 IMPACT OF URBANISATION

2.1 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.

2.2 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 results 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.

Impervious area : Depending on the percentage of land use, urbanisation may be classified into 4 categories viz. Rural; Early urban; Middle urban and 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.

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 will percolate and low flow will decrease. In addition, the volume of waterborne wastes increases. Therefore, the quality of storm water runoff deteriorates. Contaminants are washed away from roofs, streets and roads. Soluble particles go into solution and particulate matters are dislodged. 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 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;

2.3 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.

3.0 URBAN WATER MANAGEMENT

In the previous section, the adverse impacts of the quality and quantity of storm water due to urbanisation have been described. Proper urban storm water management (USM) is necessary to tackle these problems. Urban storm water management includes 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.

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 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 throughout 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.

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, the 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. 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 vide Storm Water Masterplan (Hall, 1984). Such a plan considers all impacts of Storm Water runoff and its management.

3.1 Storm Water Masterplan

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

- Definition of Goals and Objectives : This step 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.

4.0 COMMON URBAN HYDROLOGY MODELS

Simulation models are useful in the analysis of complex drainage systems where storage, pumping, silting and quality control are involved, and hence in the economic design of complex drainage systems. The type of drainage systems simulation model that is suited to urban areas in developing nations needs to be identified, and computer programs suitable for applications need to be developed. Other mathematical models may also need investigations. Several researchers have proposed and developed mathematical model for the estimation of runoff from non-linear reservoirs in an urban drainage basin. Some such 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, 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 river system into reach and routing the governing over each reach and finally determining initial concentration of conservative and non-conservative 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.

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

The above mentioned models have been used by many researchers over the years and are being improved further. Particularly, greater emphasis is being laid on non-point source pollution modelling and management.

5.0 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 processes of urban settlements have to keep pace with this scenario 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.

There is need for increasing development and application of scientific modelling approaches for urban hydrology studies, to consider various present and future scenarios for ensuring proper, sustainable development and management of urban areas. The environmental sustainability criteria for urban areas and their capacity to support water development populations has to be systematically examined, studied and simulated, so as to evolve suitable criteria for development.

REFERENCES

Bhattacharya, D.N., (1995), Development of numerical GIUH model for simulation of rainfall-runoff processes in Indian catchments..Phd thesis, IIT, Kharagpur.

Davis, K., (1965), "The Urbanisation of the Human Population", *Scientific Am.*, 213(3), 40-54.

Falk,J and Niemczynowicz, J (1979), Modelling of runoff from impermeable surfaces.Dept of WRE, Lund Institute of Technology, University of Lund.

Gupta, V. K. and Waymire, E. (1983), On the formulation of an analytical approach to hydrologic response and similarity at basin scale., J. Hydrology, 65, 95-123.

Hall, M. J., (1984), Urban Hydrology, Elsevier Applied Science Publishers, New York.

Kidd, C.H.R. (1978), Rainfall-Runoff processes over urban surfaces. Proceedings Internal workshop, Institute of Hydrology, Wallingford, UK

Lazaro, T. R. , (1990), Urban Hydrology, Technomic Publishing Co. Inc., Lancaster.

McPherson, M. B., (1974), Hydrological effects of urbanisation, UNESCO PRESS, Paris.

Niemczynowicz, J. (1996), "Megacities from a water perspective", Water International, Vol. 21, No. 4, pp 1-14.

Niemczynowicz, J. (1999), "Urban hydrology and water management- present and future challenges", Urban Water, Vol. 1, pp 1-14.

Savani, J. and Kammerer, J. C., (1961), Urban Growth and the Water Regimen, US Geological Survey Water Supply Paper No. 1591-A, 43.

Suresh, V., (2000), Integrated Water Management for Urban Areas, National Seminar on Rain Water Harvesting, Vigyan Bhawan, New Delhi.

Viessman, Jr., John, W. Knapp, Gary, L. Lewis and Terence E. Harbaugh, (1977), Introduction to Hydrology, Harper & Row, Publishers, New York.