Effects of Increasing Urbanization on River Basins- State of Art

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Abstract

Rapidly changing demography has brought tremendous change in the land use and land cover patterns of the river basins. Increasing urbanization in the river basin is followed by a number of serious impacts on the health of the river basin system. Alteration in the hydrology and geomorphology of the streams as well as the deterioration of its water quality are the most detrimental effects identified due to urbanization. This paper reviews the various effects of urbanization on river basins, methods to assess these effects and the existing research gaps in the field of study. The changing river basins provide opportunity for the river basin planners, engineers and ecologists to study the cause-effect relationship between urbanization and river basin. This may help for further research and better river basin management.

Keywords: *Eutrophication, Impervious surface cover (ISC), Remote sensing, River basin, Urbanization*

1. Introduction

Due to movement of people from rural to urban areas, physical growth of the urban areas occurs, which ultimately leads to the urbanization. River basins throughout the world are suffering from anthropogenic pressures like urbanization, industrialization and population growth resulting into river basin changes. Any natural system like river basin is elegant in its own way. All the biotic and abiotic components of a natural system interact with each other and the study of these interactions is called ecology. Therefore, stress on any component disturbs the entire system. A land area drained by its rivers and its tributaries is called a river basin. River basin helps to maintain the water cycle. They are also helpful in sustaining human as well as other forms of life and resources. Most of the population throughout the world lives on various river basins. Therefore, changes in river basin due to anthropogenic activities require extensive research.

The major factor responsible for unprecedented growth of cities is uncontrolled in-migration of people from rural areas to big cities. People migrate in search of employment, food, and modern amenities to have a better life. Natural resources are limited and demands of the increasing population are also increasing. This results in gradual depletion of the natural resources. Over urbanization and poor management of the natural resources is deteriorating the quality of the natural river basin environment. Urban development is associated with the land use transformations, degradation of the water quality of rivers, increased flooding, and disturbance in the natural river basin ecology. Flooding disasters in mega cities like Mumbai floods in 2005 and Delhi floods 2010 left a lesson that the encroachment of a natural drainage system for developmental purposes may result a threat to urban life. Some of the important effects of urbanization on a river basin are summarized below:

1) Deforestation and catchment degradation in the river basins.
2) Increased erosion of soil due to increased surface runoff.
3) Increased silting and sedimentation of the rivers.
4) Alterations in the hydrology due to increasing imperviousness of the catchment area i.e. modifications in aquatic ecosystem.
5) Severe water scarcity in the river basin.
6) Environmental pollution.
7) Declined water quality of rivers.
8) Morphological alterations of the rivers and extinction of the river channels.
9) Unpredictable local climate.

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10) River fragmentation and flow regulation in rivers.
11) Over exploitation of the natural resources.
12) Changes in ecosystem processes and stability.
13) Frequent natural disasters like floods and droughts.
14) Habitat and community modifications.
15) Biotic homogenization and biodiversity loss in a river basin ecosystem.
16) Loss of aesthetic value or recreation.

Sustainable development in a river basin requires the knowledge of the interrelations between urbanization, river basin ecosystem and climate. It also requires the knowledge of the instruments and techniques available for better planning and management of a river basin. It is required to regularly monitor, manage and preserve urban river basins to control their degradation. Collection of data related to river basin with available sophisticated tools and techniques as well as preparation of integrated river basin management plan may help as a control strategy to reduce degradation of urban river basins.

2. Effects of urbanization on river basins

Effects of urbanization on river basins can be broadly categorized into three types: physical effects, chemical effects and biological effects. Landscape comprises of built-up areas, open vegetative spaces, water bodies, natural or anthropogenic elements. Urbanization is rapidly changing the landscape composition. Some of the major physical effects of urbanization on urban streams are alterations in hydrology of the river basin along with changes in geomorphology and temperature of the rivers. Landscape changes such as converting open vegetative spaces into Impervious Surface Cover (ISC) influences the regional hydrology of a river basin. This leads to the problems like water scarcity, water quality deterioration, basin closure and occurrence of frequent floods in the region. There are several studies done which state that a decrease in the perviousness of the catchment to precipitation impairs important soil functions like decrease in infiltration property of the soil and an increase in surface runoff, which may lead to the disturbance in the water balance and reduction of ground water recharge in the river basin [8] [17]. Due to soil sealing during precipitation Lag time shortens in urban catchments and modifications in the storm water drainage systems results in floods, which peak more rapidly [16]. Another significant effect of urbanization is the alteration of the stream flow. Some base flow is required in the river basin for its proper ecosystem functioning. Montana method is used to calculate the ecological base flow of a river basin. Some studies reveal that base-flow decline by as much as 20% with only small changes in perviousness of soil. [29] [33]. Over exploitation of the water resources of the basin to meet the increasing anthropogenic water demands results a basin closure [11].

Anthropogenic activities in the basin alter the river morphology [14]. These changes occur due to changes in the following factors: river morphometry, flow pattern, sedimentation, and siltation property of rivers. Urban development increases river sediment production and deposition within channels. This is followed by increased river bank erosion which widens the channels. Construction of dams, land-use changes throughout the basin, and construction of flood defence structures change the river system behaviour [3]. Recently, a number of studies have been done to understand effects of global warming on aquatic ecosystems. It may be associated with deterioration of river water quality through eutrophication of rivers [23]. Urbanization increases water temperature by directly discharging heated water from furnaces of industries into the rivers or by adding surface water runoff during summers. It is found to increase the microbial activity in river water [4]. Warming of the water enhances the algal growth in spring and is responsible for phytoplankton mortality in late summer [1].

Chemical effects of urbanization are due to increased loading of nutrients, metals and organic contaminants into the river water. Chemical properties of the urban rivers get altered due to municipal and industrial discharges. Direct dumping of garbage into the river and addition of harmful chemicals from agricultural runoff also contributes to the river pollution. Urban rivers are characterized by presence of organic pollution, salinity, total suspended solids, heavy metals, nitrate, organic micro-pollutants, acidification, eutrophication, complete death of the river inhabitants due to high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), and storage of heavy metals such as lead in the river [19]. Urban land uses are positively correlated with the decline in the water quality [32]. Eutrophication causes increased COD and BOD of the urban river water which leads to the death aquatic organisms like fishes. Urban rivers are facing serious water pollution problems. One remedial measure can be recycling of organic matter within communities [1]. Presence of metals such as Cu

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and Zn in the river water are indicators of anthropogenic pollution. Others metals are Hg, Ca, Cr, Ni, Co, K, Mg, Na, Fe, Al, Mn, Cu, and Zn and Pb [4]. These metals may have adverse effect on the biogeochemistry of the river environment [21]. Runoff from urban areas during precipitation and floods add the highly toxic organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), and faecal coliform bacteria in the river water. This may lead to the mortality of the aquatic organisms and diseases such as cancer in the human beings [5] [6].

Changes in the natural habitat of native flora and fauna of river basins, biodiversity loss and impairment of ecosystem functions are the biological effects of urbanization on river basins. Changes in landuse patterns reduce species richness and decrease ecosystem stability. Benthic macro-invertebrates and fishes act as indicators to give the relationship between urban development patterns and ecological conditions in the basins [15]. River provides habitat for the several groups of organisms. Biotic homogenization problem is a very important effect found in urban rivers. Biotic homogenization is the increase in the similarity of species over time. It is mainly caused by the replacement of native species with foreign / introduced species. It causes the migration or extinction of native species [10] [20]. Urbanization induced landuse changes effect the ecosystem processes such as primary productivity, leaf decomposition, nutrient cycling and ecosystem structure of the urban rivers. Effects of urbanization on ecosystem processes are required to be explored [30].

3. Methods and tools to study effects of urbanization on river basins

There are various methods to study urban river basins, their quality, disturbances in their ecosystems either nature induced or anthropogenic. The conventional methods used for such studies are: Biological indicators and Mathematical models. There are numerous types of indicators being used to detect the health of river basin or its processes. Especially biological indicators have been used well to predict the status of river basin health because they are extremely sensitive to the environmental changes whether nature induced or anthropogenic. Macro-invertebrates, fishes and mussels are highly sensitive to physico-chemical changes of the quality of the river water [15]. Eutrophication is another phenomenon which is an indicator of poor water quality of the river. Besides the biological indicators, few metals act as anthropogenic indicators like Cu and Zn. They are found in polluted urban rivers along with other metals such as Hg, Cr, Al, Ca, K, Na, Fe, Mg, Mn, Cu and Zn [7].

Models can be used to study all the physical, chemical and biological aspects of river basins. The models use various complex mathematical algorithms for modelling and analysis. Few examples are: Patuxent Landscape Model (PLM), General Ecosystem Model (GEM), Stochastic Dynamic Methodology (StDM) Model, Mesoscale hydrological models (Catchment Models) and Eco-hydrological models like EPIC, etc. They are used to study and model the effects of landuse changes on eco-hydrological parameters of a river basin [9] [12]. One-dimensional Transport with Inflow and Storage (OTIS) modelling package and Mathematical Material Flow Analysis (MMFA) help to understand the solute transport behaviour of river sediments to detect changes [22] [27]. (Hydrological Simulation Program—Fortran (HSPF) and urban growth model (LEAMluc) are used to predict stream flow in response to urbanization. One-dimensional unsteady state flow model (UNET)- HSPF model give daily flow simulations of a river for better prediction of flood-peak occurrence time.

Storage, treatment, overflow and runoff model (STORM) and storm water management model (SWMM) studies the dynamics and long term simulations of urban runoff for river flood management. The variables used in these models are LULC type, runoff, flow regimes, % imperviousness, meteorological input data like rainfall, temperature, solar radiation, channel geometry, soil moisture, flood frequency, drainage patterns, water physio-chemical parameters etc. These models may help to understand the flooding in the river basins, increase in the surface runoff due to imperviousness, and changes in the river flow patterns [24] [26] [31]. Thus, the models are efficient assessment tool for urban river basin management.

Using conventional methods such as biological indicators include in-situ observations which are tedious and time taking. It is very difficult to predict sources of problem and future impacts. Study of a global phenomenon is also very difficult using conventional methods. Besides all the uses of models in studying an urbanized river basin, there are some drawbacks in using models to study urban river basins. A river basin is a very complex system having numerous variables and various dynamic processes involved in space and time. First drawback in studying a river basin with mathematical models involves

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solving complex and huge equations. Also, deriving conclusions is not easy and takes lots of time and efforts. There is no single mathematical model known which can define all the problems together and predict the dynamics of an urban river basin. Sometimes two or more models are required to be integrated to understand a single process [22] [31] [34]. The accuracy of the result depends upon the type of model used, parameters or variables considered, sensitivity of a model to a particular parameter, methodology followed for analysis, assumptions, and expertise of the observer. Therefore, it is very much susceptible to human biases and errors.

To keep an eye on the health of a river basin, regular monitoring of the changes and developmental activities in a river basin is required. Nowadays, availability of a wide variety of sensors such as air borne sensors and space borne sensors has helped to provide temporal and spatial data in different resolutions. Therefore, Remote Sensing and GIS have emerged as a modern and very efficient tool to collect the information on a river basin. With these tools it has become very easy to analyse, store and manage the data but with few limitations. Satellite observations have the advantage of global coverage, better sampling, easy to map unreachable areas, homogeneous quality, and fewer chances of human biases and instrumental errors. Remote sensing data are reliable, repetitive in collection, having digital mode, easy storage, economical, and time saving. But remote sensing has few disadvantages such as their limited spatial and temporal resolution.

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Several satellite sensors having low spatial resolutions to high spatial resolutions are available for river basin studies. High resolution satellite data provided by satellites such as IKONOS, Quickbird, Catosat-1 provide lots of information about an area in large scale. Medium resolution satellites such as MODIS, INSAT, Landsat, etc. though having medium spatial resolution but provide good temporal resolution and better coverage over an area. Few river basin parameters which can be studied using satellite remote sensing and GIS based models are Land use land cover (LULC), Impervious surface cover, Surface runoff, Infiltration, Ground water recharge, Soil moisture, Stream flow, Vegetation, Net primary productivity (NPP), Drainage morphometry, etc. [13] [28] [35]. In a study multi-date Landsat TM-5 imagery along with aerial photography called the Geographic Information Retrieval and Analysis System (GIRAS) has been used to quantify effect of land use land cover (LULC) change on the river basin environment [2]. In a study, information such as surface geology, DEM, Landsat TM images, historical river flow data, precipitation and temperature data from weather stations has been used as input in a Distributed Rainfall–Runoff model to understand the relationship between runoff over the catchment and river flow [18]. Not only optical remote sensors but Synthetic Aperture Radar (SAR) images from multi-temporal L-band JERS-1 and C-band ERS-1 satellites integrated with GIS have been used to model the potential of flood inundation within the river flood plains [25].

4. Existing research gaps

One of the major problems in urban river basin management is inadequate knowledge about the factors influencing river basin due to urbanization. The following research gaps were observed during the study:

1) Interaction between hydrology and geomorphology of an urban river basin requires research.
2) Further research is required to study the effect of decrease in soil water on the temperature of urban land surfaces and air temperature to understand its link to climate change.
3) Tropical regions have a strong sedimentological response because of the heavy rainfall and highly weathered soils. Effects of urbanization on river basins of tropical countries are to be explored more.
4) One interesting problem is to map and predict the self-purification capacity of the whole river network of a river basin.
5) Some future investigations are required on questions such as how do the different types of urban surfaces affect runoff and sediment production?
6) A better eco-hydrological modelling system should be developed for river basins.
7) Quantification of water pollution from the diffuse pollution sources like that from agricultural and urban runoff is required to be done for urban streams.
8) Ecological disturbances of urban river basins are to be explored more. What are ecological responses to the disturbances caused due to urbanization?
9) The improved estimation of net primary productivity (NPP) to be done.
10) Options of better river basin management for sustainable development are to be explored.

5. Conclusion

Urbanization in the river basins is unavoidable due to rapid population growth. The landscape related transformations have significantly changed the river system. Urbanization induced changes in the hydro-geomorphology of the streams as well as the water pollution are the most consistent and harmful effects of urbanization on river basins. Inadequate knowledge of the factors affecting river basins and their inter-relationships are the major research areas to be explored. Remote sensing and GIS may serve as wonderful aids to collect the information on the study area and then to store this data for further analysis to monitor status of river basins. Therefore, an integrated river basin management (IRBM) strategy is required to be made for a river basin severely affected by urban sprawl.

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