Effects of Urbanization on River morphometry: A case study for Nag River Urban Watershed using Geomatics Approach

Pinak Ranade*, Y.B. Katpatal**

* Center for Development of Advance Computing (C-DAC), Pune University Campus, Pune – 411 007 (M.S), India Tel: +91-20-25503241, pinakranade@rediffmail.com

** Department of Civil Engineering, Vishveshwarya National Institute of Technology (VNIT), Ambazari Road, Nagpur – 440 010 (M.S), India

Key Words: Urban watershed, Basin, Drainage, River channel, Remote sensing

Abstract

Urbanization is responsible for the unexpected environmental degradation, which in turn has resulted in resource scarcity and damage to the towns and cities surroundings. Besides urbanization, the successive economic activities also exert tremendous pressure on the available limited natural resources. Especially in developing countries such as India, heavy urbanization has converted vast stretches of agricultural lands into built-up area, roads and other impervious surfaces, which obstructs water to get absorbed into the surface (UNEP 2000)

It is estimated that 75% of pollution loads of all the rivers in India is due to urban wastewater. Nagpur is one of the fastest growing urban city with multitude of problems cropping up over the period of time. The severity of the problem can be understood by the fact that growing urbanization has changed the morphometry of Nag River. In this case study for Nag River urban watershed, remote sensing & GIS technologies are utilized to understand the impacts of growing urbanization on the river morphometry.

Introduction

The study area is a part of Nag River watershed which lies between 21°07'- 21°10' N and 78°59'- 79°10' E. The study area covers the Nag River flowing from its origin in the eastern side of Ambazari Lake to Punapur village till it meets Pili River. For most of the course, the river traverses through Nagpur city urban area. (Nagpur Gazetteer)

For this case study, Nag river urban watershed has been selected, since the term "urban watershed" comes into picture. While studies on rural watersheds has been well taken care in many researches in the past, very less work has been done on urban watershed in Indian context. In such scenario of the growing urbanization in Indian cities, the water resources (surface & ground water) are facing the maximum pressure resulting in either water scarcity in summers or flooding due to heavy rainfall.

Also the factors affecting the urban watershed are precisely man-made features apart from other factors such as population increase, concrete encroachment of land, population pressure on existing resources, garbage dump in rivers (river pollution) etc. Turning of rivers into nallahs (heavily polluted streams) is affecting the watershed at micro-level, which indeed affects the sub-watershed of the river (Naomi et. al.). Nag river watershed is one such dynamic urban watershed, which has undergone a dramatic change in its morphometric characteristics in last few decades. It offers a good study environment to understand all the parameters & factors affecting an urban watershed in Indian context.

Methodology

Indian Remote sensing (IRS-1C) data is mainly used for the study, which is having a spatial resolution of 23.5 m for LISS III image (Fig. I) & 5.8m resolution for PAN image. Apart from this, requisite Survey of India (SOI) toposheets on the scale of 1:50,000 were used to prepare the base map of the study area.

Survey of India (SOI) toposheets & IRS-1C (LISS III & PAN) satellite images were georeferenced with UTM – WGS 84 (zone 44) projection and the required Nag river urban watershed was extracted based on the drainage pattern along with its tributaries and the contours.

Features extraction for contours, drainage pattern etc. was carried out from Survey of India (SOI) toposheets (1976). Then data fusion was performed on IRS – 1C (2003)

LISS III & PAN images to get a better high resolution image from which features of interest such as drainage pattern of Nag river & its tributaries were extracted. Finally a drainage analysis with emphasis on comparative study was carried out to understand the impacts of growing urbanization on the morphometry of Nag River.

Drainage analysis

The Nag river urban watershed area forms a part of Godavari river basin and Kanhan river sub basin, while topographically the area in general is gently sloping. The streams of the Nag River urban watershed area are dendritic to sub dendritic in pattern and are originating in western part of the area.

Morphometry

Development of drainage is the result of climate, lithology, structure and geomorphic processes. Occurrence of ground water and its recharge also depend on these factors. Defining the basin or watershed in quantitative term also help in understanding their functional relationship with runoff.

Basin order and stream order

The order of basin is the order of its highest-order stream. The Nag river urban watershed basin is of fourth order. For ordering the various streams in the basin, Horton - Strahler ordering scheme has been adapted. The orders of various streams and their lengths are computed and summarized in table I.

Number of streams and their orders

The number of stream channels of each order is expressed by a mathematical relation known as Horton's law of channels numbers, in which numbers of streams channels of each order from an inverse geometric sequence with order number.

$Nw = R\,b\,(W- w)$……………. (1)

or $\log Nw = W\log Rb - w\log Rb$……… (2)

or $\log Nw = a - bw$…….(3)

In which $a = w \log Rb$

$B = \log Rb$

Nw = numbers of streams of order w

W= order of the basin

w= order of the basin

Rb = bifurcation ratio

And

$Rb = Nw/ N\,(w+1)$…………. (4)

This fourth order basin has a drainage area of 76.11 sq. Km. Fourth order represents the highest order of the stream in the basin. Ordering of basin shows that there is 1- fourth order stream, 3 - third order stream, 14- second order streams and 55-first order streams. Following relationship has been established for the basin:

$\log Nw = 2.590-0.652\,w$ (Where, Nw is number of streams of order w)

Bifurcation ratio (Rb)

The number of streams in each order is counted for the basin and bifurcation ratio, a relationship between the number of streams of one order to that of the number of streams in the lower order are computed.

According to Strahler (1952) the value of bifurcation ratio, higher than five, indicates structural control over the drainage network. In 1976, the average values of bifurcation ratio (Rb) for Nag river urban watershed fourth order basin was 5.46, which indicates complete structural control of the fracture zone over the Nag river drainage network. While in 2003, the average value of the bifurcation ratio (Rb) for Nag river urban watershed is 4.29, which indicates that only some portions of the major streams are controlled by the lineaments / fractures.

The change in bifurcation ratio (Rb) may be attributed to the growing urbanization, population pressure and lessening of existing land cover in the Nag river urban watershed. This average value of bifurcation ratio (Rb) indicates that on an average, there are about 4.29 times as much number of streams of any given order as that of the next higher order.

Length ratio

Length ratio is the ratio of the mean length of the stream of the next lower order. The variation in the values of the length ratio, for different stream orders within a basin indicates the relative permeability of the surface contributing to the drainage network of the basin.

The length ratio for Nag river urban basin has been calculated and presented in table III, which shows the length ratio for the Nag river urban basin for first, second, third and fourth order basin. It is evident from the values for Nag river urban watershed basin (1976) that the length ratio for the third order stream is higher than the length ratio for the streams of the other order. While the values for Nag river urban watershed basin (2003) indicate that the length ratio for the fourth order stream is higher than the length ratio for the streams of the other order. This fact indicates the permeable nature of the geological formation through which the third order / fourth order streams flow.

Similarly, when the length ratio of Nag river lower and upper basin were compared for 1976 & 2003, it is observed that very high length ratio 7.24 was noticed for the III order stream of Nag river lower basin (1976) as compared to 4.06 in 2003 which indicates that III order stream of Nag river lower basin was flowing through more permeable strata than of the III order stream of 2003 basin.

It is also seen from the table III that the average length of III order stream of Nag river lower basin is longer (9.5 Km - 1976) than the average length of III order stream of the lower basin (4.41 Km – 2003). Similarly, the average length of III order stream of Nag river upper basin is longer (4.14 Km - 1976) than the average length of III order stream of the upper basin (1.95 Km – 2003).

Drainage density [Dd]

Drainage density is defined as the total stream length cumulated for all orders in a basin to the total area of the basin. The drainage density is the measure of the texture of the drainage basin. Lithology, infiltration capacity, vegetative cover, climate, runoff etc. are the major controlling factor of the drainage density.

In bedrock areas, drainage textures and patterns depend among other factors, on the lithologic character of underlying rock and their structural disposition. Fine textured (high density) drainage over flat areas may lead to the inference that the underlying strata are impermeable and favorable for high runoff and erosion, thereby indicating poor infiltration possibilities.

The drainage density for the Nag river urban basin has been calculated and presented in table III, which shows that the drainage density values of Nag River Urban basin was high (1.12 km/km2 –1976), while it reduced to moderate (0.95 km/km2 –2003) which indicates its medium texture. Tendency of ground water contribution to the stream flow decreases with the increasing drainage density. The high value of drainage density in the study area for Nag river basin (1976) indicates moderate permeability and moderate relief for the area, while the moderate value for 2003 indicates more permeable zone.

Form factor [Ff]

The form factor is the ratio of basin area to the square of basin length. The form factor for the Nag river urban basin has been calculated and presented in table III, which indicates that the value for the Nag river upper basin has varied from 0.22 (1976) to 0.23 (2003), while the value for the lower basin has varied from 0.19 (1976) to 0.20 (2003) and the form factor for the entire basin has been found to be 0.183.

Shape factor

Shape factor is the ratio of basin length to the basin area. A square drainage basin would have a shape factor [Sf] =1, whereas the long narrow drainage basin would have a shape factor [Sf]>1. If a basin is long and narrow, then it will take longer for water to travel from basin extremities to the outlet. A compact basin is more likely to be covered by the area of maximum rainfall intensity of local streams.

The shape factor for the Nag river urban basin has been calculated and presented in table III, which indicates that the value for the Nag river upper basin has varied from 4.45 (1976) to 4.34 (2003), while the value for the lower basin has varied from 5.25 (1976) to 4.91 (2003) and the shape factor for the entire basin has been found to be 5.46, which indicates an almost compact elongated basin.

Circularity ratio [Rc]

The circularity ratio of basin is to the area of a circle having the same perimeter. The circularity ratio for the Nag river urban basin has been calculated and presented in table III that indicates that the values for circularity ratio vary from 0.41 to 0.51. The circularity ratio for the entire basin is found to be 0.41.

Elongation ratio [Re]

Elongation ratio is the ratio between the diameters of the circle having same area as that of the basin to the maximum length of the basin. The values of elongation ratio calculated for Nag river basin are tabulated in table III, which shows the variation from 0.49 (1976) to 0.51 (2003) for the Nag river lower basin, while it varies from 0.53 (1976) to 0.54 (2003) for the upper basin and the elongation ratio for the entire basin has been found to be 0.48. The values for circularity ratio and elongation ratio are more equal for lower basin and upper basin; this indicates the seasonal tend towards elongated shape.

Compaction coefficient

Compactness coefficient for a drainage basin is the ratio of basin perimeter to the perimeter of circle of basin area.

The compactness coefficient for the Nag river basin has been calculated and presented in table III, which shows that the values for compactness coefficient vary from 1.57 (1976) to 1.58 (2003) for the Nag river lower basin, while it varies from 1.40 (1976) to 1.41 (2003) for the upper basin and the same is found to be 1.57 for the entire basin.

Constant of channel maintenance [C]

The constant of channel maintenance [C] is the inverse of drainage density. In general, the constant of channel maintenance increases with the size of the basin. The constant of channel maintenance for the Nag river basin has been calculated and presented in table III, which indicates that the constant of channel maintenance for the entire basin has varied from 0.9 (1976) to 1.05 (2003).

The comparative values for Nag river basin indicates that 1.05 sq. Km (2003) area is required to support one km length of stream as against 0.9 Sq. Km. (1976) respectively. The relatively higher value of constant of channel maintenance for Nag river basin (1.05 Sq. Km) indicates more permeable geological strata.

Stream frequency [F]

Stream frequency is the ratio of the total number of stream of all orders with in a given basin to the area of the basin. The stream frequency for the Nag river basin has been calculated and presented in table III, which indicates that the stream frequency ratio for the entire Nag river basin has changed from 0.94 (1976) to 0.96 (2003). The lower stream frequency for Nag river basin (0.96 / km2) indicates a gentle gradient and more permeable surface.

Length of overland flow [Lg]

As the rain falls on a drainage-basin surface, it flows down the slope towards a channel; the maximum length of this surface flow is called the "length of overland flow". The average length of overland flow is approximately one-half the average distance between stream channels. Since drainage density is the function of infiltration characteristics of drainage basin, it must be the length of overland flow.

The length of overland flow for the Nag river basin has been calculated and presented in table III, which indicates that the values for the entire Nag river basin has changed from 0.45 (1976) to 0.52 (2003). This value indicates slope of the channels and surrounding area is gentler in this basin.

Results & Conclusions

The cities grow with the migration of population from rural surroundings in search of fulfilling their food and other domestic needs, resulting major stress on the infrastructure. Hence their settlement and water supply in urban area is always one of the major concerns to the local civic authorities. Also, due to growing pressures and the complexities involved, little attention is paid during the city planning and respective management processes. (Sharifi 2002)

From the drainage analysis performed, It can be concluded that the morphometry of Nag River has been substantially altered in last 27 years; the major points of concern are the decrease in upper basin & lower basin area of Nag river, which in turn has resulted in the reduction of Nag river stream length by approx. 12 Km (Table II). Also, it has been observed that the ill-planned urban sprawl of Nagpur city has almost changed the Nag river basin and the sub-basins have changed most of the river morphometric properties.

Finally it can be concluded that Urbanization has caused an irreversible impact on Nag river natural drainage pattern and its flow impacted by the urban development. It is assumed that within the next few decades, more than 50% of India's population would be living in urban areas. Quality of life of majority of India's population depends on the existing environment within the cities. If development progresses in a planned manner, the adverse impacts on population and river properties can be minimized.

References:

1. *Cohn J. Naomi, Voices of the Watershed, A Guide to Urban Watershed Management Planning, Illinois Environmental Protection Agency, ISBN-10: B0006R71M2, 1999*
2. *How Can We Manage and Use Our Freshwater Resources in an Environmentally Sustainable Manner? - The Watershed: Water from the Mountains into the Sea, Newsletter and Technical Publications, Lakes and Reservoirs vol. 2, UNEP 2000*
3. *Nagpur Collectorate > Gazetteer > Contents > Physical Features*
4. *Shariffi M.A, Integrated Planning & Decision Support Systems for sustainable Watershed Development, Resource Paper – Study Meeting on Watershed Development, Tehran, October 2002*