International Journal on Emerging Technologies **8**(1): 196-201(2017)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

River Water Quality Modelling For the Assessment of the Impact of Urbanization

Kosha Amish Shah and Geeta S. Joshi
Civil Engineering Department, Faculty of Technology and Engineering, The M.S. University of Baroda, Kalabhavan,Vadodara 390001,

(Corresponding author: Kosha Amish Shah)
(Received 27 December, 2016 accepted 16 January, 2017)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: The surface water bodies are under a continuous threat due to growth of urbanization and industrialization. As urbanization increases, water quality is impaired. In this study, two models have been used, namely, Water Quality Index model, which is a measure to assess the status of quality of a surface water body and Urbanization index model, which is a measure to assess the urbanization level of the station located on the river. A Water Quality – Urbanization Regression model (WQURM) for assessing the impact of urbanization on the surface water quality and for predicting the river water quality for the future growth of Urbanization has been developed. The WQURM model formulated is applied on the Sabarmati river basin, India. The results show that with the increase in urbanization levels of the station, its water quality deteriorates with a linear pattern.

I. INTRODUCTION

In developing countries, cities are growing the fastest (UNEP). Urbanization affects the surface water quality. Growth of urbanization without proper planning causes water quality deterioration in the downstream reaches of the nearby streams or river. Water Quality – Urbanization Regression model (WQURM) for assessing the impact of urbanization on the surface water quality and for predicting the river water quality for the future growth of Urbanization is developed in the basin. The WQURM model formulated is applied on the Sabarmati river basin, India.

II. METHODOLOGY

In this study, the Water Quality Index model and Urbanization Index model is used to develop the Water Quality – Urbanization Regression model (WQURM). The application of WQURM model is demonstrated on Sabarmati river basin.

A. Water Quality Index model

Water Quality Index is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues (Tyagi *et al*, 2013). It is found from the study of various literatures that the Water Quality Index measurements are based on five types of WQI aggregation functions: (Horton, 1965; Brown et al.,1970; Helmer & Rescher,1959; Dalkey & Helmer, 1963; Brown et al.,1972; Bhargava et al. 1998; Dwivedi et al., 1997; Dee et al.,1973; McClelland, 1974; Walski and Parker,1974; Bhargava, 1983; Landwehr et al., 1976; Dinius, 1987; Dojlido et al., 1994; Walsh & Wheeler, 2012; Khan *et al*.,2003; Lumb *et al*., 2006; Smith, 1987).

a) arithmetic aggregation function **b)** multiplicative aggregation function **c)** geometric mean **d)** harmonic mean and **e)** minimum operator.

The Water Quality Index model developed in this study is a modified version the index given by Tiwari and Mishra in terms of deriving the weightage of each parameter. A rating scale is developed as shown in table 1.The basis of selection of the ranges of concentrations of each parameter in rating scale is in accordance to the water quality criteria for various uses of fresh waters laid down by Central Pollution Control Board (CPCB, India). Where the CPCB criteria are not available, other standards such as European Community Standards and criteria given by researchers across the world have been used.

The Water Quality Index model (Shah & Joshi, 2015a) used in this study is based on the weighted arithmetic mean method. The limits of parameter (Si) are selected as limits in class 2 of the rating scale. The weighing factor of each parameter is calculated and shown in table 2.

Table 1: Rating Scale.

Parameters	Range				
Class	***1***	***2***	***3***	***4***	***5***
pH	7-8.5	8.5-8.6 6.8-7.0	8.6-8.8 6.7-6.8	8.8-9.0 6.5-6.7	> 9.0 < 6.5
DO (mg/l)	> 6	5.0-6	4.0-5	3.0-4	< 3
BOD (mg/l)	0-3	3.0-6	6.0-80	80.0-125	> 125
Electrical conductivity (micromhos/cm)	0-75	75-150	150-225	225-300	> 300
Nitrate Nitrogen (mg/l)	0-20	20.0-50	50.0-100	100-200	> 200
Total Coliform MPN/100 ml	0-5	5.0-50	50-500	500-10000	>10000
Extent of pollution	Clean	Slight	Moderate	Excess	Severe
Vr	**100**	**80**	**60**	**40**	**0**

Table 2: Water quality parameters and their assigned Weighing factors.

Parameter	S_i	Weightage ($1/S_i$)	Weighing Factor (K/S_i)
pH	8.5	0.118	0.165
DO	5	0.200	0.281
BOD	6	0.167	0.234
Electrical Conductivity	150	0.007	0.009
Nitrate Nitrogen	50	0.02	0.028
Total Coliform	5	0.2	0.281
∑ (1/Si)		0.711	
K=1/Sum(1/Si)		1.407	

Water Quality Index is the sum of product of rating value (Vr_i) and Weighing factor (W_i) of all the parameters.

$$\mathrm{WQI} = \sum_{i=1}^{n} (\mathbf{W_i} \times \mathbf{Vr_i})$$

B. Urbanization Index Model

The degree or level of urbanization is defined as relative number of people who live in urban areas.

In the study, the development of Urbanization Index model consists of two steps:

1. Development of Urbanization Index of districts.
2. Development of Urbanization Index of catchment of the station under consideration on the river.

Formulation of Urbanization Index model (Shah & Joshi, 2015b) is based on four multi - dimensional aspects of Urbanization, namely, demographic, economic aspect, spatial & infrastructural development aspect. Under the four aspects identified, nine indicator parameters of Urbanization are selected namely, population size, population density, number of Industries, percentage of built- up area, roofing types, electricity facilities, educational facilities, availability of health services and assets (i .e. T V, computer/ laptop, telephone/mobile phone and scooter/car.) have been used. Using the Urbanization Index model (Shah & Joshi, 2015b) developed, the urbanization index of the various districts can be evaluated. The station on the river which is under consideration for the assessment of water quality and urbanization will lie in a district. But the urbanization of that district may not specify the urbanization of that station because it is not the district that contributes the inflow to that station but it is the catchment area that contributes to the inflow to the station. Therefore, there is a need to develop a methodology to evaluate the urbanization status of the catchment area of the station.

The overall composite index of the catchment of the station cannot be determined by taking simply an average of the Urbanization Index of the various districts lying in the catchment of the Station.

There are two possibilities:

1. A1: The entire district falls in the catchment of the Station.
2. A2: A portion of district falls in the catchment of the Station.

There are again two possibilities:

1. B1: Only one district falls in the catchment of Station.
2. B2: Multiple districts fall in the catchment of Station.

The methodology for the determination the overall composite Urbanization Index of the Station is detailed below:

1. For the Case A1 B1, i.e, the entire district falls in the catchment of the Station (A1) and only one district falls in the catchment of Station (B1), the catchment of the Station forms the boundary of the district. Here, the Urbanization Index of the district is the Urbanization Index of the Station.

2. For the Case A1 B2, i.e, the entire district falls in the catchment of the Station (A1) and multiple districts fall in the catchment of the Station (B2). Here, the average of Urbanization Index of all districts is taken as Urbanization Index of the station.

3. For the Case A2 B1 i.e, a portion of district falls in the catchment of the Station (A2) and only one district falls in the catchment of Station (B1). For this case, the Urbanization Index of the catchment of the station is in proportion to the ratio of area of the district falling in the catchment to the area of the district. Urbanization Index of the catchment of the station is given by equation (1)

$$\mathbf{UI_k = UI_j \times \frac{a_{j,k}}{A_j}} \quad (1)$$

Where, UI_k= Urbanization index of the catchment of the station k , j = district , k = station, A_j = Area of the district j , $a_{j,k}$ = Area of the district portion j lying in the catchment of the station k.

4. For the Case A2 B2 i.e, a portion of district falls in the catchment of the Station (A2) and multiple districts fall in the catchment of Station (B2). The Urbanization Index of the catchment of the station is the weighted average of the Urbanization Index of the portions of the multiple districts.

The Urbanization Index of the catchment of the station is shown by equation (2)

$$\mathbf{UI_k} = \sum_{j=1}^{N} \left(\frac{\mathbf{UI_j \times a_{j,k}}}{\mathbf{A_j}} \frac{\mathbf{\times a_{j,k}}}{\mathbf{A_k}} \right) \mathbf{X\ N} \quad (2)$$

where, UI_k= Urbanization index of the catchment of the station k , j = district , k = station, N= Total no. of district portions in the catchment of the station, A_j = Area of the district j,

$a_{j,k}$ = Area of the district portion j lying in the catchment of the station k, A_k = Area of the catchment of station k.

C. Water Quality - Urbanization Regression Model (WQURM)

The Water Quality-Urbanization Regression model (WQURM) to predict the quality status of surface water body for an estimated Urbanization level of the location can be developed. Regression model can be established from the Water Quality Index computed using Water Quality Index model and the Urbanization Index obtained using the Urbanization Index model.

III. APPLICATION OF THE MODELS ON STUDY AREA OF SABARMATI RIVER BASIN

The models are applied on the Sabarmati river basin in India. Five stations have been selected in the Sabarmati river basin. These five stations have been selected on the river Sabarmati and its tributaries. The stations located on the Sabarmati River and its tributaries: are listed as follows:

1. Station-1 (S_1) –Sabarmati river at V. N Bridge, at Ahmedabad city located in Ahmedabad district.
2. Station-2 (S_2) -Shedhi tributary of Sabarmati river at Kheda city located in Kheda district.
3. Station-3 (S_3)- Sabarmati river at Kheroj bridge at Sabarkantha district in Khedbrahma Taluka, located at latitude 24.23085°N & longitude 73.01773°E.
4. Station-4 (S_4)- Sabarmati river at Miroli village, Dascroi Taluka, Ahmedabad district located at latitude 22.8660°N & longitude 72.5145°E.
5. Station- 5 (S_5) - Hathmati tributary of Sabarmati river at Mahudi Jain temple, Mansa Taluka, Gandhinagar district located at latitude 23.5138°N & longitude 72.7361°E.

A. Data base for Water Quality

Water quality quarterly concentration for the parameters, pH, Dissolved oxygen, BOD, Electrical Conductivity, Nitrate nitrogen and Total Coliform for the stations S_1, S_2, S_3, S_4 and S_5 has been collected for the present study from year 2005 to 2011 from Gujarat Pollution Control Board, Gandhinagar.

B. Data base for Urbanization level

Data base for parameters for measurement of Urbanization level are collected. District-wise records of households by main source of lighting, number of households having specified assets, census houses by predominant material of roof, Population size, Population density are collected from Census of India, 2011. District-wise data base of number of Industries in Gujarat , India is collected from Vibrant Gujarat, Government of Gujarat. Land Use, Land cover pattern, district-wise in Gujarat is collected from National Remote Sensing Centre (NRSC), Hyderabad, India.

IV. RESULTS AND DISCUSSIONS

A. Water Quality Index model

The quarterly water quality index are obtained using Water Quality Index model developed in this study for the stations, S_1,S_2, S_3, S_4 & S_5 from year 2005 to 2011. The average water quality index is computed. The results of Water Quality Index obtained using the Water Quality Index model developed in the study is shown in table 3.

Table 3: Results of Water Quality Index of the stations.

Station	**Water Quality Index**
S_1	48.7
S_2	76.4
S_3	79.8
S_4	38.1
S_5	80.6

B. Urbanization Index model

The results of Urbanization Index for the districts under study obtained using the Urbanization Index models are shown in table 4.

Table 4: Results of Urbanization Index for the districts under study

Districts	Urbanization Index of districts
Ahmedabad	84.44
Kheda	40
Sabarkantha	36.67
Mehsana	46.67
Gandhinagar	56.67
Banaskantha	31.11

C. Urbanization Index of the catchment of the stations

To determine the Urbanization Index of the catchment of the each station, the watershed map of the Sabarmati river basin is referred. Watershed map of Sabarmati river basin with stations under study is shown in figure 1. Districts and watershed map of Sabarmati river basin with stations under study is shown in figure 2. From figure 1 & 2, for station S_3, it is observed that the catchment area of this station consists of watershed no. 1, 2, 3, 4, 5 & 6. Urbanization Index obtained as 7.7.

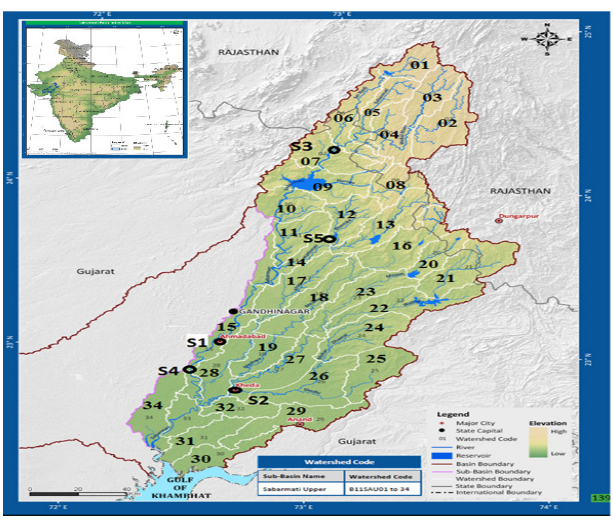

Fig. 1. Watershed map of Sabarmati river basin with stations under study.

Urbanization Index for the catchment area of Stations S_5 and S_2

The station S_5 is lying on the tributary of Sabarmati river i.e. river Hathmati. From figure 1, for station S_5, it is observed that the catchment area of this station consists of watershed no. 12 & 13. For station S_2, it is observed that the catchment area of this station consists of watershed no. 24, 25 & 26. So case A2 B1 is applicable and equation (1) is used for computation of Urbanization Index of station S_5 and station S_2.

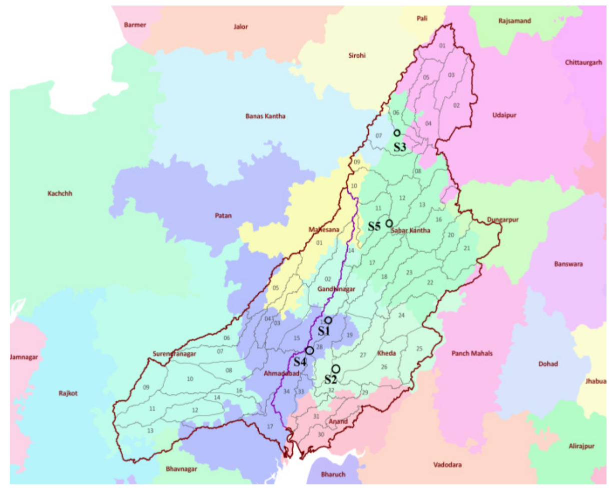

Fig. 2. Districts and Watershed map of Sabarmati river basin with stations under study.

Urbanization Index for the catchment area of Stations S_1 and S_4

From figure 1 & 2, for station S_1 and S_4, it is observed that the catchment area of these stations consists of watershed no. 1 to 15. These watersheds (i.e. catchment of station S_1 and S_4) are falling in various districts. So case A2 B2 is applicable and equation (2) is used for computation of Urbanization Index of station S_1 and station S_4.

Results of Urbanization Index of the catchment area of the stations are shown in table 5.

Table 5: Results of Urbanization Index of the catchment area of the station.

Station	Urbanization Index of the catchment area of the station
S_1	70.46
S_2	29.2
S_3	7.7
S_4	74.43
S_5	4.4

D. Water Quality - Urbanization Regression model (WQURM)

In the present study, to develop the Water Quality-Urbanization Regression Model, various regression types are considered for fitting, namely, exponential, logarithmic, power and linear. The best fit curve/line is determined from all the above regression types by computing the sum of square of error.

The regression showing the least sum of square of errors is selected as the best fit curve and the corresponding equation defines the Water Quality - Urbanization Regression Model (WQURM). Table 6 shows sum of square of error obtained for the different regression types. From table 6, it is observed that the Linear regression shows the least sum of square of error and R^2 = 0.94. Figure 3 shows the Water Quality- Urbanization Regression Model (WQURM) plot developed for the Sabarmati river basin.

Table 6: Sum of Square of Error for different types of Regression.

Sr. No.	Type of Regression	Regression Equation	2	Sum of Square of Error
1.	Exponential	**$y = 89.042\ e^{-0.01x}$**	.91	166
2.	Logarithmic	**$y = -13.48\ \ln(x) + 106.42$**	.76	378.8
3.	Power	**$y = 125.06\ x^{-0.227}$**	.72	491.8
4.	Linear	**$y = -0.5737x + 86.084$**	.94	99.4

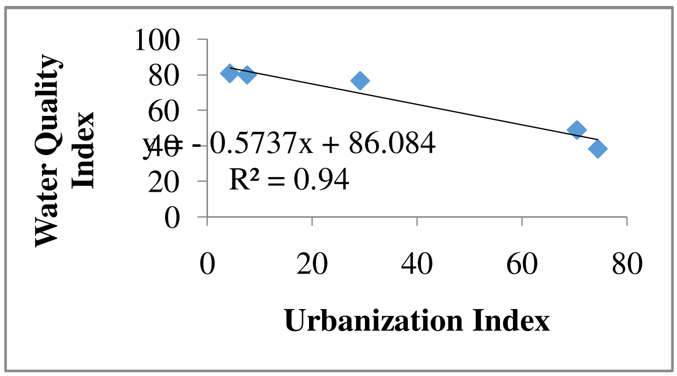

Fig. 3. Water Quality- Urbanization Regression Model (WQURM) plot.

The WQURM linear mathematical model is **$y = -0.5737x + 86.084$**

Where, y = Water Quality Index of the station, x = Urbanization Index of the catchment area of the station. R^2= 0.94 shows a high degree of correlation between the Water Quality Index and Urbanization Index. The trend of the linear Regression line shows a negative correlation between the two parameters. The trend of the regression line shows that as the urbanization increases, the water quality deteriorates with a linear pattern.

V. CONCLUSION

The paper has presented the methodology to measure the influence of urbanization on surface water quality in a scientific and quantitative method using various water quality and urbanization indicator parameters. The Water - Quality Urbanization Regression Model (WQURM) is developed to assess the impact of Urbanization on the river water quality and to predict the Water quality of a river for a future growth of urbanization. The application of Water Quality - Urbanization Regression Model (WQURM) is demonstrated on the Sabarmati river basin. The WQURM model can be generated for any river to predict the river water quality for a future growth of Urbanization, using the methodology formulated in the present research. Based on the predictions of status of water quality, policies can be proposed by policy makers and/ or government regulatory bodies to promote the urbanization processes in a scientific manner so as to curb the water deterioration problems and carry out sustainable economical development without affecting the quality of surface waters.

REFERENCES

[1]. Bhargava, D. S., (1983). Use of a Water Quality Index for River Classification and Zoning of the Ganga River, *Environmental Pollution (Series B),* **6**, pp 51-67.

[2]. Bhargava, D. S, Saxena, B. S., and Dewakar, (1998). A study of geo-pollutants in the Godavary river basin in India, Asian Environment, IOS press, pp 36–59.

[3]. Brown, R.M., McClelland, N.I., Deininger, R.A. and Tozer, R.G., (1970). "Water quality index-do we dare?", *Water Sewage Works*, **117**(10), pp 339-343.

[4]. Census of India, (2011). Directorate of Census Operations, Ministry of Home affairs, Government of India.

[5]. CPCB, ADSORBS/3: 1978–1979. Scheme for Zoning and Classification of Indian Rivers: Estuaries and Coastal Waters.

[6]. Dalkey, N. C., & Helmer, O., (1963). An experimental application of the Delphi method to the use of experts. *Management Science,* **9** (3), pp 458-467.

[7]. Dalkey, N. C., 1968. DELPHI, The Rand Corporation.

[8]. Dee, N., Baker, J., Drobny, N., Duke, K., Whitman, I. and Fahringer, D.,1973. 'An environmental evaluation system for water resource planning', *Water Resour. Res.,* **9**(3), pp 523–535.

[9]. Dinius, S. H., (1987). 'Design of an index of water quality', *Water Res. Bull*., **23**(5), pp 833–843.

[10]. Dojlido, J., Raniszewski, J. and Woyciechowska, J.,1994. 'Water quality index-application for river in Vistula River Basin in Poland, *Water Sci. Technol*., **30**(10), pp 57–64.

[11]. Dwivedi, S., Tiwari, I. C., and Bhargava, D. S., (1997). Water quality of the river Ganga at Varanasi, Institute of Engineers, Kolkota, **78**, pp 1–4.

[12]. Helmer, O., & Rescher, N., (1959). On the epistemology of the inexact science. Management Science, **6**, pp 25-53.

[13]. Horton, R. K., (1965). An index number system for rating water quality, *Journal of Water Pollution Control Federation*, **37**(3), pp 300–306.

[14]. Indian Standard Specification for Drinking Water (Second revision) IS-10500-2012, Bureau of Indian, New Delhi, Gr. 6.

[15]. Khan F, Husain T, Lumb A, (2003). Water quality evaluation and trend analysis in selected watersheds of the atlantic region of Canada, *Environ Monit Assess*, **88**(1): pp 221–248

[16]. Landwehr, J. M. and R. A. Deininger, (1976). "A Comparison of Several Water Quality Indices." *Journal of the Water Pollution Control Federation*, **48**(5), pp 954-958.

[17]. Lumb A, Halliwell D, Sharma T, (2006). Application of CCME water quality index to monitor water quality: a case of the Mackenzie River basin, Canada. *Environ Monit Assess,* **113**, pp 411–429

[18]. McClelland NI, (1974). Water quality index application in the Kansas River Basin. EPA-907/9-74-001. US EPA Region VII. Kansas City, MO

[19]. Shah K. A & Joshi G. S., (2015a). Evaluation of water quality index for River Sabarmati, Gujarat, India , Appl Water Sci, Springer, DOI 10.1007/s13201-015-0318-7.

[20]. Shah K. A & Joshi G. S., (2015b). Development of Urbanization Index Model using Multi-dimensional approach, *Asian Journal of Research in Social Sciences and Humanities,* **5**(1): 128-139, DOI 10.5958/2249-7315.2015.00010.6.

[21]. Smith RA, Alexander RB, Wolman MG, (1987). Analysis and interpretation of water-quality trends in major U.S. rivers, 1974–81. U.S. Geological Survey Water-Supply Paper, 2307

[21]. Tiwari, T. N. and Mishra, M., (1985). A preliminary assignment of water quality index to major rivers. *Ind J Environ Protect*. 5: 276.

[22]. Tyagi S, Sharma B, Singh P, Dobhal R, (2013). Water quality assessment in terms of water quality index. *Am J Water Resources* **1**(3): pp 34–38

[23]. Walsh P, Wheeler W, (2012). Water quality index aggregation and cost benefit analysis. U.S. Environmental Protection Agency, Working Paper, pp 12-05

[24]. Walski TM, Parker FL, (1974). Consumer's water quality index, *J Environ Eng ASCE* 100: pp 593–611

[25]. WHO, (1992). GEMS/WATER Operational Guide. Third edition. World Health Organization,Geneva.