Chapter 3

Development of Water Quality- Urbanization Regression (WQURM) model

3.1 Introduction

Cities in developing countries are growing the fastest (UNEP). Urbanization affects the water quality. The surface water bodies are under a continuous threat due to growth of urbanization and industrialization. As urbanization increases, water quality is impaired due to the high anthropogenic activities, illegal discharge of sewage and industrial effluent, lack of proper sanitation, unprotected river sites and urban runoff .Thereby, the surface water is unable to support a human use, such as drinking water, or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. There is a need to develop a model to assess the impact if urbanization on the surface water quality and thus to predict the water quality status of a surface water body for future growth of urbanization. The model can act as a decision support system for the urban development authorities to plan a sustainable urbanization growth of a city.

3.2 Methodology

The methodology evolved to develop Water Quality Urbanization Regression model in the research study is shown in the flow diagram, Figure 3.1 and Figure 3.2

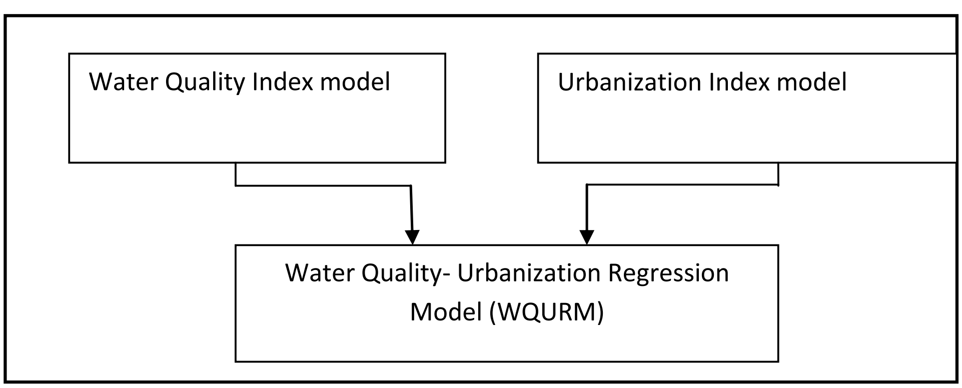

Figure 3.1 Concise Schematic diagram of Methodology of Water Quality- Urbanization Regression Model (WQURM)

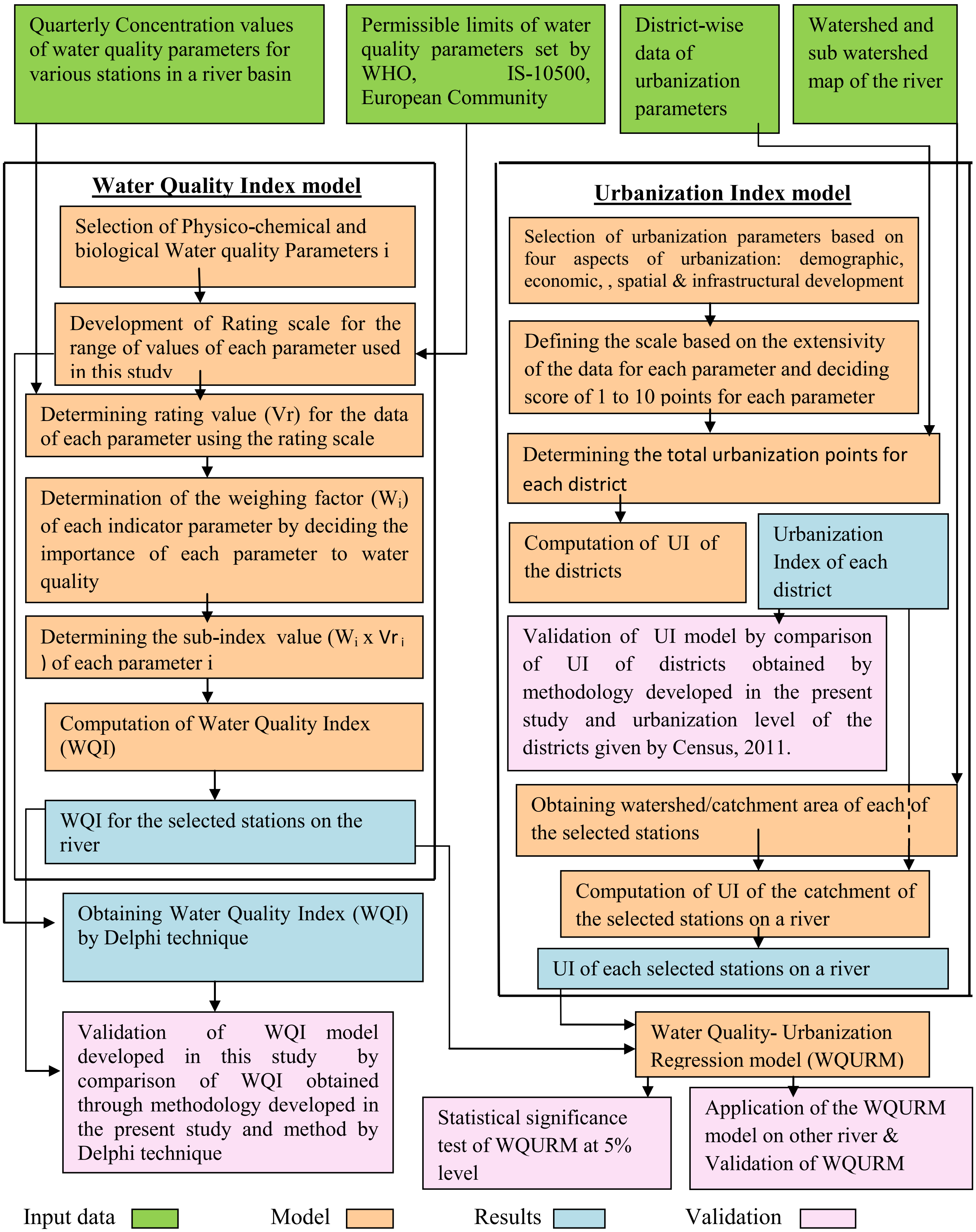

Figure 3.2. Detailed schematic diagram of Methodology of Water Quality- Urbanization Regression Model (WQURM) formulated in this study

3.2.1Water Quality Index model

3.2.1.1 Introduction

In this study, for the formulation of the Water Quality Index model, the weighted arithmetic mean method is used.
The advantages of weighted arithmetic mean method used in this study are (Tyagi et al. 2013).

1. This method incorporates data from multiple water quality parameters into a mathematical equation that rates the health of water body with number.
2. Less number of parameters required in comparison to all water quality parameters for particular use.
3. Useful for communication of overall water quality information to the concerned citizens and policy makers.
4. Reflects the composite influence of different parameters i.e., important for the assessment and management of water quality.

3.2.1.2 Selection of parameters for Water Quality Index model formulation

Water quality assessment often examines the effects of specific activities on water quality. Typically, such assessment is undertaken in relation to effluent discharges, urban or land run-off or accidental pollution incidents. (Chapman, 1996)

3.2.1.2.1 Sewage and municipal wastewater

Municipal wastewaters consist of sewage effluents, urban drainage and other collected wastewaters. They usually contain high levels of faecal material and organic matter. Therefore, to assess the impact of such wastewaters it is advisable to measure parameters which are indicative of organic waste such as BOD, COD, chloride, ammonia and nitrogen compounds. If the wastes contain sewage, then faecal indicators are also important. (Chapman, 1996)

3.2.1.2.2 Urban run-off

Rivers running through, or lakes adjacent to, large urban developments are inevitably subjected to urban run-off during periods of heavy rain. In some cities, rain water is collected in drains and directed through the sewage collection and treatment facilities before discharge to the river or lake. In other cities, rainwater is channelled directly into the nearest water body. Even where urban run-off is collected in the sewerage system, excessive rainfall can lead to an overload which by-passes the sewage treatment plants. Parameters associated with urban run-off are largely the same as those selected for municipal wastewater. (Chapman, 1996).

3.2.1.2.3 Agricultural activities

Impacts relating to agricultural activities principally concern organic and inorganic matter (such as arising from intensive animal rearing and land run-off associated with land clearing) and those chemicals incorporated in fertilisers and pesticides. Irrigation, especially in arid areas, can lead to salinisation of surface and groundwaters and, therefore, inclusion of conductivity, chloride, alkalinity, sulphate, fluoride and sodium is important in water quality assessment programmes in these areas. (Chapman, 1996).

The significant water quality variables to be selected for the assessment of water quality with respect to the three kinds of pollution sources namely, Sewage and municipal wastewater, Urban run-off and Agricultural activities are as follows. (Chapman, 1996).

1. General parameters : Suspended solids, Electrical Conductivity, Dissolved Oxygen
2. Nutrients: Ammonia, Nitrate/ Nitrite, Organic Nitrogen, Phosphorus
3. Organic Matter: Biochemical Oxygen Demand
4. Microbial Indicators: Faecal Coliform

3.2.1.3 Input parameters for the Water Quality Index model

Since the objective of water quality assessment in the present study is to assess the influence of urbanization and urban activities on the river water quality, the input water quality parameters for the Water Quality Index model are selected for each of the above mentioned category, namely, general, nutrients, organic matter and microbial indicators. Six physico-chemical and biological parameters namely, pH, Dissolved Oxygen (DO), biochemical Oxygen Demand (BOD), Electrical Conductivity (EC), nitrate nitrogen and total coliform are the input indicator parameters of surface water quality in the Water Quality Index model developed in the study. The significance of each parameter is discussed below:

3.2.1.4 Effect of water quality parameters on water quality

3.2.1.4.1 Effect of pH

The pH is a measure of the acidic or alkaline conditions of the water. When the water is used for drinking purpose, the pH level of the water has an important effect on all body chemistry, health and disease because human body consists of 50–60 % water. The pH level of our body fluid should be in the range 7–7.2. If pH is less than 5.3, assimilation of vitamins or minerals is not possible; hence, it should be above 6.4. If pH is greater than 8.5, causes the water taste bitter or soda-like taste. If the pH is greater than 11, causes eye irritation and exacerbation of skin disorder. pH in the range of 10–12.5 cause hair fibers to swell. pH in the range 3.5–4.5 affects the fish reproduction. (Avvanavar and Shrihari 2008; Leo and Dekkar 2000).

3.2.1.4.2 Effect of Dissolved oxygen

The amount of DO present in surface waters depends on water temperature, turbulence, salinity, and altitude Natural waters in equilibrium with the atmosphere will contain DO concentrations ranging from about 5 to 14.5 mg O2 per liter. The DO concentration present in water reflects atmospheric dissolution, as well as autotrophic and heterotrophic processes that, respectively, produce and consume oxygen. DO is the factor that determines whether biological changes are brought by aerobic or anaerobic organisms. Thus, dissolved–oxygen measurement is vital for maintaining aerobic treatment processes intended to purify domestic and industrial wastewaters. A rapid fall in the DO indicates a high organic pollution in the river. The optimum value for good water quality is 4 to 6 mg/l of DO, which ensures healthy aquatic life in a water body (Sawyer et al. 1994; Leo and Dekkar 2000; Burden et al. 2002; De 2003).

3.2.1.4.3 Effect of biological oxygen demand

Biochemical oxygen demand (BOD) determines the strength in terms of oxygen required to stabilize domestic and industrial wastes. For the degradation of oxidizable organic matter to take place minimum of 2–7 mg/l of DO level is to be maintained at laboratory experimentation or should be available in the natural waters (De 2003).

3.2.1.4.4 Effect of total dissolved solids/electrical conductivity

Total dissolved solids (TDS) is the amount of dissolved solids (i.e., salts) in the water. TDS can be measured indirectly by measuring the EC. The more dissolved salts in the water, the more electricity the water will conduct. EC is the ability of the water to conduct an electrical current. Conductivity is important because it directly affects the quality of the water used for drinking and irrigation. Waters with higher solids content have laxative and sometimes the reverse effect upon people whose bodies are not adjusted to them and cause the water to have an unpleasant mineral taste. TDS consists of oxygen-demanding wastes, disease-causing agents, which can cause immense harm to public health. The presence of synthetic organic chemicals (fuels, detergents, paints, solvents, etc) imparts objectionable and offensive tastes, odors and colors to fish and aquatic plants even when they are present in low concentrations (Sawyer et al. 1994; Leo and Dekkar 2000). Dissolved ions affect the pH of water, which in turn may influence the health of aquatic species.

3.2.1.4.5 Effect of Nitrate Nitrogen

Excess nitrate nitrogen can cause eutrophication of surface waters due to overstimulation of growth of aquatic plants and algae. It causes anaerobic conditions in the water bodies leading to fish kills, and can even ‘‘kill’’ a lake by depriving it of oxygen. High levels of Nitrate nitrogen can cause the respiration efficiency of fish and aquatic invertebrates to lower down, leading to a decrease in animal and plant diversity, and affects use of the water for fishing, swimming, and boating. High levels of Nitrate nitrogen in water can cause serious health hazards. The acute health hazard associated with drinking water with elevated levels of nitrate occurs when bacteria in the digestive system transform nitrate to nitrite. The nitrite reacts with iron in the hemoglobin of red blood cells to form methemoglobin, which lacks the oxygen carrying ability of hemoglobin. This creates the condition known as methemoglobinemia (sometimes referred to as ‘‘blue baby syndrome’’), in which blood lacks the ability to carry sufficient oxygen to the individual body cells. Infants under 1 year of age have the highest risk of developing methemoglobinemia from consuming water with elevated levels of nitrate.

3.2.1.4.6 Effect of micro–organisms

The most common risk to human health associated with water stems from the presence of disease-causing micro-organisms. Many of these microorganisms originate from water polluted with human excrement. Human faeces can contain a variety of intestinal pathogens which cause diseases ranging from mild gastro-enteritis to the serious, and possibly fatal, dysentery, cholera and typhoid. Contamination of water bodies by animal or human excrement introduces the risk of infection to those who use the water for drinking, food preparation, personal hygiene and even recreation. (Chapman, 1996).

3.2.1.5 Development of a rating scale to obtain the rating value (Vr) for each parameter

A Rating scale was prepared for range of values for each parameter. The rating value varies from 0 to 100 and is divided into five classes in this study The rating value (Vr) = 0 implies that the concentration of the parameter in water is exceeded by the standard maximum permissible limits and water is considered to be severely polluted. The rating value (Vr) = 100 denotes the excellent water quality since the parameter remained well within the prescribed permissible limit for drinking water and water is clean. The other ratings are considered to fall between these two extremities and are Vr = 40, Vr = 60, and Vr = 80 standing for excessively polluted, moderately polluted and slightly polluted, respectively. Accordingly, 5 classes are proposed, (class 1–5). This scale is modified version of rating scale given by Tiwari and Mishra (1985). The concentrations ranges of these parameters in the given classes are defined with due consideration of standards/criteria of Central Pollution Control Board (CPCB) of India and Indian Standards (IS) 10500. For parameters and classes not included in the CPCB standards, reference is made in this study to the standards defined by other agencies. The CPCB has identified 5 "designated best uses" namely, A, B, C, D and E of water bodies as shown in Appendix III, where,

A: Drinking water (without conventional treatment but after design)

B: Outdoor bathing (Swimming pool-bathing ghat).

C: Drinking water with conventional treatment and after design.

D: Propagation wild life, fisheries (recreation and aesthetic).

E: Irrigation, industrial cooling and controlled waste disposal.

The proposed classification along with ranges of concentrations of these parameters developed in this study is given in Table 3.1. The basis for selecting the concentration levels for each of the parameters under consideration in the above classes is detailed below.

3.2.1.5.1 pH

The IS-10500 states the acceptable limit of pH as 6.5-8.5. Also, the Central Pollution Control Board (CPCB, ADSORBS/ 3/78–79), (Appendix III) has given pH range 6.5–8.5 for classes A, B, D, and E. and 6–9 for class C Considering the similar classification for pH for this study, pH ranges for classes 1–5 are allotted in increasing or decreasing geometric progression and are shown in Table 3.1.

3.2.1.5.2 Dissolved oxygen (DO)

The maximum concentration of oxygen that can dissolve in water is the function of water temperature, and therefore may vary from place to place and time to time. In India average tropical temperature is 27^{o} C. The corresponding average DO saturation concentration reported is 8 mg/l (Metcalf and Eddy, 1972). The minimum value of DO as recommended by Indian Council of Medical Research (ICMR) is 5 mg/l. Central Pollution Control Board (CPCB, ADSORBS/3/78–79), (Appendix III) has defined DO values 6, 5, 4, and 4 mg/l for classes A, B, C, and D, respectively. Considering the classification in the similar guideline for DO for this study, the DO ranges for classes 1–5 are allotted in decreasing progression and are shown in Table 3.1

3.2.1.5.3 Biochemical oxygen demand (BOD)

Reference is taken from primary water quality criteria for various uses of fresh waters laid down by the Central Pollution Control Board (CPCB) (Appendix III). The maximum value of BOD is given by CPCB as 3 mg/l for class B & C. The maximum permissible limits of BOD are not specified by other National agencies of Standards. Hence reference is made to the European Community standards. The European Community freshwater fish water quality standards specifies the Maximum admissible level of BOD is 6 mg/l, which indicates recreational use. The classes 1 and 2 in Table 3.1 are taken as per these standards in this study. The concentration ranges above this standard in this study are assigned the classes 3 and 4, as moderately polluted, excessively polluted. It is found that some excessively polluted rivers have reported the BOD values more than 100-125 mg/l and hence class 5 in Table 3.1 representing severely polluted is assigned > 125 mg/l in this study.

3.2.1.5.4 Total coliform

WHO guideline specifies coliform action level in drinking water as absent/100 ml. Hence class 1 has been given a range of total coliform as 0–5 MPN/100 ml in this study. CPCB has classified the total coliform organism count 50, 500 MPN/100 mL, (maximum) in classes A, B, respectively, as shown in Appendix III and the same has been retained in this study as classes 2 and 3, respectively. A count of 10,000 (MPN/100 mL) has been indicated as Maximum Admissible Level in European Community (EC) bathing water standards. This value is assigned to class 4 (500–10,000) in this study indicating excess Polluted water quality, making the criteria more stringent. Coliform count more than 10,000 obviously indicates severe pollution, and therefore it is considered in class 5 for this study.

3.2.1.5.5 Nitrate nitrogen

In CPCB Standard concentration 20 and 50 mg/l are given for class A and C water as shown in Appendix III. Hence a range is assigned to class 1 (0–20) indicating clean and class 2 (20–50) indicating slight pollution in this study. Nitrate nitrogen at or below 90 mg/l have no adverse effect on warm water fish (Train, 1979). Therefore, concentration range of 100–200 and >200 mg/l are considered for class 4 and class 5 of water, respectively, for this study.

3.2.1.5.6 Electrical conductivity

Since CPCB guidelines do not mention the concentration limits for class A, B, and C for the parameter Electrical conductivity as shown in Appendix III, the reference is taken from European community Standards. European community specifies guide level of 400 micromhos/cm. Hence, value >300 micromhos/cm indicates severe pollution, and therefore, it is considered in class 5. Other classes are given in geometrical progression, as class 1, 2, 3, and 4.

Table 3.1 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**

3.2.1.6 Estimating the weighing factor of each indicator parameter (W_i)

3.2.1.6.1 Weightage of each parameter

In the Water Quality Index model, there are six input parameters. For each parameter, weighing factor is evaluated on the basis of its weighing. Weighing means the relative importance of each water quality parameter that play some significant role in overall water quality. The weighing depends on the permissible limits set by National and International agencies viz., World Health Organization (WHO),Bureau of Indian standards (BIS), Indian Council of Medical Research (ICMR) etc. Those parameters, which have low permissible limits can influence the water quality to a large extent. Such parameters allocate high weighing. While parameter having high permissible limit are less harmful to the water quality, allocate low weighing.

The intended use of water is considered for this study is as per class B & C of CPCB i.e, outdoor bathing Organized (B), drinking water source with conventional treatment followed by disinfections (C). Hence the weightage is assigned with respect to class 2 of Table-3.1.

Weightage of parameter is considered to be inversely proportional to its limits in class 2 of the rating scale, i.e, Weightage of parameter i = $1/S_i$, where S_i = limits of the parameter or limits in class 2 of the rating scale.

3.2.1.6.2 Derivation of the weightage of each parameter

pH

From Table 3.1, for class-2, the limit of pH is 6.5-8.5. Hence, the maximum value of pH=8.5 is considered as a limit. i.e, Si (pH) = 8.5.

Dissolved Oxygen (DO)

The minimum value of DO as shown in Table 3.1 for class- 2 is 5 mg/l. Hence, Si (DO) = 5 mg/l

Electrical Conductivity (EC)

For deriving the Si value for EC, maximum limits are taken from class-2 of the Rating scale. Si (EC) = 150 micro mhos/cm.

Biochemical Oxygen Demand (BOD)

For deriving the S_i value for BOD, maximum limits are taken from class-2 of the rating scale. Si (BOD) = 6 mg/l

Total Coliform

The WHO guidelines for drinking water and the IS -10500 drinking water standards specifies Coliform MPN as absent /100 ml. Hence adhering to stringent limit for Total Coliform, the maximum limits is taken as 5 (MPN /100 ml) from Table 3.1. Hence, Si (Total Coliform) = 5 (MPN/ 100 ml)

Nitrate Nitrogen

From Table 3.1, Class 2, the limit of 50 mg/l is taken for Nitrate Nitrogen. Hence Si (Nitrate Nitrogen) = 50 mg/l.

3.2.1.6.3 Weighing factor of each parameter

The Weighing factor (W_i) of each parameter is inversely proportional to the permissible limits of each parameter. i.e, W_i ά 1/ S_i or $W_i = K/S_i$. (Kumar A., Dua A.,2009)

$$\text{Where, } K = 1/\sum_{i=1}^{n} 1/S_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

i.e, K = 1/ (Σ 1/S_i) = 1/ [Σ 1/S_i (pH)] + 1/ [Σ 1/S_i (DO)] + 1/ [Σ 1/S_i (BOD)] + 1/ [Σ 1/S_i (Total Coliform)] + 1/ Σ [1/S_i (Nitrate- Nitrogen)] + 1/**[** Σ 1/S_i (EC)]

Where, K = constant of proportionality, W_i = Weighing factor of the parameter & n = total number of water quality parameters

The Weighing factor computation of each parameter calculated are shown in Table 3.2

Table 3.2 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 mg/l	0.200	0.281
BOD	6 mg/l	0.167	0.234
Electrical Conductivity	150 Micro mhos/cm	0.007	0.009
Nitrate Nitrogen	50 mg/l	0.02	0.028
Total Coliform	5 (MPN/100 ml)	0.2	0.281
∑ (1/Si)		0.711	
K=1/Sum(1/Si)		1.407	

3.2.1.7 Development of the sub-index value (W_i x Vr_i) for each water quality parameter

The sub-index value is determined by multiplying its weighing factor with its rating value obtained from Table.3.1

Sub-index value of parameter i = W_i X Vr_i

3.2.1.8 Development of Water Quality Index (WQI)

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

$$WQI = \sum_{i=1}^{n} (W_i \times Vr_i) \qquad (3.2)$$

Where,

$\Sigma W_i \times Vr_i = W_i (pH) \times Vr (pH) + W_i (DO) \times Vr (DO) + W_i (BOD) \times Vr (BOD) + W_i (EC) \times Vr (EC) + W_i (Total Coliform) \times Vr (Total Coliform) + W_i (Nitrate- Nitrogen) \times Vr (Nitrate- Nitrogen) + W_i (EC) \times Vr (EC)$

The Water Quality Index designed in the study is a modified version of the index given by Tiwari and Mishra (1985). In this study the weightages derived are different than Tiwari and Mishra. Also the ranges of concentrations of each parameter rating scale derived in this sudy is based on CPCB criteria , European Community Standards and criteria given by researchers across the world, unlike Tiwari and Mishra.

The Water Quality Index determined from the Water Quality Index model evaluates the status of the quality of water numerically at the station at which the water quality parameters are measured. Higher value of WQI is indicating good water quality whereas lower value of WQI is indicating towards bad water quality.

3.2.2 Urbanization Index Model

3.2.2.1 Urbanization

Urbanization is the process by which there is an increase in the proportion of people living in urban areas. Urbanization is defined by the United Nations as movement of people from rural to urban areas with population growth equating to urban migration. There is a wide range of definitions for an 'Urban area' across the world. In many Latin American and West African countries, an urban settlement has 2000 people or more; in the US the threshold is 2,500 people; and in Italy an urban settlement has a population above 10,000 (Gupta, 2013). According to Census definition of India (2011), an urban area must have a minimum population of 5,000; 75 per cent of the male working population must be engaged in non-agricultural employment; and the population density must be at least 400 sq. Km.

Satterthwaite (2010) writes that a simple classification system adopted for the collection and dissemination of population data does not reflect the blurring of rural and urban areas, the diversity of settlements within urban and rural contexts, the increasing index and complexity of urban systems, and the new forms of urbanization that are emerging' (Hugo et. al., 2004). Therefore there is a need to re-examine the urban in its multi-dimensional concept, moving a step ahead of the demographic criteria to have a realistic index (Gupta, 2013).

3.2.2.2 Selection of parameters for Urbanization Index model

In the present study, an attempt has been made to develop the correlation between urbanization and water quality using the Urbanization Index and Water Quality Index as independent parameters. Only those parameters have been taken in the study for developing the Urbanization Index which are direct indicators of the urbanization level of a district.

Furthermore, the most important urbanization indicator parameters are selected whose data are available from the authorized government sources.

In the present study, to develop the Urbanization Index four multi-dimensional aspects have been considered for selecting the indicator parameters for urbanization: 1. Demographic aspect 2. Economic development aspect 3. Spatial Aspect and 4. Infrastructural development aspect: This aspect includes physical and social infrastructures. 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) for developing the Urbanization Index model.

Table 3.3 shows the indicator parameters selected for different aspects of urbanization.

Table 3.3. Indicator Parameters for different aspects of Urbanization

	Aspect of urbanization				
	Demographic	Economic development	Spatial	Infrastructural development	
				Physical	Social
Indicator parameter	a)Population size b)Population density	Number of Industries	Built- up area	a) Electricity facility b) Type of Roofing material	a) Educational facilities b) Availability of health services c) Assets (i .e. TV, computer/ laptop, telephone/mobile phone and scooter/car

The four different aspects for urbanization are described. The basis of selection of the indicator parameters under the different aspects is also discussed below.

3.2.2.2.1 Demographic aspect

The demographic concept of urbanization deals with the dynamics of population in a particular region. The demographic approach to understand urbanization has been used mainly by geographers and demographers. According to this approach, the process of urbanization and the growth of cities are the result of increase in population and population density. Urbanization, from demographic point of view, refers to the proportion of country's population living in urban areas. Increase in urban population of an area, over a period of time, is an indicator of the rate of urbanization in that area. (website:www.yourarticlelibrary.com)

Two parameters are considered under the demographic aspect: Population size and population density.

Population size and population density

The demographic aspect is the primary aspect of defining urbanicity. The Census criteria of most of the countries have considered the demographics to delimit the urban areas.

3.2.2.2.2 Economic development aspect

Urbanized cities are often considered as major drivers of economic development and growth. Urbanized locations create large markets for business, and can attract international investment and tourism from around the world. They result in growth of industries for economic development. Growth of number of Industries is considered as a parameter under the economic development aspect.

Growth of number of industries

Growth of number of Industries directly influences the economic growth. The economic growth of an area is closely linked with urbanization. Industries are important sources of employment which attract people to relocate from rural to urban areas, thus influencing other development activities contributing to economic growth and thereby urbanization.

This study is carried out to assess the influence of urbanization on water quality. For the selection of parameters for the measurement of urbanization, the parameters like sewage network development, quantum of treated sewage / untreated sewage etc. have not been considered due to the following reason: If an area is urbanized, then it is likely that the capacity of sewage treatment plants is not able to accommodate the increased sewage load. Thereby there are chances of untreated sewage remaining. Also, if an area is not urbanized then there might be lesser sewage treatment plants or the sewage treatment plants may not exist. Thereby again there are chances of untreated sewage remaining. Hence the quantum of treated sewage/ untreated sewage is not a measure of urbanization for India.

3.2.2.2.3 Spatial aspect

Spatial aspect indicates the urban sprawl. The urban sprawl can give the extent of an urban area. The parameter that can be indicative of an urban area and urbanization under the urban sprawl is: Built- up area.

Percentage of Built-up Area

As the economic activities of an area increases, the agricultural area decreases and solid and permanent dwellings increase. As urbanization occurs, soils are covered by increasing quantities of impervious surfaces such as parking lots, roads, sidewalks and rooftops.

3.2.2.2.4 Infrastructural development aspect

Urbanization is the biggest driver of infrastructural development in a developing country. The infrastructural development namely, electricity, rail, roads, water, power, energy, telecommunications, health services, educational facililties etc. are the indicators of urbanization. The infrastructural development aspect is of two types: physical and social. Under the physical infrastructural development aspect, two parameters are considered, namely, electricity facility and the type of roofing material and under the social infrastructural development aspect, three parameters are considered, namely, educational facilities, availability of health services, and Assets (i .e, TV, computer/ laptop, telephone/mobile phone and scooter/car).

Electricity facilities

Facility of electricity connection is an indication of urbanization because electric transmission development starts from urbanized area and progresses towards rural area.

Roofing types

In this study, roofing type has been selected to measure urbanization. In India, the households having concrete as predominant roof material are generally found in urban areas whereas the households having grass/ thatch/bamboo/wood/mud/plastic/polythene/ hand made tiles/ slate / stone are indicative of lower economic status and are generally observed in rural areas.

Educational facilities and availability of health services

The parameters such as Educational facilities and availability of health services are considered as correlates of urbanicity by a number of researchers. (Yach et al.,1990 ; McDade and Adair, 2001).

Assets (i .e, T V, computer/ laptop, telephone/mobile phone and scooter/car)

The standard of living is higher in urban areas compared to moderately urban or rural areas. Hence the possibility of owning the assets like T V, computer/ laptop, telephone/mobile phone and scooter/car increases as one moves from rural to urban areas. This is a parameter indicative of the quality of life which is better in urban areas than rural areas.

3.2.2.3 Development of urbanization scale for each of the urbanization parameter

Since the data for the urbanization parameters is available from Census of India for the districts, urbanization scale for each of the urbanization parameter is prepared for district. For each of the above urbanization parameters the scale is formed to assign the points from 1 to 10. Table 3.4 to 3.12 shows the scale formed for the various parameters and the corresponding assigned points for district. The basis of selecting the range of values for each urbanization parameter is discussed below.

For the purpose of assigning the ranges for each parameter, the district wise database for all the states of India is difficult to analyze and the variation of minimum and maximum Figures is too large to arrive at conclusive scaling. Hence, for the purpose of assigning the ranges for each parameter, district wise database of two states are considered as representative for India. Database of parameters for districts lying in two states, Gujarat and Rajasthan in the Western India are considered as a base.

3.2.2.3.1 Population size

Maximum population of a district in Gujarat is 7208200 (Ahmedabad district), in Rajasthan is 6626178 (Jaipur district).Minimum population of a district in Gujarat is 226769 (The Dangs district) , in Rajasthan 669919 (Jaisalmer district), (Appendix VI & VII). Hence the minimum Figure of 300000 and maximum Figure of 8000000 is taken for the scale of population size. The intermediate ranges are then assigned accordingly in the scale and shown in Table 3.4.

3.2.2.3.2 Population density

Maximum population density of a district in Gujarat is 1376 persons/sq.km (Surat district), in Rajasthan is 595 persons/sq.km (Jaipur district).Minimum population density of a district in Gujarat is 46 persons/sq.km (Kachchh district) , 167 persons/sq.km (Surendranagar district), 129 persons/sq.km (The Dangs district), 153 persons/sq.km (Jamnagar district).

Maximum population density in Rajasthan is 595 persons/sq.km (Jaipur district), 476 persons/sq.km (Dausa district) Minimum population density in Rajasthan is 172 persons/sq.km (Jalor district), 161 persons/sq.km (Jodhpur district). (Appendix VI & VIII). Hence, the minimum Figure of 200 persons/sq.km and maximum Figure of 1500 persons/sq.km is taken for the scale of population density. The intermediate ranges are then assigned accordingly in the scale and shown in Table 3.5.

3.2.2.3.3 Number of industries

The database for districts of Gujarat is taken as a reference from the Ministry of micro small and medium enterprises (MSME).(website:http://msme.gov.in/).The maximum number of industries (MSME) is 20556 (Surat district),16246 (Ahmedabad district). Minimum number of industries (MSME) is 0 (The Dangs district), 128 (Dahod district) & 204 (Patan district). Hence, the minimum figure of 100 and maximum figure of 14000 is taken for the number of industries. The intermediate ranges are then assigned accordingly in the scale and shown in Table 3.6.

3.2.2.3.4 Built- up area

Maximum figure of % built-up area to total area in a district, in Gujarat is 3.82 % (Ahmedabad district), in Rajasthan is 3.63 % (Jaipur district).Minimum figure in Gujarat is 0.2 % (The Dangs district), in Rajasthan is 1.63 % (Churu district). Hence, the minimum figure of 0.3 % and maximum figure of 2.7 % is taken for the % built-up area to total area in a district .The intermediate ranges are then assigned accordingly in the scale and shown in table 3.7.

3.2.2.3.5 Roofing types

Maximum figure of households in a district having concrete as predominant roof material (as a % of total population of the district) in Gujarat is 18.01 % (Rajkot district), in Rajasthan is 6.82 % (Jaipur district).Minimum figure in Gujarat is 0.69 % (The Dangs district) and 2.65 % (Dahod district), in Rajasthan is 0.37 % (Churu district). (Appendix XI & XII). Hence, the minimum figure of 4 % and maximum figure of 22 % is taken for the scale for roofing types. The intermediate ranges are then assigned accordingly in the scale and shown in Table 3.8.

3.2.2.3.6 Electricity Facilities

Maximum figure of households in a district having main source of lighting as electricity (as a % of total population of the district) in Gujarat is 20.60 % (Surat district), in Rajasthan is 14.94 % (Jaipur district).Minimum figure in Gujarat is 13.13 % (The Dangs district), in Rajasthan is 6.43 % (Jaisalmer district). (Appendix IX & X). Hence, the minimum figure of 5 % and maximum figure of 28 % is taken for the scale for electricity facilities. The intermediate ranges are then assigned accordingly in the scale and shown in Table 3.9.

3.2.2.3.7 Educational Facilities

The availability of a primary school, secondary school, senior secondary school, vocational training facility is assigned one point each. Availability of colleges which is facility for higher education is a indicator of an urban area. Hence, availability of colleges i.e, greater than 40 are assigned 6 points in the scale for educational facilities and shown in Table 3.10.

3.2.2.3.8 Health Services

The availability of dispensary, family welfare centre, nursing home, primary health sub centre is assigned one point each. If in the district, health centres are available (more than 2) than 2 points will be allocated. Availability of hospitals (more than 15) is assigned with 4 points and shown in Table 3.11.

3.2.2.3.9 Assets

Maximum figure of assets, i.e, households in a district owning TV, computer/ laptop, telephone/mobile phone and scooter/car (as a % of total population of the district) in Gujarat is 3.17 % (Ahmedabad district), in Rajasthan is 2.1 % (Jaipur district).Minimum figure in Gujarat is 0.11 % (The Dangs district) and 0.20 % (Narmada district), in Rajasthan is 0.16 % (Pratapgarh district) and 0.21 % (Jaisalmer district). (Appendix XIII & XIV). Hence, the minimum figure of 0.2 % and maximum figure of 1.8 % is taken for the Assets. The intermediate ranges are then assigned accordingly in the scale and shown in table 3.12.

Table 3.4 Points for population size in a district

Population size (Number)	**Points**
< 300000	1
> 300000 - 500000	2
> 500000 - 1500000	3
> 1500000 - 2500000	4
> 2500000 - 4000000	5
> 4000000 - 5000000	6
> 5000000 - 6000000	7
> 6000000 - 7000000	8
> 7000000 - 8000000	9
> 8000000	10

Table 3.5 Points for population density in a district

Population density (Persons/sq.km)	**Points**
< 200	1
> 200 - 400	2
> 400 - 600	3
> 600 - 800	4
> 800 - 900	5
> 900 - 1000	6
> 1000 - 1300	7
> 1300 - 1400	8
> 1400 - 1500	9
> 1500	10

Table 3.6 Points for number of industries in a district

Number of Industries	**Points**
< 100	1
> 100 - 500	2
> 500 - 3000	3
> 3000 - 6000	4
> 6000 - 9000	5
> 9000 - 11000	6
> 11000 - 12000	7
> 12000 - 13000	8
> 13000 - 14000	9
> 14000	10

Table 3.7 Points for % of built-up area in a district

% of Built-up area to total area	**Points**
< 0.3	1
> 0.3 - 0.6	2
> 0.6 - 0.9	3
> 0.9 - 1.2	4
> 1.2 - 1.5	5
> 1.5 - 1.8	6
> 1.8 - 2.1	7
> 2.1 - 2.4	8
> 2.4 - 2.7	9
> 2.7	10

Table 3.8 Points for Roofing Types in a district

Households ** (%)	**Points**
< 4	1
> 4 - 8	2
> 8 - 10	3
> 10 - 12	4
> 12 - 14	5
> 14 - 16	6
> 16 - 18	7
> 18 - 20	8
> 20 - 22	9
> 22	10
**Households having concrete as predominant roof material (% of total population)	

Table 3.9 Points for Electricity Facilities in a district

Households * (%)	Points
< 5	1
> 5-10	2
> 10-15	3
> 15-20	4
> 20-25	5
> 20-22	6
> 22-24	7
> 24-26	8
> 26-28	9
> 28	10
*Households having main source of lighting as electricity (% of total population)	

Table 3.10 Points for available educational facilities in a district

Educational facilities	Points
Primary school	1
Secondary school	1
Senior secondary School	1
Vocational training facility	1
Colleges (if > 40)(otherwise 0 pts)	6

Table 3.11 Points for available health services in a district

Health Services	Points
Hospitals (if >15)	4
Health centre	2
Dispensary	1
Family welfare centre	1
Nursing home	1
Primary health sub centre	1

Table 3.12 Points for assets in a district

Households * (%)**	**Points**
< 0.2	1
> 0.2-0.4	2
> 0.4-0.6	3
> 0.6-0.8	4
> 0.8-1.0	5
> 1.0-1.2	6
> 1.2-1.4	7
> 1.4-1.6	8
> 1.6-1.8	9
> 1.8	10
***Households with TV ,computer/laptop, telephone/mobile phone and scooter/car (% of total population)	

3.2.2.4 Urbanization score of a district

Urbanization score for each of the district have to be obtained by aggregating the points obtained as above for each urbanization parameter. As there are 9 urbanization parameters considered in this study, the urbanization score for each district varies from 0 (i.e, minimum) to 90 (i.e, maximum). Hence, the urbanization score obtained for each district ranges from 0 to 90 points from low urbanization towards high urbanization. Urbanization score (US) of the district is expressed by the equation given below.

Urbanization score (US) of the district

$$USj = \sum_{i=1}^{n} \left(P_{i,j}\right) \quad (3.3)$$

Where , P= points obtained for the parameter for the district, n = total number of urbanization parameters, j= district under consideration, i = urbanization parameter under consideration

3.2.2.5 Urbanization Index of a district

Urbanization index is formed by normalizing the urbanization score of the district over the maximum value of the urbanization score.

Urbanization Index (UI_j) = (US_j /Max. score i.e, 90) x 100 (3.4)

From the Urbanization Index model developed in the present study, the status of the urbanization level can be evaluated numerically for the districts for which the urbanization parameters are collected as a data.

3.2.2.6 Urbanization Index of catchment of station

Using the Urbanization Index model developed as above, 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 Urbanization Index is found for various districts in the earlier section. There are various districts lying in the catchment of a station. Each district has a different value of the Urbanization Index. So, there is a need to determine the overall composite Urbanization Index of the station. The overall composite index 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 has been evolved for the case, where there is one whole district falling in the catchment and forming the catchment boundary (under case A1 B1). (Urbanization Index of the catchment is same as the Urbanization Index of the district).

The methodology has been evolved for the case, where there are number of (multiple) whole district lying in the catchment (under case A1 B2). (Urbanization Index of the catchment is the average of the Urbanization Index of the districts).

The methodology has been also evolved for the case, where there is one district portion lying in the catchment (under case A2 B1). (Urbanization Index of the catchment is the multiplication of the Urbanization Index of the district to the ratio of the area of the district falling in the catchment to the total area of the district).

But if the case is such that there are Multiple district portions lying in the catchment (under case A2 B2), then the urbanization of the catchment is determined by summation of weighted urbanization of the district portion multiplied by ratio of area of district portion contributing to the total area of the catchment and then multiplied by the total no. of district portion. The weighted urbanization is determined by the ratio of the district portion to the total area of the district multiply by urbanization of the district.

The methodology for the determination of 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), as shown in fig.3.3, 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.

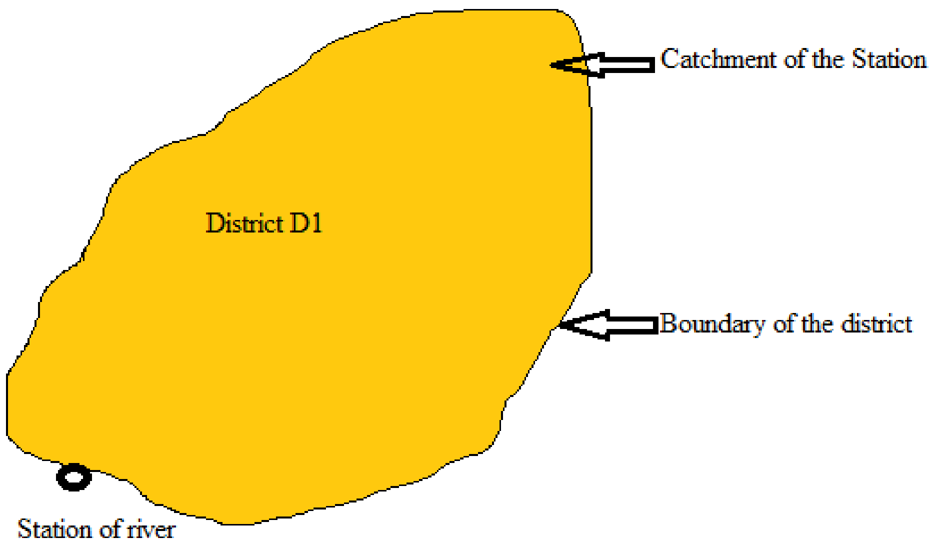

Figure 3.3. Schematic diagram for Case A1 B1

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), as shown in fig.3.4. Figure 3.4 shows that the entire districts, D1, D2, D3 etc. are falling in the catchment of station, then the average of Urbanization Index of all districts is taken as Urbanization Index of the station.

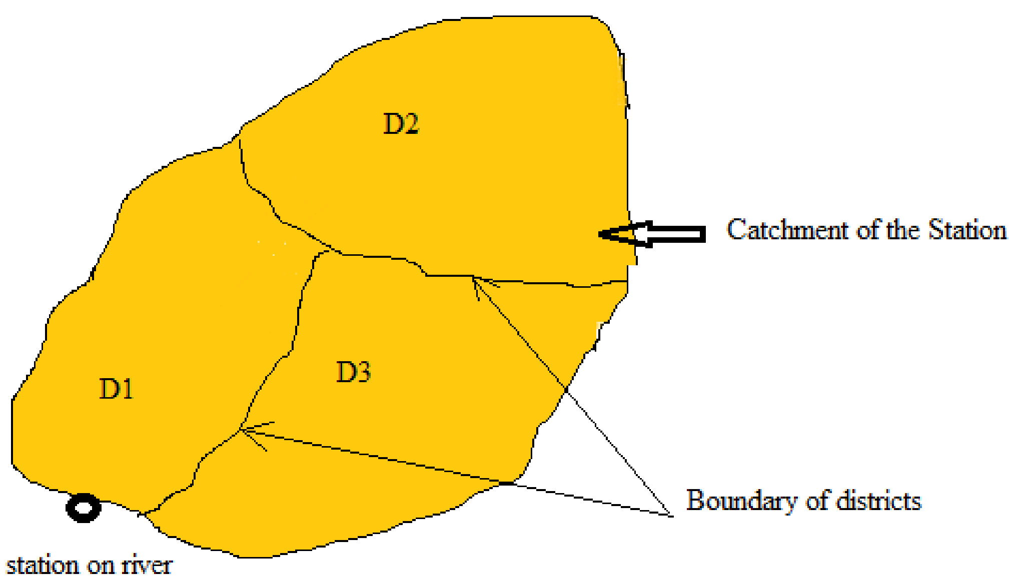

Figure 3.4. Schematic diagram for Case A1 B2

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) as shown in Figure 3.5. 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 (3.5)

$$UI_k = UI_j \times \frac{a_{j,k}}{A_j} \qquad (3.5)$$

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,

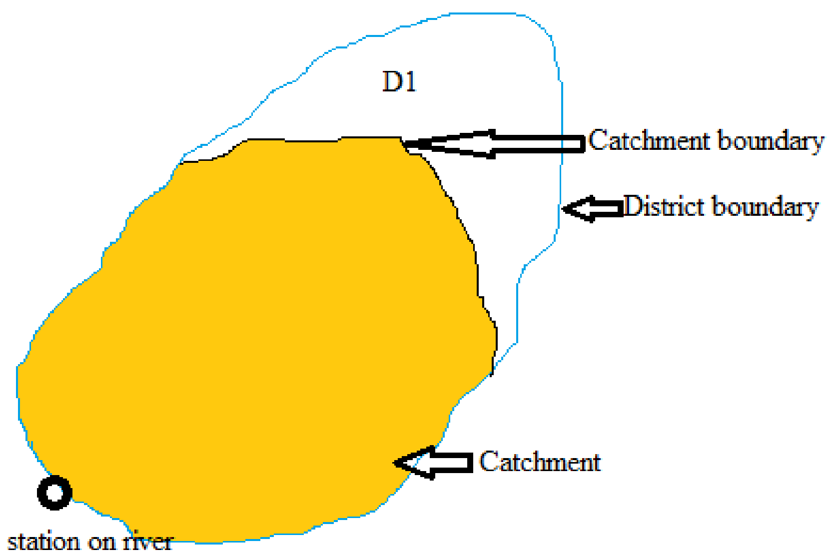

Figure 3.5 Schematic diagram for Case A2 B1

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) as shown in Figure 3.6. 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 portions of the districts is as shown in the equation 3.6.

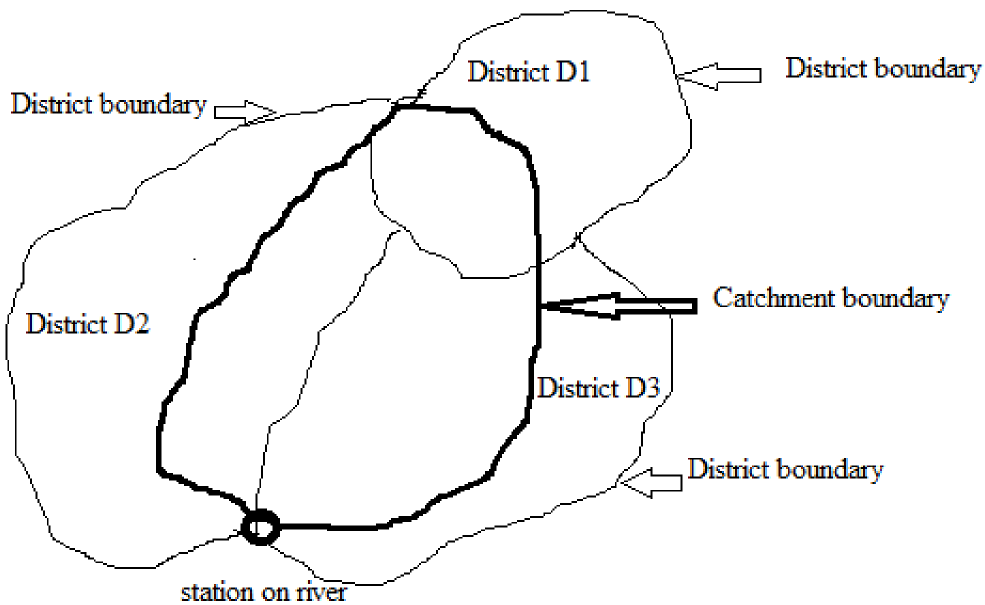

Figure 3.6. Schematic diagram for Case A2 B2

Urbanization Index of the portions of districts =

$$\text{Urbanization Index of district } (UI_j) \times \frac{\text{Area of the district portion } (a_{j,k})}{\text{Area of the district } (A_j)} \quad (3.6)$$

The Urbanization Index of the catchment of the station is shown by equation 3.7

$$UI_k = \sum_{j=1}^{N} \left(\frac{UI_j \times a_{j,k} \times a_{j,k}}{A_j \quad A_k} \right) X\ N \quad (3.7)$$

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.

Using the above methodology for evaluating the Urbanization Index of the catchment of the station, the Urbanization Index of all stations on a river can be computed.

3.2.2.7 Development of Classes of Urbanization in this study

To categorize the urbanization level of the district, the urbanization index of the district have been classified into 5 categories of equal range in this study as shown in Table 3.13

Table 3.13 Classes of Urbanicity developed in the study

Urbanization Index	Level of urbanization
0 - 20	Highly rural
> 20 - 40	Moderately rural
> 40 - 60	Moderately urban
> 60 - 80	Urban
> 80	Highly urban

3.2.3 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.

Simple linear regression

Simple linear regression is the most commonly used technique for determining how one variable of interest (the response variable) is affected by changes in another variable (the explanatory variable). The terms "response" and "explanatory" mean the same thing as "dependent" and "independent", but the former terminology is preferred because the "independent" variable may actually be interdependent with many other variables as well. Simple linear regression is used for three main purposes:

1. To describe the linear dependence of one variable on another.
2. To predict values of one variable from values of another, for which more data are available
3. To correct for the linear dependence of one variable on another, in order to clarify other features of its variability. Any line fitted through a cloud of data will deviate from each data point to greater or lesser degree. The vertical distance between a data point and the fitted line is termed a "residual". This distance is a measure of prediction error, in the sense that it is the discrepancy between the actual value of the response variable and the value predicted by the line. Linear regression determines the best-fit line through a scatterplot of data, such that the sum of squared residuals is minimized; equivalently, it minimizes the error variance. The fit is "best" in precisely that sense: the sum of squared errors is as small as possible. That is why

it is also termed "Ordinary Least Squares" regression. The Figure 3.7 shows a scatter plot for linear regression. The Figure 3.8 shows a residual plot.

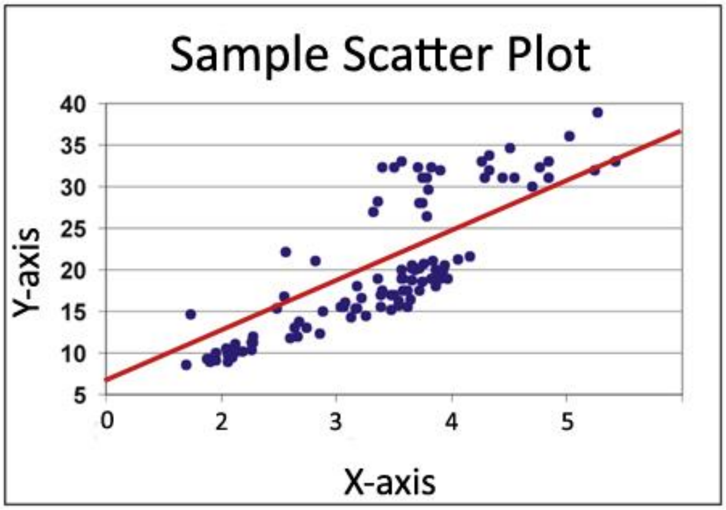

Figure 3.7 Scatter plot for linear regression

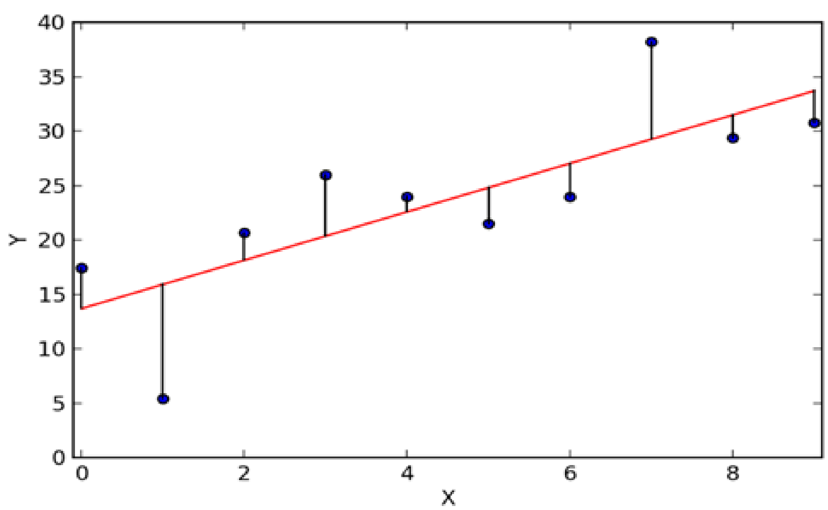

Figure 3.8 Residual plot

Nonlinear regression

In statistics, nonlinear regression is a form of regression analysis in which observational data are modeled by a function which is a nonlinear combination of the model parameters and depends on one or more independent variables.

The data consist of error-free independent variables (explanatory variables), x, and their associated observed dependent variables (response variables), y. Each y is modeled as a random variable with a mean given by a nonlinear function $f(x,\beta)$. A nonlinear system of equations is a set of simultaneous equations in which the unknowns appear as variables of a polynomial of degree higher than one or in the argument of a function which is not a polynomial of degree one. Figures 3.9 (a) and 3.9 (b) show sample scatter plots for nonlinear regression.

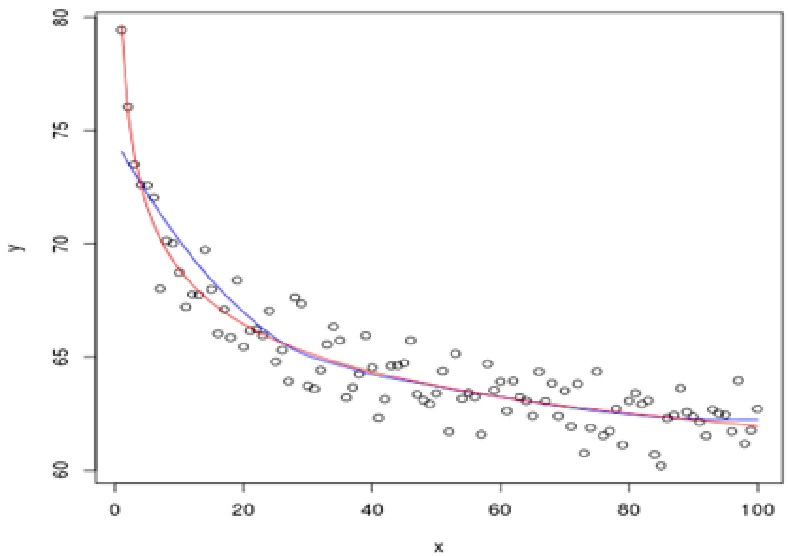

Figure 3.9 (a) Sample scatter plot for nonlinear regression

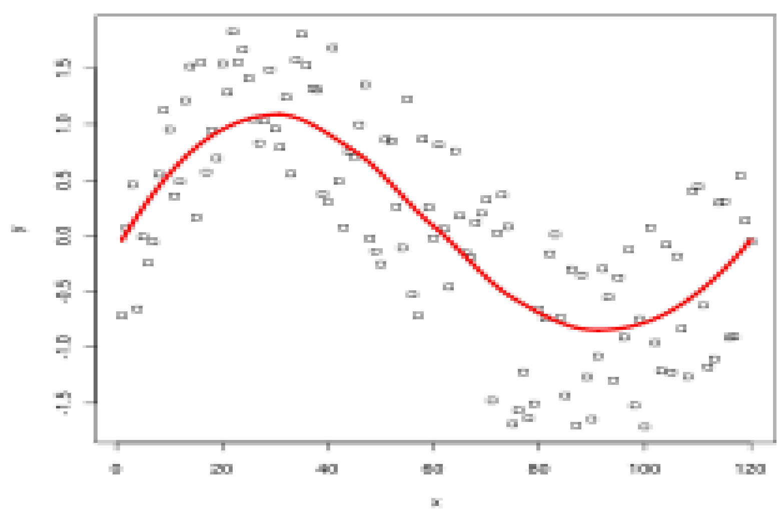

Figure 3.9 (b) Sample scatter plot for nonlinear regression