Chapter 2

Literature review

2.1 General

First, the theory related to water quality, water quality assessment, water quality monitoring guidelines are presented in this chapter.

Next, review of some of the researched methods of assessment of water quality and urbanization has been carried out. The reviews of earlier studies for assessment of water quality for the impact of urbanization have been described. Critical appraisal of the available studies and their limitations with respect to the present research are described following each reviewed study.

2.2 Definitions related to water quality

2.2.1 Quality of the aquatic environment

The quality of the aquatic environment (Chapman, 1996) is defined as follows:

• It is set of concentrations, specifications, and physical partitions of inorganic or organic substances.

• It is the composition and state of aquatic biota in the water body.

• It is a description of temporal and spatial variations due to factors internal and external to the water body.

Description of the quality of the aquatic environment can be carried out in a variety of ways. It can be achieved either through quantitative measurements, such as physicochemical determinations (in the water, particulate material, or biological tissues) and biochemical/biological tests (BOD measurement, toxicity tests, etc.), or through semiquantitative and qualitative descriptions such as biotic indices, visual aspects, species inventories, odour, etc. These determinations are carried out in the field and in the laboratory and produce various types of data which lend themselves to different interpretative techniques (Chapman, 1996).

2.2.2 Pollution of the aquatic environment

Introduction by man, directly or indirectly, of substances or energy which result in such deleterious effects as:

• harm to living resources,

• hazards to human health,

• hindrance to aquatic activities including fishing,

• impairment of water quality with respect to its use in agricultural, industrial and often economic activities, and

• reduction of amenities1 (Chapman,1996)

1 as defined by GESAMP (1988)

2.3 Water use and water quality

With the advent of industrialisation and increasing populations, the range of requirements for water has increased together with greater demands for higher quality water. Over time, water requirements have emerged for drinking and personal hygiene, fisheries, agriculture (irrigation and livestock supply), navigation for transport of goods, industrial production, cooling in fossil fuel (and later also in nuclear) power plants, hydropower generation, and recreational activities such as bathing or fishing. Fortunately, the largest demands for water quantity, such as for agricultural irrigation and industrial cooling, require the least in terms of water quality (i.e. critical concentrations may only be set for one or two variables). Drinking water supplies and specialised industrial manufacturers exert the most sophisticated demands on water quality but their quantitative needs are relatively moderate. In parallel with these uses, water has been considered, since ancient times, the most suitable medium to clean, disperse, transport and dispose of wastes (domestic and industrial wastes, mine drainage waters, irrigation returns, etc.). Each water use, including abstraction of water and discharge of wastes, leads to specific, and generally rather predictable, impacts on the quality of the aquatic environment (Chapman, 1996).

2.3.1 Factors affecting water quality

The composition of surface and underground waters is dependent on natural factors (geological, topographical, meteorological, hydrological and biological) in the drainage basin and varies with seasonal differences in runoff volumes, weather conditions and water levels.

Large natural variations in water quality may, therefore, be observed even where only a single watercourse is involved. Human intervention also has significant effects on water quality. Some of these effects are the result of hydrological changes, such as the building of dams, draining of wetlands and diversion of flow. More obvious are the polluting activities, such as the discharge of domestic, industrial, urban and other wastewaters into the watercourse (whether intentional or accidental) and the spreading of chemicals on agricultural land in the drainage basin. Water quality is affected by a wide range of natural and human influences. The most important of the natural influences are geological, hydrological and climatic, since these affect the quantity and the quality of water available. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource; for example, high salinity is a frequent problem in arid and coastal areas. If the financial and technical resources are available, seawater or saline groundwater can be desalinated but in many circumstances this is not feasible. Thus, although water may be available in adequate quantities, its unsuitable quality limits the uses that can be made of it. Although the natural ecosystem is in harmony with natural water quality, any significant changes to water quality will usually be disruptive to the ecosystem.

The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the ecosystem and/or restrict water use. Pollution of water by human faeces, for example, is attributable to only one source, but the reasons for this type of pollution, its impacts on water quality and the necessary remedial or preventive measures are varied. Faecal pollution may occur because there are no community facilities for waste disposal, because collection and treatment facilities are inadequate or improperly operated, or because on-site sanitation facilities (such as latrines) drain directly into aquifers. The effects of faecal pollution vary. In developing countries intestinal disease is the main problem, while organic load and eutrophication may be of greater concern in developed countries (in the rivers into which the sewage or effluent is discharged and in the sea into which the rivers flow or sewage sludge is dumped). A single influence may, therefore, give rise to a number of water quality problems, just as a problem may have a number of contributing influences. Eutrophication results not only from point sources, such as wastewater discharges with high nutrient loads (principally nitrogen and phosphorus), but also from diffuse sources such as run-off from livestock feedlots or agricultural land fertilised with organic and inorganic fertilisers. Pollution from diffuse sources, such as agricultural runoff, or from numerous small inputs over a wide area, such as faecal pollution from unsewered settlements, is particularly difficult to control (Bartram J. and Ballance R., 1996). Water quality is affected largely by uncontrolled land use for urbanisation or deforestation, accidental (or unauthorised) release of chemical substances, discharge of untreated wastes or leaching of noxious liquids from solid waste deposits. Similarly, the uncontrolled and excessive use of fertilisers and pesticides has long-term effects on ground and surface water resources (Chapman, 1996).

Pollution and water quality degradation interfere with vital and legitimate water uses at any scale, i.e. local, regional or international (Meybeck *et al.*, 1989). As shown in Table 2.1, some types of uses are more prone to be affected than others.

Table 2.1 Limits of water uses due to water quality degradation (Chapman,1996)

Pollutant	**Use**						
	Drinking water	**Aquatic wildlife, fisheries**	**Recreation**	**Irrigation**	**Industrial uses**	**Power and cooling**	**Transport**
Pathogens	1	0	1	2	1	NA	NA
Suspended Solids	1	1	1	2	2	2	1
Organic matter	1	2	1	+	1	2	NA
Algae	2	2	1	+	1	2	2
Nitrate	1	2	NA	+	1	NA	NA
Salts	1	1	NA	1	1	NA	NA
Trace elements	1	1	2	2	2	NA	NA
Organic Micro pollutants	1	1	2	2	?	NA	NA
Acidification	2	1	2	?	2	2	NA
1 Marked impairment causing major treatment or excluding the desired use 2 Minor impairment 0 No impairment NA Not applicable + Degraded water quality may be beneficial for this specific use ? Effects not yet fully realised							

2.4 Water quality assessment

The overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself. (Chapman,1996).

2.4.1 Objectives of water quality assessment

Since water resources are usually put to several competing beneficial uses, monitoring which is used to acquire necessary information should reflect the data needs of the various users involved (Helmer, 1994). Consequently, there are two different types of monitoring programmes, depending on how many assessment objectives have to be met:

• *Single-objective monitoring* which may be set up to address one problem area only. This involves a simple set of variables, such as: pH, alkalinity and some cations for acid rain; nutrients and chlorophyll pigments for eutrophication; various nitrogenous compounds for nitrate pollution; or sodium, calcium, chloride and a few other elements for irrigation.

• *Multi-objective monitoring* which may cover various water uses and provide data for more than one assessment programme, such as drinking water supply, industrial manufacturing, fisheries or aquatic life, thereby involving a large set of variables. The Commission of the European Communities has a list in excess of 100 micropollutants to be considered in drinking water alone.

The implementation of the assessment programme objectives may focus on the spatial distribution of quality (high station number), on trends (high sampling frequency), or on pollutants (in-depth inventories). Full coverage of all three requirements is virtually impossible, or very costly. Consequently preliminary surveys are necessary in order to determine the necessary focus of an operational programme. Table 2.2 summarises the existing types of water quality operations in relation to their main objectives. The process of determining objectives should start with an in-depth investigation of all factors and activities which exert an influence, directly or indirectly, on water quality. Inventories have to be prepared on:

• the geographical features of the area, including: topography, relief, lithology, pedology, climate, land-use, hydrogeology, hydrology etc.,

• water uses, including: dams, canals, water withdrawal for cities and industries, agricultural activities, navigation, recreation, fisheries, etc., and

• pollution sources (present and expected), including: domestic, industrial and agricultural, as well as their stage of pollution control and waste treatment facilities. (Chapman,1996).

Table 2.2 Typical objectives of water quality assessment operations

	Type of operation	**Major focus of water quality assessment**
Common operations		
1.	Multipurpose monitoring	Space and time distribution of water quality in general
2.	Trend monitoring	Long-term evolution of pollution (concentrations and loads)
3.	Basic survey	Identification and location of major survey problems and their spatial distribution
4.	Operational surveillance	Water quality for specific uses and related water quality descriptors (variables)
Specific operations		
1.	Background Monitoring	Background levels for studying natural processes; used as reference point for pollution and impact assessments
2.	Preliminary Surveys	Inventory of pollutants and their space and time variability prior to monitoring programme design
3.	Emergency surveys	Rapid inventory and analysis of pollutants, rapid situation assessment following a catastrophic event
4.	Impact surveys	Sampling limited in time and space, generally focusing on few variables, near pollution sources
5.	Modelling surveys	Intensive water quality assessment limited in time and space and choice of variables, for example, eutrophication models or oxygen balance models
6.	Early warning surveillance	At critical water use locations such as major drinking water intakes or fisheries; continuous and sensitive measurements

2.5 Water quality monitoring

The actual collection of information at set locations and at regular intervals in order to provide the data which may be used to define current conditions, establish trends, etc. (Chapman, 1996).

Water quality assessment includes the use of monitoring to define the condition of the water, to provide the basis for detecting trends and to provide the information enabling the establishment of cause-effect relationships. Important aspects of an assessment are the interpretation and reporting of the results of monitoring and the making of recommendations for future actions. Thus there is a logical sequence consisting of three components: monitoring, followed by assessment, followed by management.

Water quality monitoring is one of the first steps required in the rational development and management of water resources. In the field of water quality management, there has been a steady evolution in procedures for designing system to obtain information on the changes of water quality. The 'monitoring' comprise all activities to obtain 'information' with respect to the water system. Water quality monitoring is a complex subject, and the scope of it is both deep and wide. Water quality monitoring has a direct relation with chemistry, biology, statistics and also economics. Its scope is also related to the types of water uses and functions which are manifold and the nature of the sources of water such as surface water (rivers and lakes), sea water groundwater.

Water quality monitoring involves 8 steps as explained below:

Step 1: Setting water quality monitoring objectives

Before formulation of any water quality monitoring programme it is very important to have clear understanding on the monitoring objectives. Everybody of the programme team should be fully aware of the objectives, methodology, quality assurance, data validation and other aspects. Clearly environmental monitoring must have a purpose and a function in the process of risk assessment and pollution control. In risk management, monitoring is essential in the stage of problem recognition (indication of water quality deviations), the stage of analysis (with respect to the expected changes) and the stage of management (verification or control of strategy results).

A number of purposes for monitoring can be discerned:

- The signal or alarm function for the detection of suddenly occurring (adverse) changes in the environment. Preferably the monitoring system should be designed to immediately enable the tracing of causes;
- The control function to assess the general quality of water in relation to adopted water quality requirements or objectives, and for verification on the effectivity of pollution control strategies as well as a check on permitted effluent quality compliance;
- The trend (recognition) function based on time series analysis to enable the prediction of future developments;

- The instrument function to help in the recognition and clarification of underlying processes.Water quality monitoring is carried out for various reasons and the objectives of a particular monitoring programme have a direct bearing on the costs of carrying out the programme.

The most important objectives of water and effluent quality monitoring programmes kept in mind by CPCB/SPCBs/PCCs include:

- rational planning of pollution control strategies;
- to identify nature and magnitude of pollution control required;
- to evaluate effectiveness of pollution control efforts already in existence;
- identification of state and trends in water quality, both in terms of concentrations and effects;
- identification of the mass flow of contaminants in surface water and effluents;
- formulation of standards and permit requirements;
- testing of compliance with standards and classifications for waters and effluents;
- early warning and detection of pollution.

In practise, data from routine monitoring programmes are generally used for a variety of purposes in addition to those for which the programmes were designed. Identification of the state and trends in water quality is mainly important for policy and management, while the identification of the mass flow in rivers and waste water discharges is of particular importance at the boundaries between states countries, districts or water systems. Mass flows are subject of international, national or state disputes, negotiations are an input for mass balances for specific substances. Testing of compliance with standards (control) is related to the water quality objectives for surface water as prescribed in both national and international standards. The early warning monitoring programme to signal pollution due to (accidental) spills by industry and ships is especially important if surface water of that particular river or water system is used for public water supply. Finally, data will be used for various projects including research.

Water quality monitoring is an important aspect of overall water quality management and water resources development. A well planned and well managed water quality monitoring system is required to signal, control or predict changes or trends of changes in the quality of a particular water body, so that curative or preventive measures can be taken to restore and maintain ecological balance in the water body. Monitoring is essential for the successful implementation of environmental legislation: to ensure that standards and criteria set by CPCB/SPCBs are maintained on a continuing basis.

Step 2: Assessment resources availability

Once the monitoring objectives are known, it is important to look into the availability of resources for monitoring. Generally a compromise is made between quality and quantity of data required to fulfil certain objective(s) and resources available. Before planning water quality monitoring programme it is important to ensure that following resources are available:

a. Sampling equipment (as per checklist)

b. Transport for sampling

c. Laboratory facilities

d. Trained Manpower adequate number and competence

e. Equipment/instruments for desired parameters analysis

f. Chemicals/glasswares and other gadgets for analysis of desired parameters

g. Funds for operation and maintenance of laboratory

Step 3: Reconnaissance survey

Most water quality monitoring programs have the objective of defining pollution, and relating it to its sources. After this the reductions in discharges, which are necessary to remedy the problem, can be determined. A few days spent reviewing all available reports and records concerning the water quality of all waste discharges and of the receiving water body may save several days of field work and may prevent the collection of useless data. It is important to make a reconnaissance survey of the river during the planning stage, noting all sources of wastes, all entering tributaries that might contribute a potential pollutant, and all uses and abstractions of the water. This action will also include a survey of background information such as geography, topography, climate and weather, hydrology, hydrogeology, land use, urbanization, industrialization and agriculture, including farming in the riverbed. This information will help in an appropriate siting of sampling locations.

The survey will give an overview of the geographical location of the water body to be monitored, its accessibility all kind of human influences to decide appropriate sampling location and also appropriate number of sampling locations. The survey may include acquisition of following information:

a. Location map

b. Background information on water body

c. Human activities around the water body like mass bathing, melon farming, cattle wading etc

d. Identification of potential polluting sources

e. Water abstraction – quantity and uses

f. Water flow regulation - schedule, quantity etc

The above information will help in proper designing the network and also planning the schedule for sampling.

Step 4: Network design

In designing the sampling network, it is important to consider optimum number of sampling location, sampling frequency and parameters required to fulfil the desired objectives. Some general criteria for selecting appropriate sampling sites will be summarized under the following points:

1) Always have a reference station up-stream of all possible discharge points. The usual purpose of a monitoring exercise is to determine the degree of man induced pollution, and the damage that is caused to aquatic life. The reference station serves to assess the situation with respect to background water quality and biological aspects, which may vary locally and regionally.

2) Drinking water intake points, bathing ghats, irrigation canal off-take points should be considered for monitoring.

3) Sampling stations should be located upstream and downstream of significant pollution outfalls like city sewage drains and industrial effluent outfalls.

4) All samples must be representative, which means that the determinants in the sample must have the same value as the water body at the place and time of sampling. In order to achieve this it is important that the sample is collected from well-mixed zone. A homogeneity test must be performed to identify the well-mixed zone.

5) Additional downstream stations are necessary to assess the extent of the influence of an outfall, and locate the point of recovery.

6) In large rivers like Ganga, Yamuna, Narmada, Krishna and Godavari, where mixing is poor and incomplete, the effluent may tend to follow one bank.Stations on both sides downstream are useful to make an estimate of the extent of the mixing zone.

7) In large rivers a balance has to be found between the selection of a few stations giving poor coverage, and the selection of more stations having different substrates and dissimilar fauna, which can not be compared spatially.

8) In order to enable comparisons among sampling stations, it is essential that all stations be sampled approximately at the same time. Not more than two weeks should elapse between the sampling of the first and last station in a river.

9) Sites for biological sampling should match with sites for chemical sampling.

10) Biological sampling stations need to be selected with proper attention to representative habitats (kind of substrate, depth and flow). All sampling stations in a certain river should preferably be ecologically similar. To increase biological and chemical comparability, they should have similar substrate (sand, gravel, rock, or mud), depth, presence of rifles and pools, stream width, flow velocity, bank cover, human disturbances, etc.

11) The conventional location of macro-invertebrate sampling stations in rivers arises not only from an assumed uniformity of substrate and fauna, but also from the ease with which it may be sampled by means of handnets and stonelifting or kicking, and from the ease of access.

12) For the estimation of the oxygen exchange rate of the river, a measurement of cross section is required. Any station should be typical with respect to the cross section of the river.

13) The sampling team normally has to carry an appreciable burden of sampling gear and water samples, and the distance they can walk is limited. Easily accessible sites should be selected. The site should also be accessible under all conditions of weather and riverflow. Accessibility is therefore an important consideration.

14) With respect to preservation, samples are taken to perform analysis on three types of parameters: for some parameters, such as heavy metals, the samples need not be preserved. For other parameters, samples can be preserved by cold storage or by the addition of certain preservatives. However, the samples for analysis of parameters like BOD and bacterial counts cannot be preserved and need to reach the laboratory shortly after taking the sample. The need to transport the samples to the laboratory will govern the range of determinations which can be carried out for a particular sampling site. Travel time greater than 24 hours between the site and laboratory is not recommended.

Zonation

Two general types of zonation in water bodies should be mentioned:

Cross-sectional zonation. A cross-section of the river and lakes will usually reveal gradients in depth, current velocities and sediment and water characteristics.

Longitudinal zonation. On a large geographical scale rivers may be classified in a number of zones: highland brooks and lowland courses both subdivided in upper and lower reaches.

Sampling frequency

The sampling frequency is governed by the level of variation in water quality of a water body. If variations are large in a short duration of time, a larger frequency is required to cover such variations. On the other hand, if there is no significant variation in water quality, frequent collection of sample is not required. The water quality variations could be of two types i.e. random and cyclic or seasonal. In case of random variations e.g. due to sudden rainfall in the catchment or sudden release of water from the dam etc., increased frequency may not help much as such variations are highly unpredictable. Thus, within the available resources it is not cost effective to cover such variations. In case of the water bodies having cyclic variations more frequently, sampling on monthly basis is justified. But for all those water bodies having stable water quality round the year, monthly sampling is not justified.

Frequency and parameters

A list of parameters to be considered for analysis and frequency of sampling is provided in the "Protocol for Water Quality Monitoring" notified by Govt of India. These are provided in Table 2.3.

Table 2.3 Parameters and frequency of monitoring in surface waters

Type of Station	Frequency	Parameter
Baseline:	**Perennial rivers and lakes :** Four times a year **Seasonal rivers** : 3-4 times (at equal spacing) during flow period. **Lake**: 4 times a year	**(A) Pre-monsoon**: Once a year Analyse 25 parameters as listed below : **(a)General** : Colour, odour, temp, pH, EC, DO, turbidity, TDS **(b) Nutrients** : NH3-N, NO2 + NO3, Total P **(c)Organic Matter** : BOD, COD **(d)Major ions** : K, Na, Ca, Mg, CO3, HCO3, Cl, SO4, **(e)Other inorganics** : F, B and other locationspecific parameter, if any **(f)Microbiological** : Total and Faecal Coliforms **(B)Rest of the year** (after the pre-monsoon sampling) at every three months' interval: Analyse 10 parameters: Colour, Odour, Temp., pH, EC, DO, NO2 + NO3, BOD, Total and Faecal Coliforms.
Type of Station	**Frequency**	**Parameter**
Trend:	Once every month starting April-May (pre-monsoon), i.e. 12 times a year	**(A)Pre-monsoon**: Analyse 25 parameters as listed for baseline monitoring **(B)Other months** : Analyse 15 parameters as listed below **(a)General** : Colour, Odour, Temp, pH, EC, DO and Turbidity **(b)Nutrients** : NH3-N, NO2 + NO3, Total P **(c)Organic Matter** : BOD, COD **(d)Major ions** : Cl **(e)Microbiological** : Total and Faecal coliforms **(C)Micropollutant** :Once in a year in monsoon season **(i)Pesticides**-Alpha BHC, Beta BHC, Gama BHC (Lindane), OP-DDT, PP-DDT, Alpha Endosulphan, Beta Endosulphan, Aldrin, Dieldrin, 2,4-D, Carboryl (Carbamate), Malathian, Methyl Parathian, Anilophos, Chloropyriphos **(ii)Toxic Metals**-As,Cd,Hg,Zn,Cr,Pb,Ni,Fe (Pesticides & Toxic metals may be analysed once a year)

Step 5: Sampling

Planning for sampling

When planning a sampling programme the number of sampling stations or wells that can be sampled in one day is required. For this is necessary to know the required time needed for sampling, and other actions required, at the site. Since purging is a time consuming activity an estimate of the required purging time is a must to arrive at a fair estimate of the sampling time.

Surface water sampling

• Samples will be collected from well-mixed section of the river (main stream) 30 cm below the water surface using a weighted bottle or DO sampler.

• Samples from reservoir sites will be collected from the outgoing canal, power channel or water intake structure, in case water is pumped. When there is no discharge in the canal, sample will be collected from the upstream side of the regulator structure, directly from the reservoir.

• DO is determined in a sample collected in a DO bottle using a DO sampler. The DO in the sample must be fixed immediately after collection, using chemical reagents. DO concentration can then be determined either in the field or later, in a level I or level II laboratory.

Types of samples

Apart from a separation into compartments (water, sediment and biota) different types of samples can be collected:

1) Grab sample (also called spot - or catch samples)

One sample is taken at a given location and time. In case of a flowing river, they are usually taken from the middle of the flowing water (main) stream and in the middle of the water column. When a source is known to vary with time, spot samples collected at suitable time intervals and analyzed separately, can document the extent, frequency and duration of these variations. Sampling intervals are to be chosen on the basis of the expected frequency with which changes occur. This may vary from continuous recording, or sampling every 5 minutes, to several hours or more.

2) Composite samples

In most cases, these samples refer to a mixture of spot samples collected at the same sampling site at different times. This method of collection reduces the analytical effort, because variations are middled out in one analysis. It is a useful technique when daily variations occur and seasonal variations are the objective of the programme. If, however, the series of spot samples are not mixed but analyzed individually, also information on the daily variability can be obtained, and afterwards the average can be computed. Sometimes the indication 'time-composite' is used to distinguish from 'location composite' sampling. Time-composite sampling representing a 24-hour period is often used. For many determinations, the time interval between sampling events is 1-3 hours. To evaluate the nature of special discharges (e.g. variable in volume or irregular in time), samples should be collected at time intervals representing the period during which such discharges occur. Especially in effluents, one may sample a volume that is proportional to the discharge (flow based composite). This type of sampling is also required to measure the flux of pollution load discharged through a point source.

Step 6: Laboratory work

The analytical methods are prescribed for each parameter along with measurement unit and significant Figure in the following Table 2.4.

Table 2.4 Measurement methods, units and for different parameters used in water quality monitoring

Parameters	**Unit**	**Measurement methods**
Colour	**--**	Visual method
Odour	**--**	Manual
Temperature	°C	Thermometer
pH	**--**	pH meter
Electrical Conductivity	µS/cm	Conductivity meter
Dissolved Oxygen	mg/L	DO Meter or Winkler modified method
Turbidity	NTU	Nephelometer
Total Dissolved Solids	mg/L	Gravimetry
Nitrite + Nitrate-N	mg/L	Colorimetry
Biochemical Oxygen Demand (BOD)	mg/L	DO consumption in 3 days at 27 °C
Chemical Oxygen Demand (COD)	mg/L	Potassium dichromate method
Total Coliform	No./100mL	MPN or MF method

Step 7: Data management

This includes data storage and data validation. Data analysis could be used to summarise the data; to transform them to aid understanding or to compare them with a water quality standard that is couched in statistical terms (annual mean, standard deviation, trend, seasonal changes or a percentile for certain parameters). The data can also be summarized in form of index. Statistical analysis like parametric correlation, seasonal fluctuations, seasonal trends over a period of time are also common. Graphical presentation of data includes time series graphs, histograms, pie charts, profile plots (river profiles), geographical plots (contours). The data interpretation involves understanding on the water chemistry, biology and hydrology. Normally data analysed and interpreted in terms of chemical quality, quality fluctuations, and their possible effect on different uses and ecosystem. A comparison is made with predefined criteria or standards set for protection of different uses.

Step 8: Quality Assurance

The QA programme for a laboratory or a group of laboratories should contain a set of operating principles, written down and agreed upon by the organisation, delineating specific functions and responsibilities of each person involved and the chain of command.

2.6 Policies and regulations for water quality management in India

Water quality management is for a great deal controlled by authorization of discharges of dangerous substances for which monitoring of discharges, effluents and influenced surface water is essential. On national and state levels, there are several policies and regulation like Water (Prevention and Control of Pollution) Act, 1974 to regulate pollution discharges and restore water quality of our aquatic resources including the prescription of monitoring activities (Note 1,2 and 3). (CPCB, MINARS, 2007-2008)

Note 1: ‘Protection of Environment’ Provisions in India’s constitution. The forty second amendment to the Constitution in 1976 underscored the importance of ‘green thinking’. Article 48A enjoins the state to protect and improve the environment and safeguard the forests and wildlife in the country. Further, Article 51A (g) states that the “fundamental duty of every citizen is to protect and improve the natural environment including forests, lakes, rivers and wildlife and to have compassion for living creatures".

Note 2: Policy Documents on Natural Resource Conservation Policy Statement for Abatement of Pollution (1992) has suggested developing relevant legislation and regulation, fiscal incentives, voluntary agreements and educational programs and information campaigns. It emphasizes the need for integration by incorporating environmental considerations into decision making at all levels by adopting frameworks namely, pollution prevention at source, application of best practicable solution, ensure polluter pays for control of pollution, focus on heavily polluted areas and river stretches and involve public in decision-making. The National Conservation Strategy and Policy Statement on Environment and Development, 1992 aimed at "integrating environmental concerns with developmental imperatives…. [to] meet the challenges….by redirecting the thrust of our developmental process so that the basic needs of our people could be fulfilled by making judicious and sustainable use of natural resources." The priorities mentioned in this policy document include the sustainable use of land and water resources, prevention and control of pollution and preservation of biodiversity. The National Water Policy, 2002 contains provisions for developing, conserving, sustainable utilizing and managing this important water resources and need to be governed by national perspectives. Concern due to water logging, ingress of soil salinity and over–exploitation of groundwater will be addressed on the basis of common policies and strategies. The policy includes improvements in existing strategies, innovation of new techniques to eliminate the pollution of surface and groundwater resources to improve water quality. It has emphasized on water resource planning, development of institutional mechanism, water allocation, groundwater development and participatory approach to water resource management. Regular water quality monitoring programme for both surface and groundwater will be undertaken with particular emphasis on pollution control at source. (CPCB, MINARS, 2007-2008)

Note 3: The conservation of water resources expressed in the Constitution is embodied in the following regulations:

1) The Water (Prevention & Control of Pollution) Act, 1974 as amended deals comprehensively with water issues. It empowers the Government to constitute Pollution Control Boards to maintain the wholesomeness of national water bodies. It enables Central

and State Pollution Control Boards to prescribe standards and has provisions for monitoring & compliance and penal provisions against the violators of the Act. It provides the permit system i.e. "Consent" procedure to prevent and control of water pollution. The Act empowers State Boards to issue directions to the defaulters.

2) Water Cess Act, 1977 was adopted to strengthen the Pollution control Boards financially, to promote water conservation. This Act empowers the Central Government to impose a Cess on water abstracted from natural resources by industries and local authorities.

3) Environment (Protection) Act, 1986 has a broad coverage in which 'Environment' includes water, air and land and there exists an interrelationship among water, air, land, human beings and other creatures. It empowers to take measures in protecting and improving the quality of the environment through preventing, controlling and abating environmental pollution. The Government is authorized to set national standards for ambient environmental quality and controlling discharges to regulate industrial locations, to prescribe procedure for hazardous substance management and to collect and disseminate information regarding environmental pollution. The Act provides for severe penalties for those who fail to comply with or contravenes any provision of the Act.

4) The Manufacture, Storage, Import of Hazardous Chemicals Rules, 1989 and its amendments under EPA, 1986 has identified the responsibilities of various stakeholders for management of chemicals and containment of spillage.

5) The Hazardous Wastes (Management and Handling) Rules, 1989 and its subsequent Amendment 2000 were created to provide 'cradle-to grave' or comprehensive guidance to the generators, transporters and operators of disposal facilities among others, and monitoring norms for State governments.

6) The Municipal Wastes (Management & Handling) Rules, 1999 fix responsibilities to every municipalities responsible for the collection ,segregation, storage, transportation and disposal of municipal wastes.

7) The Bio-medical waste (Management & Handling) Rules, 1998 are likewise directed at institutions that generate and bio-medical wastes in any form. (CPCB, MINARS, 2007-2008)

Under Water Act, 1974, pollution control boards were created, who are responsible for implementation of its provisions. One of the important provision of the Water Act, 1974 is to maintain and restore the 'wholesomeness' of our aquatic resources. To define the level of 'wholesomeness to be maintained or restored a system of water use classification was developed. Under this system water uses are classified in 5 classes (Appendix III) (CPCB, MINARS, 2007-2008).

If a water body or its part is used for multipurpose, then the use which demands highest quality of water is designated as 'designated best use' and accordingly water body or its part is designated. Now through regular water quality monitoring existing water quality is assessed and compared with the desired quality as identified under designated best use class and gaps are identified. Based on the identified gaps the water body or its part is identified as polluted. (CPCB, MINARS, 2007-2008)

2.7 Water quality management in India

The Central Pollution Control Board (CPCB) is an apex body in the field of water quality management in India. For rational planning of any water quality management programme, CPCB needs to know the nature and extent of water quality degradation. Therefore, a sound scientific water quality monitoring programme is prerequisite. Realising this fact, water quality monitoring was started in 1976 by CPCB with 18 stations on the Yamuna river. The programme was gradually extended. Today, there are 1032 monitoring stations in the country spread over all important water bodies. (CPCB, MINARS, 2007-2008).

For this research study, the water quality data have been obtained from CPCB in collaboration with concerned SPCB, i.e, Gujarat Pollution Control Board. The CPCB/SPCB follows all the above mentioned steps for the water quality monitoring.

2.8 Assessing water quality: Review of literature

2.8.1 Water Quality Index

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). To analyze and interpret the kinds of parameters measured along the range of a river, there are various mathematical methods that are used such as Water Quality Index. It is one of the simplest methods with wide applications. In this method a considerable amount of data resulting from measurements of water quality are converted to a single and dimensionless number in a rated scale with interpreted quality and conception (Salim et al., 2009). Water quality indices are tools to determine conditions of water quality. Relevant studies on Water Quality Index (WQI) and its modeling were reviewed. Creating the WQI involves three main steps (US EPA, 2009): (1) obtain measurements on individual water quality indicators (2) transform measurements into "subindex" values to represent them on a common scale (3) aggregate the individual subindex values into an overall WQI value. It is found from the study of various literatures that the Water Quality Index measurements are based on five types of WQI aggregation functions :

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

2.8.2 Review of significant water quality indices

Horton (1965) used the arithmetic aggregation function for the WQI. He selected 8 water quality variables for his index including dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity, chloride, carbon chloroform extract and sewage treatment (Lumb et al., 2011) . The arithmetic weighing of the water quality variables was multiplied with the temperature and "obvious pollution" to obtain the sum aggregation function from which the overall Water Quality Index was found out. The index weight ranged from 1 to 4. Similar to Horton (1965), Brown et al. (1970) also employed basic arithmetic weighting, although without the multiplicative variables. This effort was supported by the National Sanitation Foundation (NSF) in which the water quality variables were chosen using the Delphi method (Dalkey, 1968), which generates results from the convergence of expert's opinions. The index developed by NSF represented the general water quality status of monitoring stations using 9 quality parameters. Parameters required for this index are: faecal coliforms, Biochemical Oxygen demand ($B0D_5$), turbidity, pH, Total Suspended solids (TSS), dissolved Oxygen (D0) in %, Nitrate Nitrogen ($N0_3$), Phosphate ($P0_4$) and Temperature (ΔT). The NSFWQI used logarithmic transforms to convert water quality variable results into subindex values. Scientists were asked to graph the level of water quality ranging from 0 (worst) to 100 (best) from the raw data. Curves drawn were then averaged to obtain a weighting curve for each parameter. Results of the nine parameters are compared to the curves and a numerical value, or "Sub index value," is obtained. To estimate the final index the equations (2.1) and

(2.2) are used (NSF, 2003). Table 2.5 shows the ranking criteria of NSF Water Quality Index and Table 2.6 shows the weights of the water quality parameters.

$$\sum_{i=1}^{n} \text{Ii X Wi} \quad (2.1)$$

$$\sum_{i=1}^{n} \text{Wi} = 1 \quad (2.2)$$

I_i= Sub-index of each parameters

W_i= Weighting factor

n= Number of sub-indices

Table 2.5 NSF Water Quality Index ranking

Quality	**Value**
Very good	90 - 100
Good	70 - 90
Fair	50 - 70
Bad	25 - 50
Very bad	0 - 25

Table 2.6 Importance rate and parameter's weight in NFSWQI

Parameters	**Weight**
DO%	0.17
Faecal Coliform	0.16
pH	0.11
BOD5	0.11
ΔT	0.1
T.PO4	0.1
NO3	0.1
Turbidity	0.08
TS	0.07

Dinius (1972) developed a index based on multiplicative aggregation having decreasing scale, with values expressed as a percentage of perfect water quality corresponding to 100%. Similar work was carried out by Helmer & Rescher (1959), Dalkey & Helmer (1963) by introducing changes to Delphi method (Dalkey 1968). Brown et al.(1972), Bhargava et al.

(1998), Dwivedi et al. (1997); Bhargava (2006); Landwehr et al. (1976) gave multiplicative form of the index where weights to individual parameters were assigned based on a subjective opinion based on the judgment and critical analysis of the author. Dee et al. (1972, 1973) proposed a system for evaluating the environmental impact of large scale water resources projects.

McClelland (1974) introduced the geometric mean form of weighting to the WQI. McClelland was concerned that the arithmetic mean lacked sensitivity to low value parameters, a characteristic later deemed "eclipsing." McClelland instead proposed the weighted geometric mean. Walski and Parker (1974) used the weighted geometric mean for aggregation. They developed an index based on empirical information on the suitability of water for a particular use specifically for the recreational water. The sensitivity functions were determined to assign each parameter a value between one and zero, representing ideal conditions and completely unacceptable conditions respectively .To aggregate the sub-indices, a geometric mean was employed. Bhargava (1985) developed an index based on weighted geometric mean by identifing 4 groups of parameters. Each group contained sets of one type of parameters. The first group included the concentrations of coliform organisms to represent the bacterial quality of drinking water. The second group included toxicants, heavy metals, etc. The third group included parameters that cause physical effects, such as odor, color, and turbidity. The fourth group included the inorganic and organic nontoxic substances such as chloride, sulfate, etc. The sub-indices were worked out and the expression for the index a beneficial use is given by:

$$[\prod_{i=1}^{n} f_i\,(P_i\,)\,]^{1/n} \qquad (2.3)$$

where n is the number of variables considered more relevant to the use and $f_i(P_i)$ is the sensitivity function of the ith variable which includes the effect of weighting of the ith variable in the use. The index was applied to the raw water quality data at the upstream and downstream of river Yamuna at Delhi, India.

Landwehr et al. (1974); Dinius (1987) also employed a weighted geometric mean for aggregation.

Dojlido et al. (1994) used the harmonic mean to find the WQI. This mean does not use weights for the individual indicators. Dojlido (1994) found that it was more sensitive to the most impaired indicator than the arithmetic or harmonic means ,reducing eclipsing, while still accounting for the influence of other indicators (Walsh &Wheeler,2012). Other indices based on Harmonic means are Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) and British Columbia Water Quality Index. The CCMEWQI compares observations to a benchmark instead of normalizing observed values to subjective rating curves, where the benchmark may be a water quality standard or site specific background concentration (CCME,2001; Khan et al.,2003; Lumb et al., 2006).British Columbia Water Quality Index was developed by the Canadian Ministry of Environment in 1995 as increasing index to evaluate water quality. This index is similar to CCMEWQI where water quality parameters are measured and their violation is determined by comparison with a predefined limit. It provides possibility to make a classification on the basis of all existing measurement parameters (Bharti & Katyal, 2011). To calculate final index value the following equation is used:

$$BCWQI = \frac{\sqrt{{F_1}^2+{F_2}^2+\left(\frac{F_3}{3}\right)^2}}{1.453} \qquad (2.4)$$

F_1: percentage of parameters which have been violated with respect to all parameters
F_2: number of offender data with respect to all measured data
F_3: maximum percentage of violation
The number 1.453 was selected to give assurance to the scale index number from zero to 100. It is important to note that repeated samplings and increasing stations increase the accuracy of British Columbia index. The disadvantages of this method are that this index does not indicate the water quality trend until it deviates from the standard limit. Also, due to using a maximum percentage of deviation, it cannot determine the number of withdrawals above the maximum limit of standard (Ministry of Environment, 1996). Table 2.7 shows the rankings in the British Columbia Water Quality Index.

Table 2.7 Water quality ranking for British Columbia Water Quality Index.

Rating	F_1	F_2	F_3	Index Value	Index Rank
Excellent	0 to 2	0 to 1	0 to 9	0 to 4	0 to 3
Good	3 to 14	2 to 14	10 to 45	5 to 25	4 to 17
Fair	15 to 35	15 to 40	46 to 96	26 to 62	18 to 43
Borderline	36 to 50	41 to 60	97 to 99	63 to 85	44 to 59
Poor	51 to 100	61 to 100	99.1 to 100	86 to 145	60 to 100

Smith (1987) developed an index based on minimum operator for four water uses i.e., contact as well as noncontact. It is a hybrid of the two common index types and is based on expert opinion as well as water quality standards. The selection of parameters for each water class, developing sub indices, and assigning weightages were all done using Delphi. The minimum operator technique was used to obtain the final index score (Bharti & Katyal,2011):

$$I_{min} = \Sigma\,(I_{sub1}, I_{sub2}, \ldots\ldots. I_{subn}) \qquad (2.5)$$

Where, Imin equals the lowest sub index value.

2.8.3 Other water quality indices

Some of the water quality indices developed worldwide and widely used indices have been reviewed here.

Oregon Water Quality Index (OWQI)

The Oregon Department of Environmental Quality (ODEQ) developed the original Oregon Water Quality Index (OWQI) in 1980. The OWQI is calculated in two steps. The raw analytical results for each variable, having different units of measurement, are transformed into unitless subindex values. These values range from 10 (worst case) to 100 (ideal). These subindices are then combined to give a single WQI value ranging from 10 to 100. The OWQI is integrating measurements of eight water quality variables (temperature, DO, BOD, pH, ammonium - nitrate nitrogen, total phosphates, total solids, and fecal coliform) (Cude, 2001).

Florida Stream Water Quality Index (FWQI)

The Florida Stream Water Quality Index (FWQI) was developed in 1995 under the Strategic Assessment of Florida’s Environment (SAFE). It is an arithmetic average of water clarity turbidity and total suspended solids, dissolved oxygen; oxygen-demanding substances Biological Oxygen Demand [BOD], Chemical Oxygen Demand [COD], Total Organic Carbon [TOC]), nutrients (phosphorus and nitrogen), bacteria (total and fecal coliform), and biological diversity (natural or artificial substrate macroinvertebrate diversity and Beck’s Biotic Index). The values for this index were determined as follows: 0 to less than 45 represents good quality, 45 to less than 60 represents fair quality, and 60 to 90 represents poor quality (SAFE, 1995).

Overall Index of Pollution (OIP)

Sargaonkar and Deshpande (2003) developed Overall Index of Pollution (OIP) for Indian rivers based on measurements and subsequent classification of pH, turbidity, dissolved oxygen, BOD, hardness, total dissolved solids, total coliforms, arsenic, and fluoride. Each water quality observation was scored as Excellent, Acceptable, Slightly Polluted, Polluted, and Heavily Polluted, according to Indian standards and/or other accepted guidelines and standards such as World Health Organization and European Community Standards. Once categorized, each observation was assigned a pollution index value and the OIP was calculated as the average of each index value given by the mathematical expression:

$$OIP = \sum P_i / n \qquad (2.6)$$

Where P_i = pollution index for ith parameter, n = number of parameters.

The River Ganga Index

Ved Prakash et al (1990) developed The River Ganga Index to evaluate the water quality profile of river Ganga in its entire stretch. The index had the weighted multiplication form and was based on the NSFWQI, with slight modifications in terms of weightages to confirm to the water quality criteria for different categories of uses as set by Central Water Pollution Board, India.

In general, water quality indices are divided into five main groups (Sobhani, 2003):

A) Public indices: in this category, the indices ignore the kind of water consumption in the evaluation process, such as NSFWQI, Horton (Ott, 1978) (Horton, 1965).

B) Specific consumption indices: in this category, classification of water is conducted on the basis of the kind of consumption and application (drinking, industrial, ecosystem preservation etc). The most important and applicable of these indices are the Oconer, Oregan and British Columbia indices (DEQ, 2003).

C) Statistical indices: in these indices statistical methods are used and personal opinions are not considered.

D) Designing indices: this category is an instrument aiding decision making and planning in water quality management projects.

An overview of types of indices, their sub- indices, aggregation functions is shown in Table 2.8

Table 2.8 An overview of types of indices, their sub- indices, aggregation functions (Bharti & Katyal, 2011)

Index	**Subindices**	**Aggregation**
CCME	Formula	Harmonic Square sum
British Columbia	Formula	Harmonic Square sum
NSF	Implicit nonlinear	Weighted sum
OIP	Segmented nonlinear	Weighted Average
Smith	Multiple types	Minimum operator
Bhargava	Multiple types	Weighted product
Oregon	Nonlinear	Weighted product (arithmetic/ geometric) Unweighted Harmonic Square Mean
Ved Prakash	Multiple types	Weighted product

2.8.4 Critical appraisal of earlier studies for water quality assessment for Indian rivers and scope of work

The Water Quality Index designed in the present study is designed for Indian rivers. It is developed as a modified version the index given by Tiwari and Mishra in terms of deriving the weightages of each parameter. The basis of selection of the ranges of concentrations of each parameter is in accordance to the water quality criteria for various uses of fresh waters laid down by Central Pollution Control Board (CPCB). Where the CPCB criteria are not given, other standards such as European Community Standards and criteria given by researchers across the world have been used.

The River Ganga Index (Ved Prakash et al. ,1990) is designed to evaluate the water quality profile of river Ganga. It is based on the NSFWQI. It is not a generalised index formulation which can be used for other rivers in India.

In the Overall Index of Pollution (Sargaonkar and Deshpande,2003), the mathematical equations to transform the actual concentration values into pollution indices are formulated and corresponding value function curves are plotted to estimate the OIP. The value function curves, wherein, the concentration of the parameter is taken on Y-axis and index value on Xaxis are plotted. In this method, it is not possible to estimate the index value of the parameter, if the parameter concentration value exceeds the range defined by the researchers. The Water Quality Index developed in the present study is based on the weighted arithmetic mean method. It is very useful to assess the water quality of a river which is vulnerable to organic pollution under Indian conditions. The Water Quality Index developed in the present study can be applied to any river irrespective of the parameter concentration values as the range defined for each parameter has no upper and lower boundary.

2.9 Assessing urbanization: Review of literature

The degree or level of urbanization is defined as relative number of people who live in urban areas. Percent urban [(U/P)*100] and percent rural [(R/P)*100 and urban-rural ratio [(U/R)* 100] can be used to measure degree of urbanization. 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.

There are several characteristics that researchers generally associate with urbanicity.

Yach, et al. (1990) point to several characteristics of urbanization, including rapid population growth and concentration, and improved access to employment, education, and modern health care.

Montgomery et al. (2003) used number of factors viz. population density and size, access to education, the range of goods and services available, access to health services, and added factor of improved access to water and electricity to differentiate between urban and rural environment.

Vlahov and Galea (2002) suggest that urbanicity is defined by the transformations that come about due to changes in population size, density, heterogeneity, and distance from other population centers. They go on to highlight the provision of health and social services, as well as alterations in the social and built environments, as important components of the urban environment.

In a factor analysis, McDade and Adair (2001) using data from the CLHNS found that a high population density and the availability of infrastructure and services (telephone, mail, transportation, electricity, water, and health care facilities) were all correlates of urbanicity.

Various researchers have attempted to measure urbanization in terms of urban concentration:

Hirschman-Herfindahl index of concentration is constructed by squaring the share of population apportioned to each city in the national urban population and summing those squares (e.g., Wheaton and Shishido, 1981).

Pareto parameter indicates how quickly city size declines as one moves from the largest to the smallest in the size distribution (Rosen and Resnick, 1980).

Others use primacy, which is measured by the share of population contained in largest city- or metro area- in a national urban population (Ades and Glaeser, 1995).

Uchida H & Nelson A (2010) proposed an alternative measure of urban concentration called as agglomeration index. It is based on three factors: population density, the size of the population in a "large" urban center, and travel time to that urban center. Each factor used in the index is based on the conceptual framework of agglomeration economies.

Investigators typically use the urban-rural dichotomy to describe urbanicity. The dominance of the urban-rural dichotomy dates at least as far back as the 1940s when the UN began reporting statistics on world urbanization trends, and the dichotomy continues to be the principal form of urban categorization used by the United Nations Population Division (Champion & Hugo, 2004).

Dahly L & Adair L (2007) constructed a scale of urbanicity using community level data from the Cebu Longitudinal Health and Nutrition Survey. They used established scale development methods to validate the new measure and tested its performance against the dichotomy. The new scale illustrated misclassification by the urban-rural dichotomy, and was able to detect differences in urbanicity, both between communities and across time, that were not apparent before. The scale was constructed using 7 components viz. Population size, population density, communications, transportation, educational facilities, health services & markets.

The scale formed by Dahly & Adair (2007) has considered the aspects of Demographics and Infrastructure only. In the present study, in addition to Demographics and Infrastructure, the aspects of Spatial development and economic development are also incorporated to estimate the urbanization level of a location. Under four aspects considered, namely, Demographic aspect, Economic development aspect, Spatial Aspect and 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).

2.10 Impact of urbanization on water quality

As an area develops, there are various water quality issues created due to the urban development activities, namely, Population Growth, Erosion and Sedimentation impacts, (USGS, 1996) and Industrial waste water discharges.

2.10.1 Population impacts on water quality

The impact of population on the ability of water sources to meet the demands placed on them by society is paralleled by the effects of population on the quality of water resources. People alter the properties of water as they use it, often degrading the quality with each successive use. Water used in households for drinking, bathing, and cooking becomes contaminated by various chemicals and other constituents introduced during its use. Drainage from water applied in agricultural irrigation carries away chemicals that have been applied to crops to enhance their growth and control weeds and pests. Industries introduce chemicals needed for the manufacture of their products.

As a result of human intervention, waters that have been used for a variety of purposes may contain harmful constituents, including sewage, that pose threats to the environment and to the public health. Their removal can be expensive and difficult. (www.waterencyclopedia.com)

2.10.2 Impacts of erosion and sedimentation

A wooded area has little runoff associated with rain events. Most water is retained on-site and is infiltrated or evapotranspired. When such a site is to be developed for housing, commerce, silviculture, or agriculture it is often clear-cut to remove the trees. This removes much of the evapotranspiration potential of the site, and causes a large increase in surface runoff. This runoff increase causes erosion of the nearby and downslope land, with steeper slopes more susceptible to erosion than gentler slopes. The runoff picks up and transports dirt that becomes suspended sediments upon reaching a receiving water body.(Ahuja S., 2009)

2.10.3 Impacts of urban runoff

As watersheds are urbanized, much of the vegetation is replaced by impervious surfaces, thus reducing the area where infiltration to groundwater can occur. Thus, more stormwater runoff occurs. Storm water runoff flows downhill until a water body is encountered, which it becomes part of. As it moves downhill, it carries with it all manner of physical, chemical, and biological pollutants. It is storm water runoff that leads to much of the pollution of surface waters, including streams, rivers, lakes, reservoirs, estuaries, and the coastal ocean (Schueler and Holland, 2000; Dorfman and Stoner, 2007). As runoff flows over the land surface, stormwater picks up potential pollutants that may include sediment, nutrients (from lawn fertilizers), bacteria (from animal and human waste), pesticides (from lawn and garden chemicals), metals (from rooftops and roadways), and petroleum by-products (from leaking vehicles). Pollution originating over a large land area without a single point of origin and generally carried by stormwater is considered non-point pollution. (USGS, 1996).

2.10.4 Impacts of industrial waste water discharges

When an urbanized area houses industries, the water used in industries may be discharged into waterways without proper treatment. Pollution from industrial entities are industry specific (www.pollutionissues.com).

2.11 Assessing impact of urbanization on water quality: review of literature

The review of literature of earlier studies for measuring impact of urbanization on water quality is discussed in this section. The critical appraisal and the scope of the work with reference to each of the studies reported in literature are described along with it.

1) Ouyang et al. (2005) have attempted to assess the impact of urban activites on river water quality. A synthetic pollution index developed was applied to assess the river water quality for rural and urban areas.

In the above study, the rural and urban water quality have been compared, but no attempt has been made to quantitatively correlate the urbanization and water quality specifically based on Water Quality Index and urbanization levels of the locations under study.

2) Atef A., Rakad T. (2003) investigated the effect of urbanization, drought and pollution on the deterioration of water quality in the Tafila Basin in southern Jordan. The study region considered had arid and semi-arid climatic characteristics, high population growth and the lack of sewer systems. The infiltration of waste water from septic tanks into springs and ground-water resources was considered the most prominent cause for the deterioration of water quality.

The results of of the above study are case specific. There is no comparision of water quality corresponding to different levels of urbanization.

3) Dong Y., Mei Y. (2010) reviewed the progress of the urbanization in Guangzhou, China and focused on the change of water quality in the Guangzhou reach of the Pearl River. Eight kinds of main pollutant parameters were collected from nine important sections in the Guangzhou feach of the Pearl River from 1986 to 2000 and the water quality change was analyzed per time and space.

In the above study, for the assessment of water quality and urbanization, gross measurement indicators are not established. Four water quality parameters, DO, BOD, Nitrate Nitrogen and Ammonical Nitrogen were correlated individually to each of urbanization measures viz. population, industrial gross production value and social capital assets investment.

4) Lee R., Christine L. et al (2008) selected three watersheds in the Cookeville, Tenneissee area, USA to conduct a chemical and biological assessment of watershed water quality. Three streams were chosen to compare the effect of urbanization.Correlation between biotic index score and urban areas was established.

In the above study, water quality is not aggregated into a single score using various physical, chemical and biological parameters indicating the water quality. Moreover the urbanization is defined based on the percentage of urban areas only. The correlation is developed only between the biological characteristic indicators of the water quality and the percent of urban areas only.

5) Koteshwari Y., Ramanibai R. (2005) carried out a study focused on water quality of permanent and temporary water bodies along the urban and suburban gradients of Chennai City, South India. Water samples were analyzed for their major elements and nutrients.
In the above study, water quality of water bodies are compared at urban and sub urban locations. The results of the study are generalized to indicate the decline in water quality in urban locations compared to sub-urban locations. No correlations are developed for assessment of water quality and urbanization levels.

6) Lee C. (1997) compared the water quality along a gradient of urbanization. A gradient of development in Madison County, Georgia was chosen to demonstrate the difference in water quality from a completely developed area to extremely rural area. The development considered is mainly in the form of residential, subdivision development.

In the above study, development measuring urbanicity was in form of % of Residential areas. No water quality measurement indicator, urbanization indicator was developed.

7) He H., Zhou J. et al. (2008) studied the response of surface water quality to urbanization in Xi'an, China. The study described the change in urban land use from 1996 to 2003, analyzed the quality of the surface water, and developed a model of urban expansion to simulate the water environment's response to urbanization.

8) Liu Y., Ke-Ming M. et al. (2007) carried out study to investigate the impacts of urbanization on lake water quality in Hanyang, Hubei Province, China. Correlation between different land uses and water quality indicators at both whole lake watershed and small catchment scales was established.

9) Ren W., Zhong Y. et al. (2003) undertook a preliminary investigation into the relationship between water quality and urbanization as well as the changing patterns of land use within Shanghai. Longitudinal changes to water quality at various points along the course of the Huangpu River were analysed and compared to changes in the rates of urbanization and changes in land uses.

10) Ashantha G., Evan T. (2004) undertook an in- depth investigation of pollutant wash –off by analyzing the hydrological and water quality data from areas having different land uses in order to correlate urban form to water quality. The three main catchments selected were forested catchment, low density residential catchment, high density residential catchment.

11) Hwang C., Friedmann J. et al. (2006) examined relationship of urbanization (based on land cover, Agriculture, village and urban) with Total Suspended Solids (TSS), Escherichia coli colony counts (MPN), nutrient levels (NH_4-N, PO_4, NO_3-N) and stream discharge in the lower Kaskaskia watershed in Southern Illiois.

In study 7), 8), 9), 10) and 11), the increasing urban land use was correlated with fluctuations in water quality. The studies have defined the urbanized areas through the land uses only. The researchers have not quantitatively distinguished the Urbanized and rural areas based on other parameters such as industrial growth, etc. Morever the water quality is not summarized.

12) Melissa K. (2008) evaluated the effects of varying degrees of urban land use in the upstream watershed by examining the composition of macroinvertebrate communities in creeks of San Francisco Bay Area. For comparison, three sites on each stream were selected with increasing levels of urbanization. Water quality was evaluated by calculating biological metrics such as Family Biotic Index scores based on benthic macroinvertebrate samples.

In the above study, only biological characteristics were selected for indicating the water quality. Only degrees of urban land use were used to indicate levels of urbanization. No correlations for the above were developed.

13) Sung R., Myung B. (2000) evaluated the effects of land use and municipal wastewater treatment changes on streamwater quality in a tributary of the Han-river, Korea from 1994 to 1999.

In study the above study, correlations between urbanization, water quality, stream flow is not established. Moreover only water quality and land use changes are described and not the absolute measures.

14) Larry M., James P. (1997) conducted a study of urban- related water quality effects in the Kansas River, Shunganunga Creek Basin, and Soldier Creek in Topeka, Kansas from October 1993 through September 1995. The purpose of this report was to assess the effects of urbanization on instream concentrations of selected physical and chemical constituents within the city of Topeka.

In study the above study, the differentiation of urbanized and non- urbanized area is not carried out. Water quality and urbanization is not aggregated into a single score. Correlations are not established. From the levels of urbanization, water quality prediction is not done.

15) Hongming H., Jie Z. et al. (2007) carried out study to investigate water quality pollution impacts on urbanization by analyzing temporal and spatial characteristics of different water quality parameters, and simulating economic loss resulting from the impact of water pollution on human health, industry, crop yields, livestock and fisheries in Xi'an, China based on data from 1996 to 2003.

In study the above study, water quality pollution impacts on urbanization are assessed by analyzing economic loss on various factors contributing to urbanization. However model is not developed to predict water quality due to future economic growth or urbanization.

2.12 Scope of work with reference to the studies reported in the literature

Many studies have been reported in the literature for assessment of water quality, urbanization and the impact of urbanization on water quality. However, there is a scope of work to develop the following models:

1. Water Quality Index model

There is a scope of work in the present study for the developing the water quality model for the assessment of water quality under Indian conditions by using the CPCB criteria/ standards and Indian Standards for deciding the ranges of the water quality parameters.

2. Urbanization Index model

There is a scope of development of Urbanization Index using four different aspects of urbanization, namely, demographic aspect, Economic development aspect, spatial aspect and infrastructural aspect. Also, there is a scope to evolve urbanization index model for the catchment area. In the studies reported in the literature for the assessment of urbanization, the researchers have evaluated the urbanization level for the geographical boundaries or political boundaries because of the ease of availability of data for the area within that boundary. However, there is a scope of work to evaluate the urbanization for the area within the watershed boundary, even though the data availability is within the political boundary.

3. Water Quality – Urbanization Regression model

Many researchers have attempted to establish the correlation between urbanization and water quality qualitatively considering both urbanization and water quality qualitatively, e.g, water quality may be assessed in terms of ‘good’, ‘bad’, acceptable etc. and urbanization be expressed as rural, urban, etc.

Other researchers have used a single indicator parameter of water quality or urbanization for correlation.

Hence, there is a scope of work to aggregate the water quality into a single indicator parameter quantitatively and the urbanization level into a single indicator parameter quantitatively as well. Furthermore, there is a scope of work to establish correlation between the water quality and urbanization numerically.