WATER QUALITY MANAGEMENT STUDIES ON THE RIVER SATLUJ FOR THE PROTECTION OF THE HARIKE WETLAND SYSTEM

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by

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CERTIFICATE

I, hereby certify that the work being presented in the thesis entitled **'Water Quality Management Studies on the River Satluj for the Protection of the Harike Wetland System'** submitted to the Department of Biotechnology and Environmental Sciences, Thapar University, Patiala for award of the degree of **Doctor of Philosophy,** is an authentic record of my own research work carried out under the guidance and supervision of Dr. Akepati S. Reddy and Dr. R. Dalwani.

The matter embodied in this thesis has not been submitted, in part or full for the award of any other degree/diploma at this or any other university/institute. All the ideas and references have been duly acknowledged.

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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

River water quality monitoring programs are very important in the river water quality management objectives. National River Conservation Directorate, Ministry of Environment and Forests, Government of India implements many of these monitoring programs on most of the rivers across the country. Satluj river water quality monitoring program has been one such program implemented since 1996. Huge monitoring data has accumulated from this water quality monitoring program. Harike wetland system is a man-made riverine freshwater Ramsar wetland site of international importance on the river Satluj at its confluence with the river Beas. Deteriorating water quality and water hyacinth infestation have been the major problems associated with this wetland system. Heavy pollution loads delivered by the river Satluj have been mainly responsible for this rapid deterioration. There is an urgent need for the improvement of the wetland's water quality in order to ensure its continued suitability as habitat for the migratory waterfowl and to protect or conserve the wetland system's biodiversity. One strategy for this can be water quality management in the river Satluj and the river Beas, which are the contributors of both water and pollution to the wetland system.

This thesis presents the outcomes of a comprehensive research study undertaken to understand the factors that influence the water quality of river Satluj by its catchment which further affect the ecosystem of wetland system. Use specific water quality index for Ecological use (WQI_E) has been developed to evaluate the water quality of river Satluj and to communicate water quality information and strategies for water quality improvement to all the stakeholders in order to ensure appropriate actions at all levels.

All the water quality parameters against which prescribed limits exist have been selected for inclusion in the indexing. The selected parameters grouped into three sub-indices categories: general parameters (SI_{gp}), heavy metals (SI_{hm}) and pesticides and other toxic organic compounds (SI_{ptoc}). General water quality parameters included 10 variables: BOD_5, DO, pH, COD/BOD_5 ratio, Turbidity, TSS, Total-N, Total-P, Ammonical-N and Fluoride. Open ended list of heavy metals and pesticides and other toxic organic compounds has been considered.

Assignment of relative importance through the expert opinion is limited only to the selected general parameters. Further, for minimizing the uncertainty and subjectivity, instead of ranking and assigning scores to parameters individually, pair-wise comparison technique was used. Sub-index for general parameters (SI_{gp}) was calculated through transforming the parameter values and aggregating by weighted root sum function. Transformation curves were established for each of the general parameter to assess the variation in water quality levels, which were based on the water quality standards and criteria used by several countries viz. India, Canada, USA, South Africa, Vietnam and organizations viz. CPCB, WHO, European Union etc. In case of the heavy metals and the pesticides, flexibility of using open ended lists of parameters has been introduced and maximum operator sub-indices (sub-index for heavy metals - SI_{hm} and sub-index for pesticides - SI_{ptoc}) were used. Values of all the selected heavy metals and pesticides parameters were first transformed into concentration ratios by division with corresponding prescribed water quality standards. One heavy metal parameter and one pesticide parameter, both with the maximum concentration ratios (in their respective groups), were considered in the calculation of sub-indices. Overall WQI_E has been obtained by geometric mean of all the three sub-indices.

The developed WQI_E was applied on the water quality monitoring data for analyzing temporal and spatial water quality of the river Satluj. The river water quality was considered as excellent when the WQI_E was 92-100, as good when 70-92, as moderate when 30-70, as poor when 08-30 and as worst when <08. Water quality in the Satluj river is found deteriorated downstream to SAT-6 station.

In order to reduce the implementation cost of the monitoring program some suggestions were made to optimize the monitoring program while reducing the number of sampling stations, frequency of sampling and number of parameters tested through multivariate statistical analysis of the data. Cluster analysis was used to minimize the number of sampling stations and the frequency of sampling. Principal component analysis, coupled with Water Quality Index (WQI) approach was used to reduce and select the parameters required for the analysis at each of the sampling stations. The study showed that the number of sampling stations can be reduced to six from eight, the frequency of sampling to 9.5/year from 12/ year, and the number of parameters to 11.5/sample from 17/sample. The study has provided a technique for the selection of parameters and assigning relative importance value for WQI calculations. However, it is observed that the parameters selected and the relative importance values assigned are station specific.

RESEARCH PUBLICATIONS

Paper published in peer reviewed journals:

- ❖ **Sharma, S.**; Reddy, A.S. and Dalwani, R. (2015) "Ecological Water Quality Index Development and Evaluation of Water Quality of the Satluj River". *Indian Journal of Environmental Protection*, 35(6): 477-489.
- ❖ **Sharma, S.**; Reddy, A.S. and Dalwani, R. (2014) "A new water quality index for irrigational use and water quality assessment of the Satluj river, Punjab, India". *Journal of Environmental Research and Development*, 9(3): 585-594.
- ❖ Arora, N., Arora, A.S., **Sharma, S.** and Reddy, A.S. (2014), "Use of Cluster Analysis – A Data mining tool for improved water quality monitoring of river Satluj". International Journal of Advanced Networking Applications, Special Edition: 63-68.
- ❖ **Sharma, S.** and Reddy, A.S. (2013), "Development of water quality indices for designated best uses of surface water body". *International Journal of Engineering Science and Innovative Technology*, 2(5): 82-93.

Papers presented in international and national conferences:

- ❖ Presented a paper (Oral) entitled "**Development of use specific water quality indices & evaluation of water quality of the Satluj river**" in National Conference on Environmental Sustainability and Society organized by Jaypee University of Engineering and Technology, Guna (M.P.), held during 30-31 March, 2013.
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LIST OF ABBREVIATIONS

ATI	Aquatic Toxicity Index
BCWQI	British Columbia Water Quality Index
BOD_5	Biochemical Oxygen Demand 5 day
CA	Cluster Analysis
Cd	Cadmium
CESU	Common Environmental Scale Unit
CN	Curve Number
COD	Chemical Oxygen Demand
CPCB	Central Pollution Control Board
Cu	Copper
DA	Discriminant Analysis
DEM	Digital Elevation Model
DO	Dissolved Oxygen
EWQI	Ecological Water Quality Index
FA	Factor Analysis
GIS	Geographical Information System
GRPI	Ganga River Pollution Index

HEI	Heavy Metal Evaluation Index
Hg	Mercury
ISRO	Indian Space Research Organization
LULC	Land Use and Land Cover
MOEF	Ministry of Environment and Forests
N/P	Nitrogen and Phosphorous Ratio
NBSS	National Bureau of Soil Survey and Land Use Planning
NH_3-N	Ammonical Nitrogen
NO_3-N	Nitrate Nitrogen
NRC	National Resource Census
NRCD	National River Conservation Directorate
NRR	National Natural Resources Repository
NSF WQI	National Sanitation Foundation's Water Quality Index
OIP	Overall Index of Pollution
OWQI	Overall Water Quality Index
Pb	Lead
PC	Principal Components
PCA	Principal Component Analysis
PNPI	Potential Non-point Pollution Index

PRC/TE	Parameter Rating Curve/ Transformation Equation
RCN	Run-off Curve Number
RSI	River Status Index
SG	Spatial Group
SI_{gp}	Sub Index general parameters
SI_{hm}	Sub Index heavy metals
SI_{ptoc}	Sub Index pesticides and other toxic organic compounds
SWQI	Simple Water Quality Index
TDS	Total Dissolved Solids
TG	Temporal Group
TIET	Thapar Institute of Engineering and Technology
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
UK	United Kingdom
US EPA	United States Environmental Protection Agency
USA	United States of America
WHO	World Health Organization
WQI	Water Quality Index

WQI_B	Basic Water Quality Index
WQI_E	Ecological Water Quality Index
WQI_{min}	Minimal Water Quality Index
WQI_O	Overall Water Quality Index
WQI_{obj}	Objective Water Quality Index
WQI_{sub}	Subjective Water Quality Index
Zn	Zinc

Chapter – 1

INTRODUCTION

1.1 Background

Rivers due to their role in carrying off the municipal and industrial wastewater and run-off from agricultural land in their vast drainage basins are among the most vulnerable water bodies to pollution (Singh *et al.*, 2005; Koklu *et al.*, 2010). In many developing countries, wastewater is disposed into the natural water bodies due to their capacity to assimilate and dilute the harmful constituents of the effluents. As municipal and industrial demand for freshwater rises, increasing effluents of low quality are dumped unchecked into the natural water bodies resulting in further degradation of their water quality. Large quantities of untreated municipal sewage and industrial effluent are being discharged directly to surface water resulting in serious pollution. Generally, urban wastewater consists of high quantities of sewage (millions of pathogenic microorganisms causing enteric infections), industrial wastes (toxic ions and heavy metals) and carcinogens (Morishita, 1988).

The rapid industrialization also adversely affects the environment directly and indirectly. Industrial development manifested due to setting up of new industries or expansion of existing industrial establishments results in the generation of industrial effluents. The present method of transportation of these effluents, their ultimate disposal and treatment facilities for making effluents innocuous and safe are inadequate, unplanned and suffers negligence and shortage of funds (Kulkarni, 1997). The net result is large scale pollution of the water bodies which may act as a source of water supply for domestic use of inhabitants of localities. This loss of water quality may cause health hazards to human and livestock, death of aquatic life, crop failure and loss of aesthetics. Consequently, human health and crop yields are being affected or threatened in many cases. Each water body can assimilate a certain amount of effluents depending on numerous factors. The water quality management attempts to protect the uses of water bodies facing the threat of pollution (McBride, 2002).

Rivers provide an array of ecosystem goods and services, including biodiversity, attenuation of flood waters, abstraction, recreation, production of power, food and other marketable goods.

However, human activities in river catchments over prolonged periods, such as settlement, agriculture and forestry, impact the freshwater ecosystem and have substantially altered riverine processes (Malmqvist and Rundle, 2002). This has culminated in altered flow regimes, sources of point and diffuse pollution and widespread degradation, with negative consequences for biodiversity.

Water quality in a river at any point at any given time reflects several major influences, including lithology of the basin, atmospheric inputs, climatic conditions and anthropogenic inputs (Shrestha and Kazama, 2007). Anthropogenic activities result in significant decrease in the river water quality. River inflows contribute pollutants to the riverine wetlands, thereby tending to induce serious ecological problems (Tanriverdi *et al.*, 2010). Wetlands provide important habitat for aquatic, terrestrial and avian species (Wright *et al.*, 2006). A good number of listed endangered and threatened species depend directly or indirectly on wetlands for a variety of functions including feeding, breeding, nesting and raising their young (USEPA, 2013).

Both, natural and man made wetlands, can improve water quality of streams, rivers and lakes. Instream wetlands can improve habitat and provide some water quality functions to small streams and riparian wetlands along larger rivers provide important roles in both capturing sediments and nutrients from the river itself and serving as buffer between uplands and the river. Without wetlands, watersheds lost part of their ability to maintain a biogeochemical balance. The run-off comprising fertilizers, pesticides and sediments from agricultural land and urban areas, have nowhere to go except directly into water ways. Hence, it is needed to restore and protect the wetlands to enhance the physical, chemical and biological integrity of our streams and rivers (Mitsch, 1995).

River water quality management demands monitoring of the river waters at multitude of locations along the river and use of the monitored data both for water pollution control and for the river water resources management. River water quality monitoring generating very vast data has thus been integral part of most of the river water quality management programs. However, results of the monitoring, usually available in the form of a complex data matrix (in time and space dimensions on a large number of physico-chemical and biological parameters), are most often difficult to interpret and draw meaningful conclusions (Koklu *et al.* 2010).

Traditional approaches to assess river water quality are based on the comparison of the monitored parameter values with the existing local standard/criteria values. This approach mostly allows proper identification of contamination sources and may be essential for checking legal compliances. But, it does not provide global vision on the spatial and temporal trends in the overall water quality in a watershed (Debels *et al.* 2005).

Water quality is a complicated issue, and its monitoring and description is mostly a specialist's job. A multitude of attributes are used for describing and a multitude of parameters are used for monitoring the water quality. The quality parameters used, because of the limitations imposed by techno-economical and practical feasibilities, vary along two dimensions: nature of use and type of the water resource. Most of the stakeholders (administrators, politicians, grass-root workers, general public and many others), specially the persons who are involved either directly or indirectly in the water quality management, however, are not water quality specialists. For the water quality management in the desired fashion, proper communication of water quality information to all the stakeholders is very crucial. For this Water Quality Index (WQI) can be used.

Water Quality Index (WQI) is intended to provide a simple and easy to understand information on water quality for the managers and decision makers (on the water quality and possible uses of a given water body). It provides a mechanism for presenting a cumulatively derived numerical expression defining a certain level of water quality (Bordalo *et al.*, 2001). WQI reflects the composite influence of significant physical, chemical and biological water quality parameters.

Watershed management is widely considered as the most appropriate approach for water quality management. A watershed approach is a flexible framework for managing water resources quality and quantity within specified drainage area or watershed (USEPA, 2008). However this approach has not yet been tried for the Satluj river water quality management. The present work is also an attempt to follow the watershed management approach for the Satluj river water quality management.

1.2 Aim and objectives

Harike wetland system is a man-made riverine freshwater Ramsar wetland site of international importance. It is a vital staging post and winter home for migratory waterfowl. The head works created, on the river Satluj at its confluence with the river Beas, for diverting water for irrigational and municipal use (Jain *et al.*, 2008), is actually responsible for the creation of this wetland system. Deteriorating water quality (specially eutrophication, heavy metal and pesticide pollution) and water hyacinth infestation have been the major problems associated with this wetland system. Heavy pollution loads delivered by the river Satluj have been mainly responsible for this rapid deterioration.

There is an urgent need for the improvement of the wetland's water quality in order to ensure its continued suitability as habitat for the migratory waterfowl and to protect or conserve the wetland system's biodiversity. One strategy for this can be water quality management in the river Satluj and the river Beas, which are the contributors of both water and pollution to the wetland system. Work conducted for the Ph.D program is concerned with the water quality management in the river Satluj.

Government (both Central Government and Punjab State Government), specially the National River Conservation Directorate (NRCD) of Ministry of Environment and Forests (MOEF), has initiated the following two actions in the direction of the Satluj river water quality management:

- Satluj river water quality monitoring project, awarded to TIET, Patiala, for monthly monitoring of the river at 12 different stations, since June, 1996
- Satluj river action plan under which seven sewage treatment plants are to be constructed and operated in order to reduce pollution load into the river

For management of the Satluj river water quality emphasis was given on the following aspects:

- Monitoring of the river water quality
- Pollution mapping of the river Satluj in order to understand the actual contributors of both water and pollution
- Development of strategies for the improvement of water quality in the river Satluj

- Communication of water quality information and strategies for water quality improvement, to all the stakeholder in order to ensure appropriate actions at all levels

The work conducted here actually deals with these aspects of the Satluj river water quality management and following objectives were framed:

- To study the watersheds that contribute both water and pollution loads to the river Satluj.
- To develop Ecological Water Quality Index for the communication of the river water quality information.
- To develop the river water quality management plan for the protection of the Harike Wetland System.

1.3 Scope of the research work

Information on the quality of the river water flowing into the wetland site is immensely important in the management and conservation of the Harike wetland system. The NRCD's Satluj river water quality data available can probably prove appropriate and useful here. Since the river water, in the wetland site, is put to ecological use, for suitability, usefulness and effectiveness, the water quality monitoring, at least at the stations upstream to the wetland site, has to be ecological use biased. Further, the NRCD may have to communicate the Satluj river water quality data preferably in the form of an appropriate water quality index to the wetland sites' management.

In the present study, the NRCD's Satluj river water quality monitoring program has been evaluated against the requirements for the wetland site management and necessary modifications to the monitoring program are suggested. Alternatively, an ecological use specific water quality index is developed and attempted to use for communicating the river water quality.

Development of Ecological Water Quality Index (EWQI) is an important component of the work. This part of the work can facilitate analysis and transformation of the water quality monitoring data accumulated since 1996 into WQI values for communication to the stakeholders.

1.4 Outline of the thesis

This thesis includes five chapters. Chapter 1 describes the research background, aim and objectives of the research study. Chapter 2 provides a critical review of past research relevant to the current research study. It includes information on the various aspects related to river water quality and management, water quality index and watershed management and identifies gaps in the previous studies in context to the present study. Chapter 3 presents the research methodology adopted to achieve the objectives of the work. Chapter 4 provides the results and discussion on the extensive work undertaken involving first the demarcation of the watersheds/sub-watersheds contributing both water and pollution loads to the Satluj river followed by the characterization of individual watersheds and collection of information on the water and pollution loads contributed by them. Development of protocol for the ecological water quality index was also done. Satluj river water quality data was also statistically analyzed for the optimization of the Satluj river water quality monitoring program. Finally water quality management plan developed for the Satluj river while defining goals and objectives of management of different watersheds contributing both water and pollution load to the river has been conceptualized and presented in this chapter. Chapter 5 is conclusions. Finally all the references cited in the thesis are listed.

Chapter – 2

REVIEW OF LITERATURE

Literature review provides necessary insight and helps in conceptualization of the problems. The research required to complete this work was multidisciplinary in nature. Review of literature was carried out on the following aspects of water quality management:

- River water quality and management
- Water quality index
- Watershed management

Research done in these areas is briefly reviewed here. The literature review was carried out from sources like research papers published in peer reviewed journals, technical reports, working papers of sponsored projects, proceedings of international conferences and technical manuals published by various national and international agencies.

2.1 River water quality and management

Water quality management perspectives were studied by Bukit (1995) on the Citarum river in West Java, which was executed between 1989 and 1993 in order to define recommendation for the optimization of water quality conservation. The recommendations made included (a) reduction of domestic and industrial pollution loads (smaller units domestic water treatment and centralized industrial waste treatment); (b) propagation of clean technology; and (c) giving preference to industries with low water demand while giving licenses.

Statistical analysis of land use and water quality data from selected regions was tried by Sekhar and Raj (1995) and regression equations were developed between land use and water quality parameters. The results of the study have indicated that 25%, 39%, 58%, 46% and 72% of the observed variations in mean concentrations of nitrates, phosphates, fluoride, COD and potassium respectively can be accounted to land use.

Regional water quality of Eastern UK rivers indicate that industrial and domestic inputs cause significant increases in river concentrations for all the parameters (Robson and Neal, 1997). For parameters such as nickel, ammonium, orthophosphate, lindane and dieldrin, industrial/ domestic inputs dominate all other sources. Even for NO_3–N, which is widely recognized as having diffused sources, industrial inputs can be significant.

Intervention on point source pollution of urbanized areas results in the reduction of NH_3–N concentration and increase of DO level down stream of major cities (Bendoricchio *et al.*, 1999). Further, cropping of upland areas was found to increase NO_3–N concentration at the sources of major rivers. Quick variation of nutrient concentrations were observed during rain events in the rivers and these variations are closely related to the diffused pollution sources (close relation between the diffused pollution sources and deterioration of water quality). Progress in reduction of point source pollution increases the role of diffused sources and demands urgent and strong intervention for the final goal of stable mesotrophic conditions in the water body.

Correlation between water quality and landscape characteristics of the watershed was studied by Sliva and Williams (2001). Urban land use was found to have greatest influence on water quality. Influence of agricultural land use was variable and did not agree with the results of other studies. The only natural landscape variables, found influencing water quality, were slope and silt-clay surficial geology deposits. The chemical flux was found increasing with the increase of urban land use intensity. Forestland use was found important in mitigating water quality degradation. The catchments landscape characteristics were found to have slightly greater influence on water quality than the 100-meter buffer zone. This study was based on secondary databases and used GIS and multivariate analysis tools.

Eutrophication status was evaluated by means of N/P ratio (Voutsa *et al.*, 2001). The ratio showed large variations among the 25 sampling sites located on main rivers, tributaries, streams and ditches. N/P ratios also showed great temporal variability at particular sampling sites.

Patidar (2009) studied the effect of mass bathing on water quality eutrophication status. The study revealed the presence of high concentration of nutrients and Chlorophyll a (mesotrophic and eutrophic status). Phosphorous has been observed as the limiting nutrient.

The data set obtained from monitoring of major river systems as well as streams, tributaries and ditches of Greece at 25 sampling sites on monthly basis for 27 parameters was treated using cluster analysis, principal component analysis and multiple regression analysis of principal components by Simeonov *et al.* (2003). Cluster analysis has indicated four different groups of similarity between the sampling sites. The analysis has resulted in the identification of the following six latent factors: (1) organic, (2) nutrient, (3) physico-chemical, (4) weathering, (5) soil leaching, and (6) toxic-anthropogenic. Multivariate receptor model was applied for estimating contribution of identified sources to the concentration of the physico-chemical parameters.

A classification scheme of excellent, acceptable, slightly polluted, polluted, and heavily polluted was proposed by Sargaonkar and Deshpande (2003) for water quality criteria/ standards. Concentration ranges for these classes were defined while considering Indian standards and CPCB criteria, European community standards, WHO standards and reported effects of important water quality indicator parameters were also taken into account. On the basis of the concentrations, mathematical equations and value function curves were developed for the parameters. The index values of individual parameters were combined to estimate overall index of pollution. The developed overall pollution index was applied at a few sampling stations on the river Yamuna.

Multivariate statistical techniques, cluster analysis (CA), factor analysis (FA), principal component analysis (PCA) and discriminant analysis (DA) were applied by Singh *et al.* (2005) to the monitoring data of Gomti river (monitored at 8 stations for 31 parameters for three years). Cluster analysis indicated three significant groups (1) upper catchments (2) middle catchments (3) lower catchments. Factor analysis applied to the data of three catchments gave 7, 7 and 6 latent factors for the three catchments explaining 71.3, 73.6 and 81.1 % of the total variance of the data. The seven latent factors were (1) trace metals group (2) organic pollutants group (3) nutrient group (4) alkalinity (5) hardness (6) electrical conductivity and (7) solids. Discriminant analysis has shown 5 parameters (temperature, total alkalinity, chloride, sodium and potassium) affording more than 91 % of right assignation in temporal analysis and 10 parameters (river discharge, pH, BOD, chloride, fluoride, phosphate, ammonical-N, nitrate–N, TKN and Zinc) affording 97% of right assignation in spatial analysis. Receptor modeling revealed that soil weathering, leaching and run-off, municipal and industrial waste water, waste disposal site leaching are major sources for river water quality deterioration.

Factor Analysis and Cluster Analysis were applied on three different data sets i.e. total, fresh and saline influenced stations in Mahanadi river system by Panda *et al.* (2006) in order to establish the natural and anthropogenic process and factors. The results revealed that anthropogenic contribution of nutrients is responsible for low DO and pH levels of water with different intensities in fresh and saline water as well as in different seasons. The different magnitude of BOD loading with respect to total N and P demonstrated the intensity of organic pollution in different water system. The relationship among stations is highlighted by CA to categorize different level of contamination. Relative importance of different water quality characteristics varied with specific water system.

A total of 96 surface water samples collected from river Ganga in West Bengal during 2004-05, were analyzed for heavy metals by Kar *et al.* (2008). The results revealed that Fe, Mn, Zn, Ni, Cr and Pb were detected in more than 92% of the samples, whereas Cd and Cu were detected only in 20.8% and 37.5% samples respectively. Overall seasonal variation was significant for Fe, Mn, Cd and Cr. The dominance of various heavy metals in the surface water of the river Ganga followed the sequence: Fe>Mn>Ni>Cr>Pb>Zn>Cu>Cd.

Chemometric tools such as cluster analysis and box-whisker plots were applied by Kumari *et al.* (2013) to interpret data obtained during examination of River Ganges water quality at Varanasi for various physic-chemical parameters where numerous industrial facilities discharge their effluents mixed with municipal sewage into the River Ganges at 6 different discharge points. Based on proximity distances, EC, Cr, Ni, Fe, N, COD, Temperature, BOD and Total Acidity comprised one group; Zn, Pb, Cd, Total Alkalinity, Cu and phosphate were in another group; and DO and pH formed a separate group. Box-whisker plots revealed that at downstream points the pollutants concentration increases.

2.2 Water quality index

US EPA has created the index of watershed indicators in order to assess watershed vulnerability and condition in the US (Schultz, 2001). It is a subjective index and its credibility and applicability depends on its ability to withstand tests that challenge its internal consistency and interpretation.

Assessment of pollution of water bodies from non-point sources was tried using a new tool, Potential Non-point Pollution Index (PNPI) by Munafo *et al.* (2005). Main feature of this index is wide availability of the input data. An expert system approach, wherein judgment of scientists is used, was followed in developing this index. PNPI is a GIS based watershed scale tool used for assessing potential environmental impacts of different land use management scenarios.

Diffuse pollution coming from land units is expressed as a function of three indicators: land use, runoff and distance from the river network. Expert evaluation assigns weights to different land uses and to the three indicators. Watershed is divided into grids and for each of the grid PNPI is calculated.

Water quality in the rivers Ciliwung, Sunter and Krukut in Jakarta were determined using a WQI of scale 0 to 100 and the water quality results were presented as WQI and heavy metal concentration (Palupi *et al.*, 1995). WQI of all the rivers was found worst during dry season when compared with rainy season. The heavy metals are within limits but the river waters were polluted by Cu, Pb, Cd, Zn and Hg.

A study by Zandbergen and Hall (1998) evaluates the performance of the BCWQI (British Columbia Water Quality Index) and assesses how useful and appropriate it is as a management tool at the watershed level. This index is used to express the results of two sampling programs of two relatively small watersheds in the greater Vancouver area. For both the watersheds, the intended use is the protection of aquatic life. The study indicated that BCWQI is extremely sensitive to sampling design and highly dependent on the specific application of water quality objectives. The study has also made a comparison with another type of index, NSFWQI, which is viewed as promising for stream stewardship groups because of its simplicity and ease of use. The study has suggested alternative to BCWQI for watershed managers. This WQI is Simple Water Quality Index (SWQI) based on exceedance factors for individual objectives, which are specific to a particular water body. SWQI overcomes some of the limitations of BCWQI. It also suggests a presentation format wherein the objectives included are clearly indicated for SWQI.

The results of the applications of the water quality index were used by Stambuk-Giljanovic (1999) for water evaluation in Dalmatia (southern Croatia). The evaluation involved dividing the WQI value with that of first class water, which satisfies the maximum admissible concentration.

Usefulness of WQI to access the water quality was verified by Pesce and Wunderlin (2000). Two WQIs (WQIsub and WQIobj) taking into consideration of 20 parameters and another WQI (WQImin) taking into consideration only three parameters (turbidity, DO and conductivity or dissolved solids) were tried. WQIsub was found to overestimate the pollution. WQImin has lower analytical cost. WQImin when combined with WQIobj was found to correlate the results better.

Bangpakong River was monitored at 11 sites (at three locations close to banks and in the middle) from June 1998 to May 1999 (Bordalo *et al.*, 2001). Temperature, DO, turbidity, suspended solids, pH, NH_3-N, fecal coliform, BOD, COD, conductivity, phosphate and heavy metals were monitored. The results of monitoring were analyzed using Scottish Water Quality Index. Average WQI was found to be relatively lower (41%). The quality was lower during dry season (December to May). WQI is better in the middle than closer to banks. WQI variability along the river was 48% during wet seasons and 63% during dry season. Monthly variability has been less than 20%.

Contamination index and heavy metal pollution index were evaluated by Edet and Offiong (2002) for their suitability for contamination monitoring in southeastern Nigeria. The evaluation gave extreme results. For accommodating this deficiency, a third model Heavy Metal Evaluation Index (HEI) was developed.

Concept of WQI based on a comparison of concentration of contaminants with the respective environmental standards was used by Khan *et al.* (2003). The number, frequency and magnitude by which the environmental standards for specific variables are not met are reflected in the WQI. The concept of WQI (two different types: Canadian Water Quality Index, and British Columbia Water Quality Index) was applied to three river sites (Mersey river, Point Wolf river and Dunk river) of Atlantic region. After calculating WQI, trend analysis was carried out using linear and quadratic models. Detailed error analysis and parameter significance lists have indicated that quadratic trend models are better than linear models.

The water quality index was used by Stambuk-Giljanovic (2003) for evaluating the water quality on the 42 km. long Vrgorska Matica river of southern Croatia. This WQI used 9 parameters: temperature, mineralization, corrosion coefficient, DO, BOD5, total–N, protein-N, total phosphorous, and total coliform bacteria. The 9 parameters after transforming into q-values and after multiplying with weighting factors were added to arrive at an overall water quality index. On the basis of the index, the water was classified into the following categories:

- Water with OWQI range of 85-100- suitable for drinking or for using in food industry either in its natural state or after disinfection and for raising high quality species of fish.

- Water with OWQI score of 75-85- suitable in its natural state for swimming and recreation, sports or species of fish and suitable for drinking and other industrial purposes after treatment.
- Water with OWQI score of 50-70- suitable for use in industry and agriculture.
- Water with OWQI score of less than 50 used in areas with water shortage that too after treatment.

Water quality index was applied in Keya river of Taiwan by Liou *et al.* (2004) employing 13 variables. The variables were categorized into three aspects (on the basis of principal component analysis) namely organics, particulates and microorganisms. Overall index was taken as geometric mean of the three aspects. Arithmetic mean was used for aggregating the variables of a same aspect.

In order to characterize the spatial and temporal variability of surface water quality, water quality index was calculated for the Chillan river from nine physico- chemical parameters periodically measured at 18 sampling sites (Debels *et al.*, 2005). On the basis of the results from a principal component analysis, the original water quality index was modified in order to reduce the cost associated with water quality index implementation. The study showed that still fewer parameters (COD, DO, pH, temperature and conductivity) can adequately reproduce the most important spatial and temporal variability observed in the original water quality index.

2.3 Water quality index development protocol

Development and use of WQI for monitoring the water quality of streams and rivers and lakes has become a routine for many environmental agencies throughout the world. Abbasi (2002) reported three aspects of WQI development, identification and selection of parameters and assigning relative importance to them, development of parameter transformation equations and development of scheme of aggregation of the water quality parameters into WQI.

Brown *et al*. (1970) developed water quality index for US National Sanitation Foundation and this index was known as NSF WQI. Weights were assigned to various parameters, on the basis of the expert opinion gathered from a panel of 142 persons with expertise in water quality management. The panelists were asked to select parameters for the WQI from a list of 35 parameters, with an option for addition of additional parameters to the list by any of the panelists. Each of the listed parameters was to be assigned one of the following choices by the panelist: ‘do not include’, ‘undecided’, or ‘include’. Further, the panelists were asked to rank the parameters marked as ‘include’ according to their significance as contributor to the overall water quality. The rating was done on a scale of 1 (highest) to 5 (lowest). Responses of the panel were brought to the knowledge of each of the panelist and the panelists were allowed to review their individual judgment in the light of the full panel’s response. All the parameters of the list were then arranged in the decreasing order of significance as determined by average rating of the panel. From the list the following top eleven parameters were selected for inclusion in the WQI:

Parameters	**Average rating**	**Temporary weights**	**Final weights**
Dissolved oxygen	1.4	1.0	0.17
Fecal coliform	1.5	0.9	0.15
pH	2.1	0.7	0.12
BOD (5-day)	2.3	0.6	0.10
Nitrates	2.4	0.6	0.10
Phosphates	2.4	0.6	0.10
Temperature	2.4	0.6	0.10
Turbidity	2.9	0.5	0.08
Total solids	3.2	0.4	0.08
		Total	1.00

To convert the rating into weights, a temporary weight of 1.0 was assigned to the parameter which received the highest significance rating. All other temporary weights were obtained by dividing the highest rating by each individual mean rating. Then each of the temporary weights was divided by the sum of all the temporary weights to arrive at the final weight.

Similar technique of parameter selection and relative weights determination was used by many others (Prati *et al.* 1971; Landwehr and Deininger, 1976; Dinius, 1987).

In India, Dhamija and Jain (1995) developed a WQI where nine parameters were selected for inclusion in the WQI and the parameters were rated on a scale of 1 to 5 (1 is highest and 5 is lowest in the quality rating). Arithmetic mean rating was calculated for each of the parameters. For converting the rating into temporary weights, the individual mean ratings were divided by nine. Then each of the temporary weights was divided by the sum of all the temporary weights to arrive at the final unit weight. Please see the following table for details:

Parameters	Mean Rating	Temporary Weights	Unit weights
Chloride (mg/l)	2	0.22	0.08
Total suspended solids (mg/l)	2	0.22	0.08
Total Hardness (as $CaCo_3$) mg/l	2	0.22	0.08
Calcium mg/l	2	0.22	0.08
Magnesium mg/l	2	0.22	0.08
Total Alkalinity mg/l	3	0.33	0.12
pH	4	0.44	0.16
Dissolved oxygen mg/l	4	0.44	0.16
Total solids (mg/l)	4	0.44	0.16
	Total	2.75	1.00

Several authors used different aggregation function. Brown *et al.* (1970) used Weighted Sum function, as given by the following equation:

$$NSFWQI = \sum_{i=1}^{n} w_i . q_i$$

Where w_i = the weight of the ith parameter

q_i = the quality of ith parameter (a number between 0-100 read from appropriate sub-index graph)

Similar aggregation function was used by some Indian authors (Sinha 1995, Dhamija and Jain 1995) and others (Boyacioglu 2007).

Since no guideline values include in the Brown's NSFWQI, Prati *et al.* (1971) developed WQI based on water quality standards. 13 water quality parameters were included in the WQI. Linear sum (arithmetic mean) function was used to aggregate the sub-indexes as the following equation:

$$WQI = 1/13 \sum_{i=1} I_i$$

Where I_i = the quality of ith parameter (a number between 0-100 read from appropriate sub-index graph)

The index developed by Stoner (1978), aimed for use in public water supply and irrigation, and employed a single aggregation function which selects from two sets of recommended limits and sub-index equations. Although Stoner applied the index to just two water uses, it could be adapted to additional water uses as well.

Two types of water quality parameters are used in the Stoner's index:

Type I: Parameters normally considered toxic (for example, lead, chlordane, radium–226)

Type II: Parameters which affect health or aesthetic characteristics (for example, chlorides, sulphur, color, taste and odor).

The type I pollutant variables were treated in a dichotomous manner, giving sub-index step functions. Each type I sub-index is assigned the value of zero if the concentration is less than or equal to the recommended limit and the value 100 if the recommended limit is exceeded. The *type II* pollutant variables are represented, by explicit mathematical functions.

The overall index was computed by combining the unweighted type I sub-indexes with the weighted type II sub-indexes:

$$WQI = \sum_{i=1}^{n} Ii + \sum_{j=1}^{m} wj.Ij$$

Where I_i = subindex for the ith *type I* pollutant variable

w_j = weight for the jth *type II* pollutant variable

I_j = subindex for the jth *type II* pollutant variable

Wepener *et al*. (1992) evaluated water quality by Aquatic Toxicity Index (ATI) and used the aggregation function as per the following equation:

$$ATI = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2$$

Where qi is the quality of the i^{th} parameter (a value between 0 and 100) and n is the number of determinants in the indexing system.

Pesce and Wunderlin (2000) evaluated the water quality using three WQI, named water quality index subjective (WQI_{sub}), water quality index objective (WQI_{obj}) and water quality index minimal (WQI_{min}). WQI_{sub} was calculated on the basis of the following equation:

$$WQI_{sub} = k\,\frac{\sum_{i=1} Ci * Pi}{\sum_{i=1} Pi}$$

Where k is a subjective constant. It represents the visual impression of river contamination (as could be evaluated by a person without training in environmental issues). It takes one of the following values according to the river condition:

- 1.00 = water without apparent contamination (clear or with natural suspended solids).
- 0.75 = light contaminated water (indicated by light non-natural color, foam, light turbidity due to no natural reasons.
- 0.50 = contaminated water (indicated by non-natural color, light to moderate odor, high turbidity, suspended organic solids etc.
- 0.25 = highly contaminated water (indicated by blackish color, hard odor, visible fermentation etc.

Ci is the value assigned to each parameter after normalization. *Pi* is the relative weight assigned to each parameter. *Pi* value range from 1-4, with 4 representing a parameter that has the most importance for aquatic life preservation and 1 means the parameter has a smaller impact.

The objective water quality index (WQI_{obj}) was calculated using the same equation but with k=1 in all cases, to account only for variations due to measured parameters.

Water quality index minimal (WQI_{min}) was calculated using the normalized values of only three parameters DO, turbidity and Conductivity/TDS, as per the following equation:

$$WQI_{min} = \frac{C_{DO} + C_{turb} + C_{cond}}{3}$$

Bordalo *et al*. (2001) applied the modified Scottish Water Quality Index to the Bangpakong river quality data. Their final arithmetic weighted index is the result of squaring the sum of the products of water quality ratings (*qi*) and weighting each individual parameter (*wi*) divided by 100, according the following equation:

$$WQI = \frac{1}{100}\left(\sum_{i=1}^{n} qi.wi\right)^2$$

Cude (2001) suggested the unweighted harmonic square mean formula, as a method to aggregate sub-index results, as an improvement over both the weighted arithmetic mean and weighted geometric mean formula. The formula is given as:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI_i^2}}}$$

Where n is the number of sub-indices, SI_i is the sub-index i.

Aggregation function used by Liou *et al*. (2004) for River Status Index (RSI) of Taiwan is based on statistical analysis. The results of Principal Component Analysis are the inputs to the aggregation for overall index. The equation is as follows:

$$RSI = C_{tem}.C_{pH}.C_{tox}\left[(\sum_{i=1}^{n} I_i.w_i) \times \left(\sum_{j=1}^{m} I_j.w_j\right) \times \left(\sum_{k=1}^{p} I_k\right)\right]^{1/3}$$

Where, the unweighted arithmetic mean is assigned for the variables associated in the some component. I_i denotes the sub-index values for the n variables and w_i denotes their weights of 1^{st} principal component (PC1); I_j represents the sub-index values for the m variables and w_j denotes their weights of PC2; I_k is the sub-index value of p variables of PC3 for which no weight is assigned. In addition, the geometric mean is appointed on the extracted components. Three scaling coefficients are prefixed, which address the sub-indexes of temperature, pH and toxic substances respectively.

Sargaonkar and deshpande (2003) evaluated the Overall Index of Pollution (OIP) as the average of all the pollution indices (Pi) for individual water quality parameter and is expressed by the mathematical expression:

$$OIP = \frac{\sum_i P_i}{n}$$

Where *Pi* is the pollution index for i^{th} parameter and n is the number of parameters.

Debels *et al*. (2005) used the following equation for WQI calculation:

$$WQI = \frac{\sum_{i=1}^{n} Ci * Pi}{\sum_{i=1}^{n} Pi}$$

Where n is the total number of parameters, C_i is the value assigned to the i^{th} parameter after transformation (normalization factor i.e. parameter rating curve) and P_i is the weight of the i^{th} parameter (an indicator of its' relative importance for aquatic life/ human water use). The values for weight and normalization factors were adapted using expert judgment.

Singh *et al*. (2008) concluded from sensitivity analysis that the weighted arithmetic mean function, being a true linear, least ambiguous and eclipsing free function, is the most representative aggregation function for estimation of Ganga River Pollution Index (GPRI)

Singkran *et al.* (2010) used unweighted geometric mean to evaluate the overall WQI as per the following equation:

$$WQI = \left(\prod_{x=1}^{N} S_x\right)^{1/N}$$

Where S_x represents the sub-index scores of water quality parameter x after conversion. N is the total number of parameters

Hanh *et al*. (2011) also used statistical analysis to evaluate the WQI for surface water of Vietnam. Basic parameters were grouped by Principal Component Analysis. The aggregation function for the basic water quality parameters is proposed as:

$$WQI_B = \left[\frac{1}{a}\sum_{i=1}^{a} q_i \times \frac{1}{b}\sum_{j=1}^{b} q_j \ldots \ldots \times \frac{1}{c}\sum_{k=1}^{c} q_k\right]^{1/n}$$

Where n = number of Principal Components (PC), a = number of parameters in first PC, qi = sub-index value of the parameter of first PC, b = number of parameters in second PC, qj = sub-index value of the parameter of second PC, c = number of parameters in subsequent PC, qk = sub-index value of the parameter of subsequent PC.

Both the basic parameters and additional parameters (toxic metals and pesticides etc.) were used to form the overall water quality index (WQI_O). The sub-indexes for additional water quality parameters were first calculated. Each sub-index then was compared with the WQI_B and taken into account only if it was lower. The water temperature and pH coefficients were calculated directly from their respective sub-indexes. The toxic coefficient was calculated by averaging all scores of toxic substances. The WQI_O aggregation function is therefore proposed as:

$$WQI_O = \left(\prod_{i=1}^{m} C_i\right)^{1/m} \left[\frac{1}{a}\sum_{i=1}^{a} q_i \times \frac{1}{b}\sum_{j=1}^{b} q_j \ldots \ldots \times \frac{1}{c}\sum_{k=1}^{c} q_k\right]^{1/n}$$

Where Ci = coefficients addressing the sub-indexes of Tw, pH and toxic substances, m = number of coefficients.

2.4 Watershed management

Water quality has been classified by Gerda *et al.* (1994) according to organic pollution (DO and BOD), eutrophication (N and P levels) and cadmium concentration. It is indicated that substantially improved monitoring is a prerequisite for management.

Role of wetlands in improving water quality of streams, rivers and lakes is illustrated by Mitsch (1995) with examples of fringes, in-stream and riparian wetlands. Fringe wetlands are shown to reduce inputs to fresh water lakes. In-stream wetlands can improve habitat and serve some water quality function in small streams. Riparian wetlands along larger rivers capture sediments and nutrients from the river and serve as buffer between uplands and the river.

Use Attainability Analysis (UAA) as a tool of integrated water quality management and planning is described by Novotny (1996). UAA include three components: (1) water body assessment (2) the total maximal daily load process (TMDL Process) and (3) socio-economic analysis. Under the water body assessment component whether the water body and the watershed has water quality problem or not is assessed and the problem water bodies are categorized into those with problem because of man-made pollution inputs and those with natural loads. TMDL process categorizes the problem water bodies into those for which water quality goals can be achieved by mandated abatement of point and non-point sources and those for which water quality goals cannot be achieved by the mandated abatements. The last category requires extensive water quality management efforts. For the restoration of these water bodies and watersheds, both reduction of waste discharge and enhancement of waste assimilative capacity should be considered.

Greater emphases on the restoration of lost and degraded wetlands especially the river floodplains and lake littorals is recommended by Gopal (1999) to help checking of pollution from non-point sources.

An eight-step framework for agricultural watershed management is presented by Brezonik *et al.* (1999).

Overall hydrologic function of a watershed is to capture, store and safely release water. How well this function is performed depends on the geomorphic component landforms of the watershed (Petersen, 1999). The component landforms of a watershed include stream channels, floodplains, stream terraces, alluvial valley bottoms, alluvial fans, mountains slopes and ridge tops. Component landforms within a watershed are interrelated. Ecological alteration or degradation of a component landform can impair the overall hydrologic function of the watershed. Hence, each component landform should be considered in the setting of watershed management goals and planning the watershed management. A simple field approach to inventory, evaluate and plan watershed restoration based on geomorphic, hydrologic and ecological principals was developed and successfully used on several watersheds in Eitah, USA.

Gupta (2001) studied the fundamental issues of river basin management in a multi-objective framework with a unique case study of Narmada River Valley Development, and demonstrated that the socio-economic needs of the people of the basin override the any other working objectives.

Since causes for the river water quality problems are distributed over its basin, solutions should also be distributed over the basin (Day *et al*., 2003). Literature concerning application of the cost effectiveness analysis to evaluate management measures for the improvement of watershed quality with focus on eutrophication is provided by Zanou *et al.* (2003).

By managing a catchment effectively the range and amount of contaminants entering waters used for public water supply can be reduced. Effective management of catchments will also make a significant contribution to meeting obligations under the Water Framework Directive, by helping to address the serious issues of diffuse pollution from agriculture (Keirle and Hayes, 2007).

Dunk *et al.* (2008) described the approach adopted by Thames Water since 1997. Major emphasis was given to the requirement of comprehensive strategies by water companies to effectively manage the remediation of polluted surface water outfalls. The elimination of diffuse pollution sources by identifying and rectifying domestic and commercial foul to surface water drainage has resulted in sustainable improvements to the local environment across the Thames region.

Current situation of water quality in the Asian region was assessed by Evans *et al.* (2012). The study revealed that uncontrolled release of sewage, industrial wastes and agricultural runoff continue to affect Asia. Although many Asian countries are getting closure to meeting the improved sanitation targets, much of the wastes remains untreated. Water quality monitoring efforts are improving and several countries are now having system in place that could guide other nations in the region. Many regulatory and economic options are being tested for pollution control, but institutional and social challenges remain, in particular those related to population growth and the various ways in which it is affecting water quality across the region.

Fang *et al.* (2012) evaluated the assimilative capacity of the Qiantang river, investigating the influence of stream flow. A confidence of 75 and 90% of instream flows were selected as the design flows, while the traditional one dimensional point discharge model and QUAL2K model were used to analyse BOD assimilative capacity. The results showed that the assimilative capacity of 75% confidence stream flow was larger than that of 90% confidence. The total amount of BOD discharged into river was 171283 $t.a^{-1}$ in 2004. Under 75 and 90% confidence river flow conditions, the calculated total BOD reduction percentage of the whole river was 38.2 and 55.9% respectively. Further more, the results were used as criteria for developing a BOD total maximum daily load in order to achieve the sustainable use of water resources derived from Qiantang river watershed.

2.5 Gaps in the previous studies

It is widely believed that the sources for water quality problems of a river are distributed all over its basin and hence solutions for the problems should also be distributed over the basin. Restoration of the river water quality needs both reduction of waste discharge into the river and enhancement of rivers waste assimilative capacity. In other words, watershed management approach, which gives due importance to the control of both point and non-point sources of pollution and to the river's waste assimilative capacity, is most appropriate for the river water quality management. But efforts have not yet been made to follow this approach for the Satluj river water quality management.

The two activities, currently undertaken for the Satluj river water quality management, have been (a) the Satluj river water quality monitoring and (b) reduction of pollution loads to the river through treatment of key point sources of pollution. Data generated from the monitoring activity is not satisfactorily used for the river water quality management and the river water quality is not showing much improvement. Further, very little is known about the non-point sources of pollution of the river. Very little work is reported in the literature relating to the pollution assimilative capacity of the river Satluj.

Sufficient work has been done in the direction of analysis and communication of water quality data, through development and implementation of Water Quality Index (WQI), for its effective use in the water quality management efforts. But the WQI concept has not yet been applied to the river Satluj. Monitoring programs of Indian rivers have recently been standardized, but development and standardization of WQI for Indian rivers has not yet been tried.

Published literature indicates that both point and non-point sources contribute to the river water pollution. Identification and control of point sources of pollution is easier when compared with that of non-point sources. Further, control of non-point sources of pollution requires a different approach, watershed management approach; wherein implementation of best management practices in the catchments is important. Control of pollution from point sources is achieved through treatment of the polluted water prior to discharge into the river. Enough work has been done in the watershed management area specially in developed countries. In India also some work in this area is reported. Literature review indicated that watershed management approach is yet to catch up with the rest of the world.

The current water quality in the Satluj river indicated that the efforts to control point sources of pollution may not be sufficient for the management of the river water quality and protection of the Harike Wetland System (an internationally known Ramsar wetland site). Need for tackling even the non-point sources of pollution and for improving the river's pollution assimilative capacity was felt through implementation of the watershed management approach.

Chapter-3

METHODOLOGY

Work planned for achieving the set objectives was divided into the following five work elements:

1. Demarcation of the watersheds/sub-watersheds contributing both water and pollution loads to the Satluj river.
2. Characterization of individual watersheds and collection of information on the water and pollution loads contributed by them
3. Development of protocol for the ecological water quality index.
4. Statistical analysis of Satluj river water quality data for the optimization of the Satluj river water quality monitoring program.
5. Development of water quality management plan for the Satluj river and defining goals and objectives of management of different watersheds contributing both water and pollution load to the river.

Approach followed for carrying out the work under these work elements is briefly described in this chapter.

3.1 Demarcation of watersheds

Catchments of each of the tributaries, Khads and Chaos joining the Satluj river, between the Nangal Dam and the Harike Wetland System, were taken as independent watersheds/sub-watersheds contributing both water and pollution loads to the river. Boundaries for the individual watersheds were defined with the help of topographical sheets. The boundaries were drawn through drawing boundary lines along the ridge tops and connecting the highest elevation points. For a significant portion of the catchments, beings strategic areas, toposheets were not accessible. Toposheets 44M and 44N were not accessible. Hence, for the demarcation of the watershed boundaries ARC GIS software was used. Help of Dr. D.S. Arya, Department of Hydrology, Indian Institute of Technology, Roorkee (India) was taken here. Dr. Arya provided the Digital Elevation Maps (DEM) for the watershed area in question. Geo-referencing coordinates (latitude and longitude) of the obtained DEM were overlaid on the images obtained from the Microsoft Encarta Reference Library 2005 (which contained processed images of earth) for the manual delineation of the watershed boundaries. Area under the watersheds was then divided into 5 min. x 5 min. grids and area of the watersheds were calculated.

3.2 Characterization of individual watersheds

Information felt necessary for the characterization of the watersheds contributing both water and pollution loads to the Satluj river was collected. The information collected included the following:

- Elevation and geomorphological characteristics
- Soil types
- Rainfall and temperature
- Land use and land cover
- Human settlements and demographics
- Significant sources of pollution (point and non-point sources)

- Water quality monitoring program
- Hydrological studies of the watershed

For elevation and geomorphological features, and climate, hydrology and hydrogeology information was obtained from the review of secondary data sources. Directorate of Land Records, Punjab was depended on for the district-wise data in this regard. Rainfall data was obtained from the Indian Meteorological Department, Pune. The data was available in processed format for 0.5°x0.5° grids. At the time of compilation of this research work, the rainfall data was available only upto December 2005. Hence, the rainfall data were used for the period, January 2003 to December 2005. The gridded data points which were used for rainfall information for different sub watersheds were as follows:

- Swan river sub watershed: 76'00''E 31'30''N and 76'30''E 31'30''N
- Sirsa river sub watershed: 76'30''E 31'00''N
- Siswan river sub watershed: 76'30''E 31'00''N
- Budha Nala sub watershed: 76'00''E 31'00''N and 75'30''E 31'00''N
- Satluj river sub watershed: 76'30''E 31'30''N; 76'30''E 31'00''N; 76'00''E 31'00''N and 75'30''E 31'00''N
- East-Bein river sub watershed: 76'00''E 31'00''N; 75'30''E 31'00''N and 76'00''E 31'30''N

Data on soils was obtained from the Punjab Remote Sensing Centre, Ludhiana (for Punjab region) and for Himachal Pradesh region from the National Bureau of Soil Survey and Land Use Planning (NBSS, 1997).

Land use and land cover (LULC) data for Punjab and Himachal Pradesh regions was obtained from National Remote Sensing Centre, ISRO of Department of Space. The LULC data was developed on 1:50,000 scale, using temporal Resourcesat-1 Linear Imaging Self scanning Sensor (LISS) -III data under Natural Resources Census (NRC) Project of National Natural Resources Repository (NRR) Programme (NRSC, 2006). For human settlements and demographics, Tehsil wise maps for the watershed areas were obtained from the Census of India directory.

Information on municipal committees and industries discharging their wastewater both directly and indirectly into the Satluj river was obtained from the Punjab Pollution Control Board. All streams and drains discharging into the Satluj river were considered as important point sources of pollution, and all the point sources of pollution and water were identified and indicated on the watershed maps.

National River Conservation Directorate(NRCD), Ministry of Environment and Forests (MOEF), Government of India (GOI) has been implementing the Satluj river water quality monitoring program since July 1996 for tracking the river water quality and assessing the effectiveness of the Satluj River Action Plan. Under this program, the river is monitored at 8 stations within the 238 km stretch falling in the Punjab state and at additional 4 stations on the East-Bein (a tributary to the river Satluj, draining 39% of the total catchments of the river downstream to Nangal Dam). The parameters monitored and the frequency of monitoring are as per the NRCD’s notification “Uniform Protocol on Water Quality Monitoring”. In addition to the above, the five key sources of water and pollution to the river satluj has been monitored on monthly basis since April 2004 as a part of this thesis work. Details of the sampling stations are given in Table-3.1, and the parameters monitored are indicated in Table-3.2. The present study effectively used the monitoring data accumulated during the 7 years period (April 2004-March 2011).

Table 3.1: Description of monitoring stations at river Satluj

Station	Station Specification
SAT – 01 (Nangal)	▪ Reservoir upstream to Nangal Dam ▪ No domestic/industrial activity ▪ Crematoria,Washing, Bathing & Boating ▪ Lift Irrigation ▪ Headworks for take-off Nangal Hydel Canal and Anandpur Sahib Hydel Canal
SAT – 02 (Anandpur Sahib)	▪ 20 km from Nangal Dam ▪ National Fertilizers Limited and Punjab Alkali and Chemicals Limited are located on the upstream side
SAT – 03 (Bunga Sahib)	▪ 37 km from Nangal Dam ▪ Downstream to the river Swan a seasonal rivulet ▪ Commercial fishing
SAT – 04 (Ropar Head Works)	▪ 59 km from Nangal Dam ▪ Headworks for take-off Sirhind Canal and Bist-Doab Canal ▪ Wastewater discharge of thermal power plant ▪ Recreational activities, boating, water games
SAT – 05 (Phillaur u/s)	▪ 135 km from Nangal Dam ▪ Upstream to Phillaur drain ▪ Sand extraction from river bed ▪ Downstream to industrial discharges from Ropar ▪ Agricultural runoff
SAT – 06 (Phillaur d/s)	▪ 136 km from Nangal Dam ▪ Downstream of Phillaur drain and upstream to Budha Nala ▪ Agricultural runoff
SAT – 07 (Sangowal village)	▪ 171 km from Nangal Dam ▪ Downstream to Budha Nala and upstream to the tributary East-Bein
SAT – 08 (Yusufpur)	▪ 218 km from Nangal Dam ▪ Downstream to the tributary East Bein ▪ Sand extraction
EB – 01 (Chaheru Bridge)	• G.T. Road. 1st station on East Bein (0 km) • Carries industrial wastes from Hoshiarpur and Nawanshahar
EB – 02 (Kanganiwal Bridge)	• 21 km downstream of Chaheru • Downstream to the discharge from Phagwara town • Water hyacinth and other aquatic weeds infested
EB – 03 (Peeru Shah Ka Durgah)	• 24 km downstream of Chaheru • Upstream to the confluence of Jalandhar drain • Water hyacinth and other aquatic weeds infested
EB – 04 (Malsian-Lohian Road Bridge)	• 42 km downstream of Chaheru and prior to confluence into the river Satluj • Water hyacinth and other aquatic weeds infested
Source – 01	Swan river from Himachal Pradesh, near Santoshgarh (Una)
Source – 02	Phillaur drain near pumping station in Phillaur city
Source – 03	Budha nullah near Hambra village (Ludhiana).
Source – 04	Phagwara drain on G.T. road near bone mill factory joining the East Bein
Source – 05	Jalandhar drain near Jamsheri Khas on Jalandhar-Malsian road joining the East Bein

Table 3.2: Parameters and frequency of monitoring program

Frequency	Parameters
Annually (Pre-monsoon once a year in May)	(a) General- temperature, pH, electrical conductivity, dissolved oxygen, turbidity, total dissolved solids. (b) Nutrients- ammonical nitrogen, nitrite + nitrate nitrogen, total phosphorous. (c) Demand parameters- biological oxygen demand, chemical oxygen demand. (d) Major ions- carbonate, bicarbonate, chloride, sulphate. (e) Other inorganic- fluoride, boron. (f) Microbiological- total coliform and fecal coliform.
Monthly	(a) General- temperature, pH, EC, DO, turbidity. (b) Nutrients- ammonical nitrogen, nitrite+nitrate nitrogen, total phosphorous. (c) Organic matter- BOD, COD. (d) Major ions- chloride (e) Microbiological- total and fecal coliforms

Information on flow in the Satluj river at 6 different stations and at 3 source stations, namely, Swan river, Budha Nala and East-Bein, has been obtained from the Discharge Division, Irrigation Department, Government of Punjab. Please see the location of flow measurement stations indicated in **Figure-3.1**. The drainage division monitors flow at these stations on daily basis. The flow data was available for the period January 2003 to December 2008. Since the rainfall data available for the catchments of the river was only upto December 2005, flow data for the period January 2003 to December 2005 has been used in the present study.

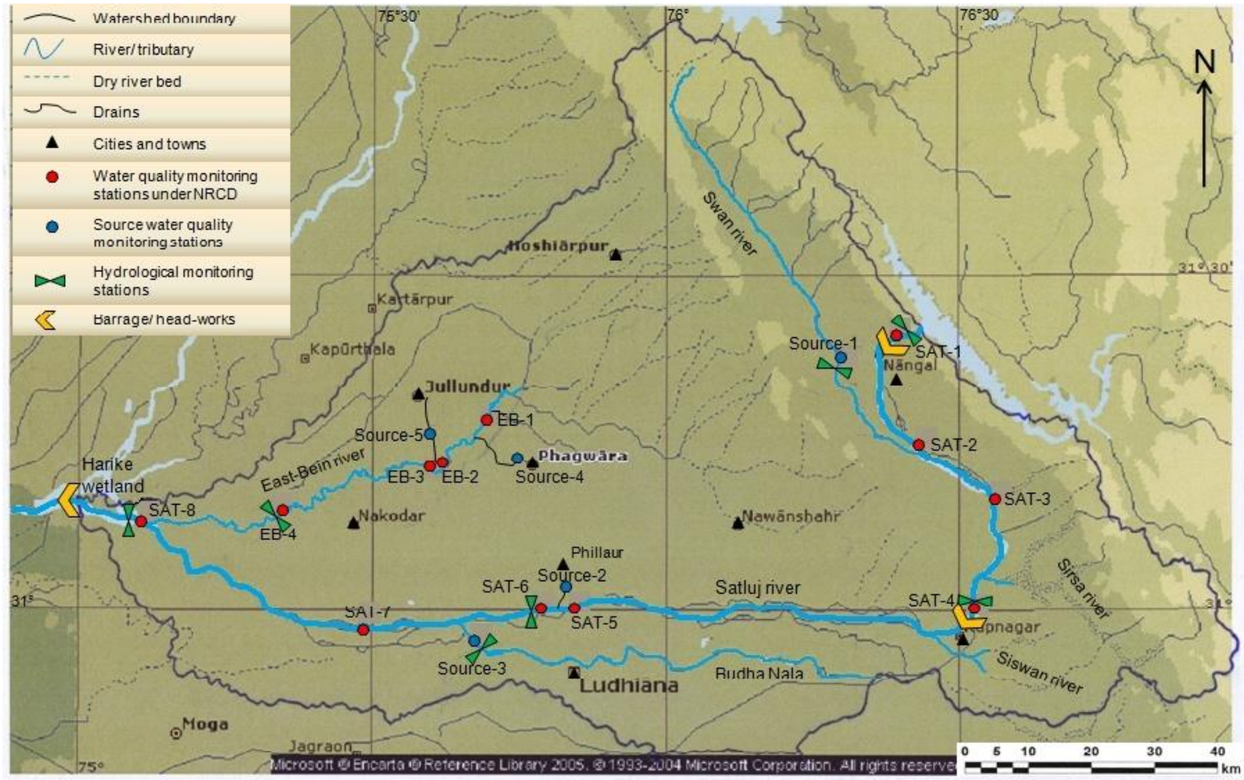

Figure 3.1: Map of Satluj river watershed showing monitoring stations.

The flow data was related with the rainfall received by the catchments for three sub-watersheds, East-Bein, Budha Nala and Swan river. Average flows in the river at different locations were arrived at by taking moving averages. Flow peaks (actual flow – 7 day moving average flow) in the river at the monitoring stations were correlated with the size of the corresponding rainfall events for identifying the stations at which rainfall and the associated storm water flows made significant contributions to the flows in the river. Further, for each of the watersheds, storm water flows were quantified by US-SCS method. The watershed area was divided into 73.51 km^2 (7.93 km x 9.27 km) size grids, required watershed characteristics (slope, hydrologic soil group, area, surface vegetation cover) for each of the grids were collected, curve numbers for individual grids were computed by US-SCS method, effective rainfall calculations were carried out (Mishra and Singh,2004), and run off volumes for the total watershed were then assessed through numerical integration of the effective rainfall for all the grids of the watershed. The storm water runoff volumes were then compared with the flows in the river for understanding their significance.

3.3 Development of Ecological Water Quality Index (WQI_E)

This work element included the following aspects:

- Identification and selection of water quality parameters for inclusion in the WQI_E and assigning relative importance values to the parameters selected
- Development of parameter conversion functions (transformation curves) for the selected water quality parameters
- Development of a scheme of aggregation of the water quality parameter values into WQI_E

Approach followed for the work on these aspects briefly described below:

3.3.1 Selection of parameters and assignment of relative importance values

Water quality is a composite and complicated term. It is expressed in terms of a large number of and a wide variety of (sometimes eclipsing) variables. There can be differences in opinion regarding the small set of parameters that mostly describe the water quality. Further, Water Quality Index (WQI) can become unwieldy if too many parameters are considered. Practicability, technological and economical constraints, and time constraints often restrict monitoring of the water quality in terms of the desired set of indicators, and force compromises.

Conventionally expert opinion has been the basis for the selection of parameters for WQI. But, this approach is fraught with both uncertainty and subjectivity. Recent trend has been to depend on the water quality criteria and standards. Non-existence of any standard or criterion for a specific parameter/variable is considered to indicate its least importance in describing the water quality. On the basis of the water quality standards and criteria and the literature on water quality, a big list of parameters/variables have been screened and probable parameters for inclusion in the WQI_E have been selected. The list of probable parameters were then categorized into three groups: General parameters; Heavy metals (open ended list of parameters); and pesticides and other toxic organic compounds (open ended list of parameters).

Water quality of the Satluj river was expected to be influenced by both municipal and industrial discharges and agricultural drainages. Organic pollution, nutrient enrichment, heavy metals and pesticide contamination was thus expected in the water. Depending on the catchments characteristics and developmental activities of the catchments, the heavy metal and pesticide parameters monitored would be decided. In the light of this, open lists of heavy metal parameters and pesticides parameters have been included in the WQI_E.

Final selection of the general parameters and assignment of relative importance to the parameters was done through the expert opinion analysis. The other two groups of parameters were not subjected to the expert opinion analysis. The expert opinion analysis was carried out using a pair-wise analysis technique (Reddy, 2003). Each of the panelists was asked to make pair-wise comparison of the selected list of parameters and rate the first parameter of the pair against the second by one of the following five options: Much more important (+2), More important (+1), Equally important (0), Less important (-1), Least important (-2). Ratings of each of the experts were analyzed to get the individual expert's relative weights for the parameters. Sum of weights assigned to all the selected parameters was taken as a unity. Through combining the relative weights assigned by all the experts for individual parameters and taking arithmetic mean, final relative weights for the individual parameters were obtained. Sample description for weight determination through opinion analysis can be seen in **Appendix-A**.

3.3.2 Parameter Rating Curves/Transformation Equations (PRC/TE)

WQI development involves aggregation of values of different water quality parameters into a WQI value. But, different parameters occurring in different ranges, expressed in different units and having different sensitivities are not compatible for the direct aggregation. Values of the parameters, prior to the aggregation, should be converted into compatible, common scale or single scale units (often referred to as Common Environmental Scale Units, CESU). Range of this scale can be 0 to 1, or 0 to 10 or 0 to 100 or even 0 to 1000.

In the present study, a common environmental scale unit (or a single scale unit) with 0-1 range had been considered. For facilitating the conversion of the monitored parameter values into the CESU values, specific parameter rating curves or transformation equations (PRC/TE) were developed. These curves/equations divided the scale of 0 to 1 into five sections: the worst quality (0-0.08), poor quality (0.08-0.30), moderate quality (0.30-0.70), good quality (0.70-0.92) and the excellent quality (0.92-1.00).

Water quality standards and criteria of several official bodies (referenced below), the Indian effluent standards and the literature available on water quality were used as the bases in the development of the parameter rating curves/ transformation equations. For detailed description of these standards, see the **Appendix-B**.

- Effluent standards given in Schedule-1 and Schedule-6 of the Environment (Protection) Rules, 1986, India.
- IS 10500: Indian Standard, Drinking Water - Specification, Bureau of Indian Standards.
- CPCB surface water quality criteria (Class-A, C, E)

- Guidelines for Drinking Water Quality, Incorporating the First and Second Addenda, Volume 1 (Recommendations): World Health Organization, 2008, Geneva.
- Water Quality for Agriculture, Food and Agriculture Organization, 1994, Rome.
- European Union Drinking Water Directive (98/83/EC).
- European Union Freshwater Fish Directive (78/659/EEC) - Salmonid water, Cyprinid water.
- Vietnam Water Quality Standards, Level-1, 2, 3 (QCVN 08:2008/BTNMT and TCVN 5945:2005).
- South African Water Quality Guidelines, Vol.1-Domestic Use, Vol.4-Agriculture Use: Irrigation, Vol.7-Aquatic Ecosystem.
- Canadian Environmental Quality Guidelines, 1999.
- National Recommended Water Quality Criteria, United States Environmental Protection Agency, 1999.

The total possible range of monitored values, which a parameter can take, were first sectionalized and related with the five sections of the PRC/TE. Rating curves for the parameters were then obtained through plotting the parameter values in CESU against the corresponding range of monitored values of the parameter. Transformation equations were obtained through transforming the plotted curves into equations through curve fitting. Statistical testing, such as, chi-square test and regression coefficient, have been used in the final selection of the transformation equations for the parameters.

For toxic metals, and for pesticides and other toxic organic compounds a slightly different approach was followed for the development of rating curves or transformation equations. The metal or pesticide and other toxic organic compound concentration was first converted into a concentration ratio scale by dividing the actual value with the water quality standard prescribed for that specific heavy metal or pesticide and toxic organic compound. The resultant concentration ratio scale was then divided into 5 sections to correspond with the five sections of the CESU range for obtaining the rating curves or transformation equations.

3.3.3 Aggregation of Parameters

For each of the three groups of selected parameters, sub-indices were developed on 0-1 scale. In case of the Sub-Index for general parameters (SI_{gp}) was calculated by weighted root sum function. Parameter CESU values were multiplied with their respective relative weights and summed up. Square root of this sum was taken as the SI_{gp}. Please see **Table-3.3** for the detailed calculations related to SI_{gp}.

Table 3.3: Sub-index calculation for the general parameters

Water quality parameter (i)	Monitored value of the parameter ($P_{i.Mon.}$)	Parameter value in CESU (P_{CESU})	Relative weight assigned to the parameter (W)	$P_{CESU} \times W$
1.	$P_{1.Mon.}$	$P_{1.CESU}$	W_1	$P_{1.CESU} \times W_1$
2.	$P_{2.Mon.}$	$P_{2.CESU}$	W_2	$P_{2.CESU} \times W_2$
…	…	…		…
I	$P_{i.Mon.}$	$P_{i.CESU}$	W_i	$P_{i.CESU} \times W_i$
…	…	…		…
N	$P_{n.Mon.}$	$P_{n.CESU}$	W_n	$P_{n.CESU} \times W_n$
			$\sum W_i = 1$	$SI_{gp} = \sqrt{\sum P_{i\ CESU} \times W_I}$

In case of the other two groups of parameters (heavy metals group and the pesticides and other toxic organic compounds group), maximum operator concept (Liou *et al.*, 2004) was used for identifying the metal parameter and the pesticide/other toxic organic compound parameter to be considered in the sub-indices calculations. Measured values of the metal parameters (or of the pesticide/toxic organic compounds parameters) were first converted into concentration to standard ratios (r_i) (Eq.1). Then the metal parameter (or the pesticide parameter) that has the maximum r_i value within the group of parameters is considered further (Eq.2 and Eq.3), and transformed into common environmental scale units (r_{CESU}) using the rating curve/transformation equation for the metals and pesticides. The obtained r_{CESU} value was considered as the sub-index value for the group of the parameters.

$$r_{\mathrm{i}} = \frac{\mathrm{C_i}}{\mathrm{S_i}} \qquad \text{---- (Eq.1)}$$

Where

r_i = concentration ratio of i^{th} substance,

C_i = substance with concentration (mg/L) and

S_i = prescribed standard value of the i^{th} substance

$$MaximumOperator(SI_{hm}) = r_{CESU} = \max\{r_1, r_2, ..., r_n\} \qquad \text{----- (Eq.2)}$$

$$MaximumOperator(SI_{ptoc}) = r_{CESU} = \max\{r_1, r_2, ..., r_n\} \qquad \text{----- (Eq.3)}$$

Geometric mean of all the three sub-indices has been taken as the overall WQI_E. For obtaining the WQI_E on 0-100 scale, the geometric mean value was multiplied by 100 (Eq.4).

$$WQI_E = 100 \times (SI_{gp}.SI_{hm}.SI_{ptoc})^{1/3} \qquad \text{----- (Eq.4)}$$

3.4 Statistical analysis of Satluj river water quality monitoring data for optimization of the Satluj river water quality monitoring program

Satluj river monitoring project (funded by National River Conservation Directorate of Ministry of Environment and Forests) has been with Thapar University since July 1996. Under this project the river, its tributaries and its different sources have been monitored monthly at as many as 17 different sampling locations. The data accumulated from the monitoring was subjected to statistical analysis along both space and time.

Statistical techniques were applied to the data set on water quality of the Satluj river, generated during April 2004-March 2011, at 8 monitoring stations of main stretch on Satluj river. Parameters which were not routinely analyzed were excluded from the statistical analysis. Then, the statistical analysis of the pretreated data was carried out. The mathematical and statistical computations were made using Microsoft Excel 2003, GraphPad Prism 4 and statistiXL 1.7 softwares.

3.4.1 Data pre-treatment

The monitored parameters were pre treated in order to avoid misclassification due to wide differences in data dimensionality. Due to the large range of numerical values and multiple units of measurement, data are standardized by z transformation function resulting in a mean of zero and standard deviation of one for each variable (Boyacioglu *et al.*, 2007).

3.4.2 Multivariate Statistical Methods

Multivariate statistical analysis (Cluster Analysis and Principal Components Analysis) was performed on the transformed values for spatial and temporal grouping of the sampling stations.

a) **Cluster Analysis (CA)**

Cluster Analysis (CA) groups the objects (cases) into classes (clusters) on the basis of similarities within a class and dissimilarities between different classes. The results of CA help in interpreting the data and indicate the spatial and temporal patterns. In hierarchical clustering, clusters are formed sequentially by starting with the most similar pair of objects and forming higher clusters step by step (Simeonov *et al.*, 2001; Zang *et al.*, 2009; Razmkhah *et al.*, 2010).

CA was performed on the transformed water quality data sets by means of the Ward's method using squared Euclidean distance as a measure of similarity (Singh *et al.*, 2005). Monthly water quality data of the 8 monitoring stations on the Satluj river was subjected to cluster analysis. In order to interpret the cluster significance some degree of subjectivity was used. Final clustering was decided while giving due importance to the spatial and temporal consecutiveness. Spatial clustering was done first and the temporal data was grouped as per the spatial clustering prior to the temporal cluster analysis. Cluster significance was determined using the criterion of similarity factor greater than 0.8 and the most similar consecutive sampling sites in a cluster were considered as one Spatial Group (SG) and the most similar sampling months in a cluster were considered as one Temporal Group (TG). Based on the analysis, both sampling stations and sampling frequencies were rationalized.

b) Principal Component Analysis (PCA)

PCA provides information on the most meaningful parameters, and renders data reduction with minimum loss of original information. PCA attempts to extract a lower dimensional linear structure from the data sets.

PCA transforms a data set containing *p* variables, interrelated or correlated to various degrees, to a new data set containing *p* new orthogonal, uncorrelated variables called Principal Components (PCs). The PCs are linear functions of the original variables such that the sum of their variances is equal to that of the original variables. The PCs are ordered from largest variance (PC1), to next largest variance (PC2), and so on for all *p* PCs. The goal is that the first few or *k* PCs ($k << p$) will retain most of the information in all of the *p* original variables, thus reducing the practical dimensionality of the data set. In other words, if the correlations are high among many of the original variables, the first few PCs will tend to contain (or explain) a large percentage of the total variance and may be used to describe multivariate patterns or variation in water quality across the watershed, almost as well as does the complete set of *p* original variables (Olsen *et al.*, 2012).

The PCA of the monitored data set indicated that, most of the data variance is contained in the first 2 components. Hence, the Biplots were developed between PC1 and PC2 for pattern recognition and for discussion on probable sources and types of pollution. The angle between two loading vectors is inversely related to the degree of correlation between two parameters in question. Vectors situated closely together represent variables that are highly positively correlated while orthogonal vectors represent variables that are uncorrelated. Vectors that are on vertical side are negatively correlated (Goonetilleke *et al.*, 2005).

Interpretation of PCs in a watershed PCA involved evaluating the association between the loadings and geochemical and biological processes and/or sources of contamination. Simply put, high loadings for variables that are important to a given process or contaminant source and low loadings for variables that are not important to that process or source, then one logically associates the given PC with the given source. Hence, pollution sources can be identified with some subjective logics.

Component loadings are measure of how much each variable contributes to the explanation of the extracted components. Variables that load heavily on a component are most representative of that component (Singh *et al.*, 2000). However, there are no specific criteria on what constitutes a high loading. Liu *et al.* (2004) classified component loadings as strong, moderate and weak, corresponding to absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30 respectively.

PCA was performed on correlation matrix of transformed data of combined data (mean of observation for each spatial group). Any component with an eigenvalue greater than unity (>1) was considered significant (Sakan *et al.*, 2009; Tanriverdi *et al.*, 2010), hence corresponding variable loadings and explained variance were determined. In order to interpret the component loading matrix some degree of subjectivity was used. Any variable with loading value greater than 0.5, irrespective of positive or negative sign, was considered as significant to that PC.

c) WQI approach for minimizing the water quality parameters using PCA results

Number of water quality parameters used for the river water quality monitoring was 17. It was belived that this number can be sufficiently minimized through the use of the PCA results for the individual spatial groups. Water Quality Index (WQI) approach was followed for this purpose. WQI involves the following steps:

- Selection of the water quality parameters for inclusion in the WQI

- Conversion of the water quality monitoring (carried out against the selected parameters) data into Common Environmental Scale Units (CESU) using transformation curves/equations.
- Assigning relative importance values for the individual parameters (obtained through pair wise comparison techniques or through the analysis of PCA results) and obtaining weighted values for the parameters
- Aggregation of the weighted parameter values to obtained the WQI

Transformation curves/formulae developed by Sharma *et al.* (2013) were used here. Pair-wise comparison technique (Reddy, 2003) was used for assigning the relative importance values.

Analysis of PCA results for relative importance values (for the selected parameters) involved the following:

- Multiplication of loadings of each of the selected parameters with the variability of the corresponding PC for obtaining the parameter importance values
- Consideration of the maximum importance value for each of the parameters obtained under all the PCs (considered), and estimation of parameters' relative importance values from them

The following aggregation function was used for estimating the WQI:

$$WQI = 100 \times \sqrt{\sum \left(P_{CESU}.W\right)}$$

Where,

P_{CESU} = Transformed value of monitored parameter

W = Relative importance assigned to the monitored parameter

In the WQI approach of analysis of the PCA results included the following:

a) Finding the following WQIs while considering the selected water quality parameters:

- WQI while considering only the parameters of the PC-1 with significant loadings >0.5 (WQI for PC-1)
- WQI while considering the parameters with significant loadings >0.5 of PC-1 and PC-2 (WQI for PC-1 and PC-2)
- WQI while considering the parameters with significant loadings >0.5 of PC-1, PC-2, --, PC-*i*, ---, PC-*n*. (WQI for first *n* PCs)
- WQI while considering all the 17 monitored parameters (overall WQI)

b) Application of the test-of-hypothesis between the overall WQI and WQI for 1 PC, for 2 PCs, and so on upto *n* PCs. The minimum number of PCs was identified at which the null hypothesis was accepted.

All the parameters with significant loads (>0.5) listed in these minimum number of PC were taken as the minimum number of water quality parameters required for the monitoring.

3.5 Development of water quality management plan for the Satluj river

Protection of the ecological health of Harike Wetland system was the goal of the developed Satluj River Water Quality Management Plan. Under this, desired quality of the water being discharged by the river into the wetland system was defined by developing use specific Ecological Water Quality Index and a management plan was developed for implementation and achieving this desired Satluj river water quality.

Development of this water quality management plan was suggested to be incorporated with the Satluj River Action Plan, which is presently under implementation. The goal of the proposed plan was reached through defining appropriate watershed management objectives separately for each of the watersheds that contribute both water and pollution loads to the river. The developed plan was supposed to include a program for the monitoring of progress made in achieving the objectives and goals.

Chapter-4

RESULTS AND DISCUSSION

4.1 The study area (the Satluj river watershed) and the Harike wetland system

The Satluj river is one of the five great rivers of the undivided Punjab. It originates in Tibetan Plateau, flows through the Himalayan Range in the Indian state of Himachal Pradesh and enters the plains of Punjab from the Shivalik hills near Nangal. It flows in the east-west direction. Most of the river water is diverted for irrigation, municipal and industrial uses at the Nangal head-works and then at the Ropar head-works, and very little of the river water flows in the river beyond Nangal. Flow in the river includes the seepages and the water intentionally let into the river mainly due to the differences in hydal power generation at Bhakra and in water diversion at the Nangal and the Ropar head-works for meeting the varying off-line water demands. Beyond Nangal the river flows across the Punjab plains for about 238 km and then joins the river Beas at the Harike wetland system, a manmade wetland system created from the construction of head-works for diverting the river water for agricultural, municipal and industrial uses (Jain et al. 2008). In this 238 km stretch of the river, the Himachal Pradesh hills bordering the Punjab state and the agricultural plains and the urban settlements of a major part of the Punjab state constitute the catchments of the Satluj river.

Watershed area (between 31° 45' N 74° 57' E and 30° 45' N 76° 50' E) of the river, in this stretch of 238 km length, is about 10,880 km^2 (**Figure 4.1**). Parts of Hoshiarpur district, Nawanshahar district, Jalandhar district, Kapurthala district (Phagwara tehsil), Ludhiana district and Rupnagar district of Punjab and Una district and parts of Solan district of Himachal Pradesh fall within this watershed area. Most of the watershed area is a flat terrain, and it is divisible into the following sub-watersheds.

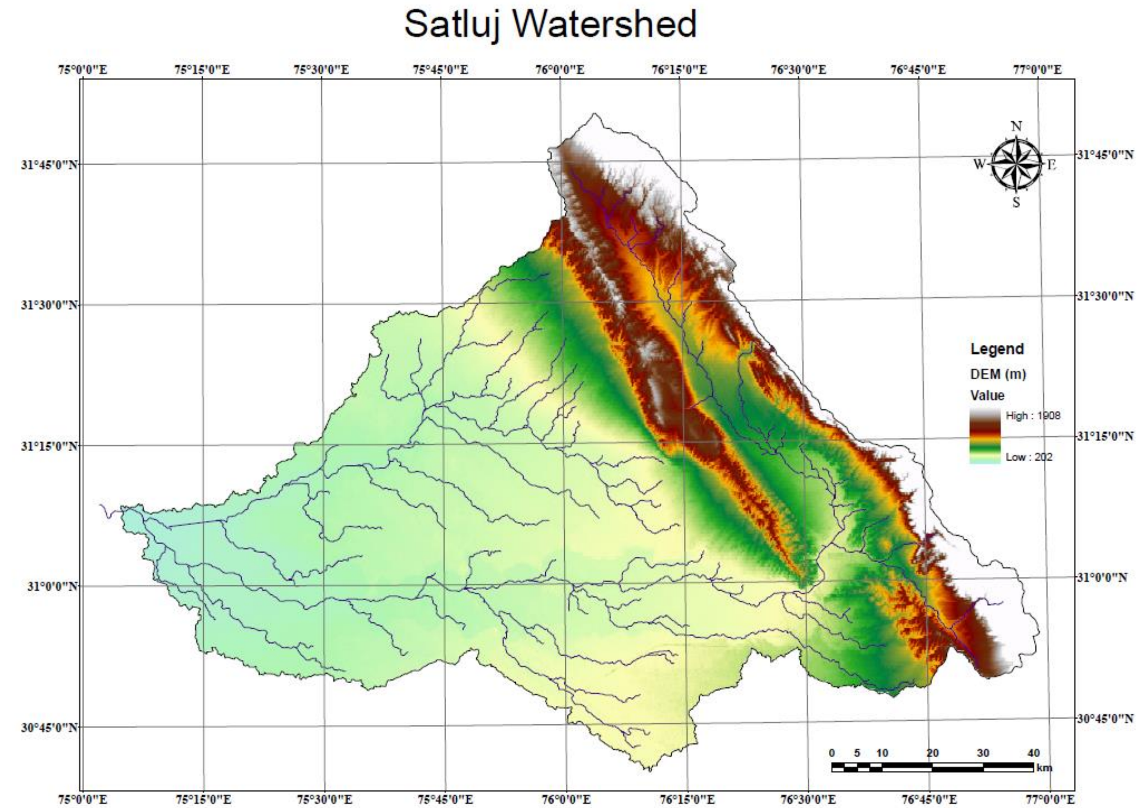

Figure 4.1: Digital Elevation Map (DEM) of the Satluj river watershed.

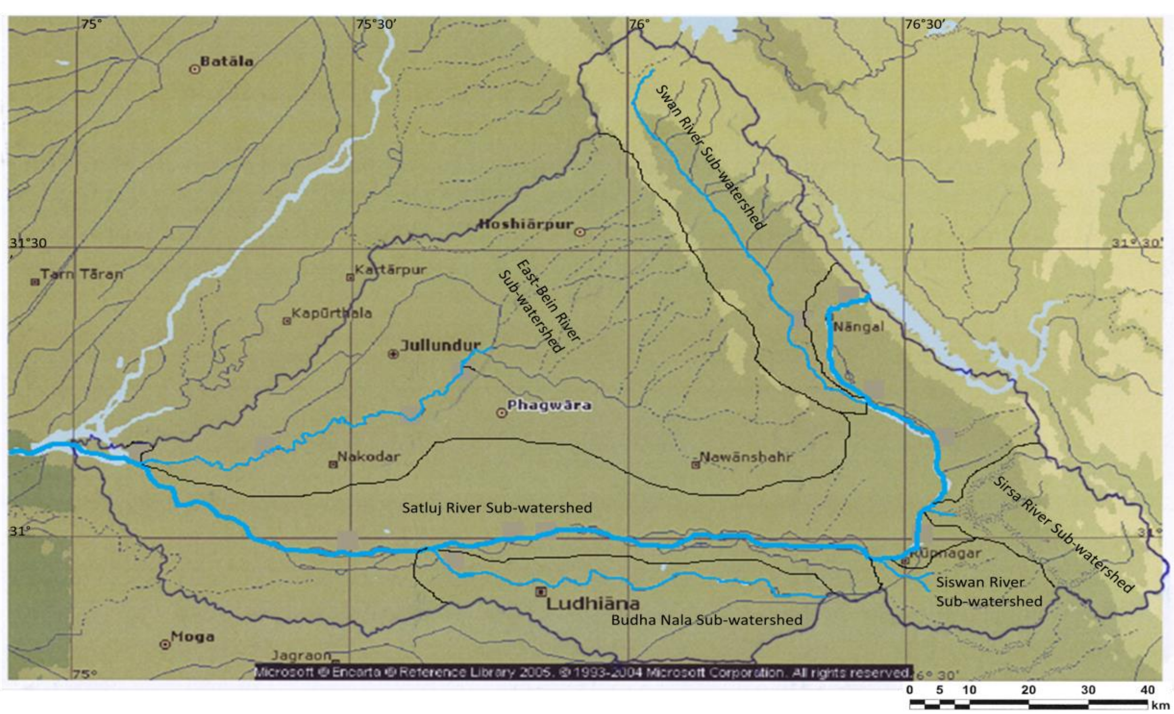

Figure 4.2: Map of sub-watersheds in Satluj river watershed.

a) ***The Satluj river sub-watershed:*** Out of the total area, 3053.18 km^2 area, on either side of the river, starting from Nangal head-works to Harike head-works directly drains into the Satluj river. This area has been considered as the Satluj river sub-watershed.

b) ***The Swan river sub-watershed:*** This sub-watershed is of about 1250 km^2 area. Slopes of the Swan river catchments vary from gentle to steep. The Swan river of approximately 66 km length, which originates in the southern slopes of the Shivalik ranges also known as Solasinghi range, drains this sub-watershed into the Satluj river. In the summers, discharge in the river drops drastically, while during monsoon it remains in spate.

c) ***The Sirsa river sub-watershed:*** Approximate area of the Sirsa river sub-watershed is 662 km^2. The Sirsa River, which originates in the Himachal Pradesh state near Baddi, drains this sub-watershed and joins the Sutlej river near Ropar, upstream to the Ropar head-works.

a) ***The Siswan river sub-watershed:*** Approximately area of the sub-watershed is 478 km^2. The Siswan river, originating from the western slopes of Kolahi range facing the Punjab plains, drains this sub-watershed into the Satluj river.

b) ***The Buddha Nala sub-watershed:*** The Buddha Nala runs parallel to the river Satluj, on its south, for a fairly large section of its course in the Ludhiana district and ultimately joins the river Satluj at Gorsian Kadar Baksh in the north-western corner of the district. Approximate length of the stream is 86.5 km and area of the sub-watershed is 1176 km^2. Buddha Nala is a flooding stream during the rainy season. Ludhiana and Machhiwara are situated to the south of the Budha Nala. The water of the stream becomes polluted after it enters the Ludhiana city.

c) ***East Bein river sub-watershed:*** The East Bein river sub-watershed is of 4263.58 km^2 size. The sub-watershed is drained by the 147 km long East-Bein river (also known as the White-Bein). This river originates in the Garhshankar Tehsil of Hoshiarpur district, flows through Phagwara Tehsil and Jalandhar district and joins the river Satluj near Yusufpur village. Two seasonal streams, one to its south, called as the Kail Nala, and the other to its north, join the river in its course. The area to the north of the East Bein is usually swampy and there are a few jhils or chhambs in this area.

Urban settlements (Nangal, Ropar, Phillaur, Ludhiana, Phagwara, Jallandhar, Nawashahar and Hoshiarpur and others) and multitude of industries (textile processing, metal surface finishing, leather processing, distilleries, fertilizer, chemical, etc. industries) contribute water and pollution to the river. Agricultural drainage and storm-water are also the contributors of both water and pollution to the river Satluj.

Harike wetland system is an internationally recognized Ramsar wetland site (Jain et al. 2008). This system is manmade and was created from the construction of head-works on the river Satluj at Harike (the confluence point of two rivers, the Satluj and the Bias). These head-works divert the Satluj river water into canal systems for irrigational, municipal and industrial use.

The Harike wetland system is fed mostly by the Satluj river. Quality of the water fed by the river Satluj is believed to immensely influence the environmental health of the wetland system. Hence, protection and conservation of the wetland system heavily depend on the water quality management in the Satluj river (and in its catchments), specially downstream of the Ropar Head-works.

Most of the original water flow of the river is diverted into the canal system at the Nangal Headworks (upstream of the Ropar wetland site), and only the seepages and the water intentionally let into river flow in the river Satluj beyond the Nangal Headworks. Diversion of the river water at the Ropar Headworks into a canal system further reduces the original water flows in the river to the Harike wetland system. Agricultural drainage (mainly during the paddy season), industrial and municipal effluents, and rural and urban storm water runoff from the catchments downstream to Nangal account for most of the flow in the river Satluj.

4.2 Catchment characteristics

4.2.1 Geomorphology of the Satluj river watershed

Surface of the Satluj river watershed is a part of Indo-Gangetic plain. It was formed by the deposition of alluvium, brought by the rivers originating in Himalayas, taking place in recent geological past. Macroscopically, the watershed is a part of Punjab plain and is featureless. Bist-Doab plain area, enclosed by the Beas and the Satluj rivers, is the main topographic feature of this watershed. General slope of the ground is from northeast to south west. But, on a microscopic perspective, this watershed has the morphological variations shown in **Figure 4.3.** On the basis of local differences in slope, topographic texture and surface materials, the following physiographic units are identified and described within this watershed:

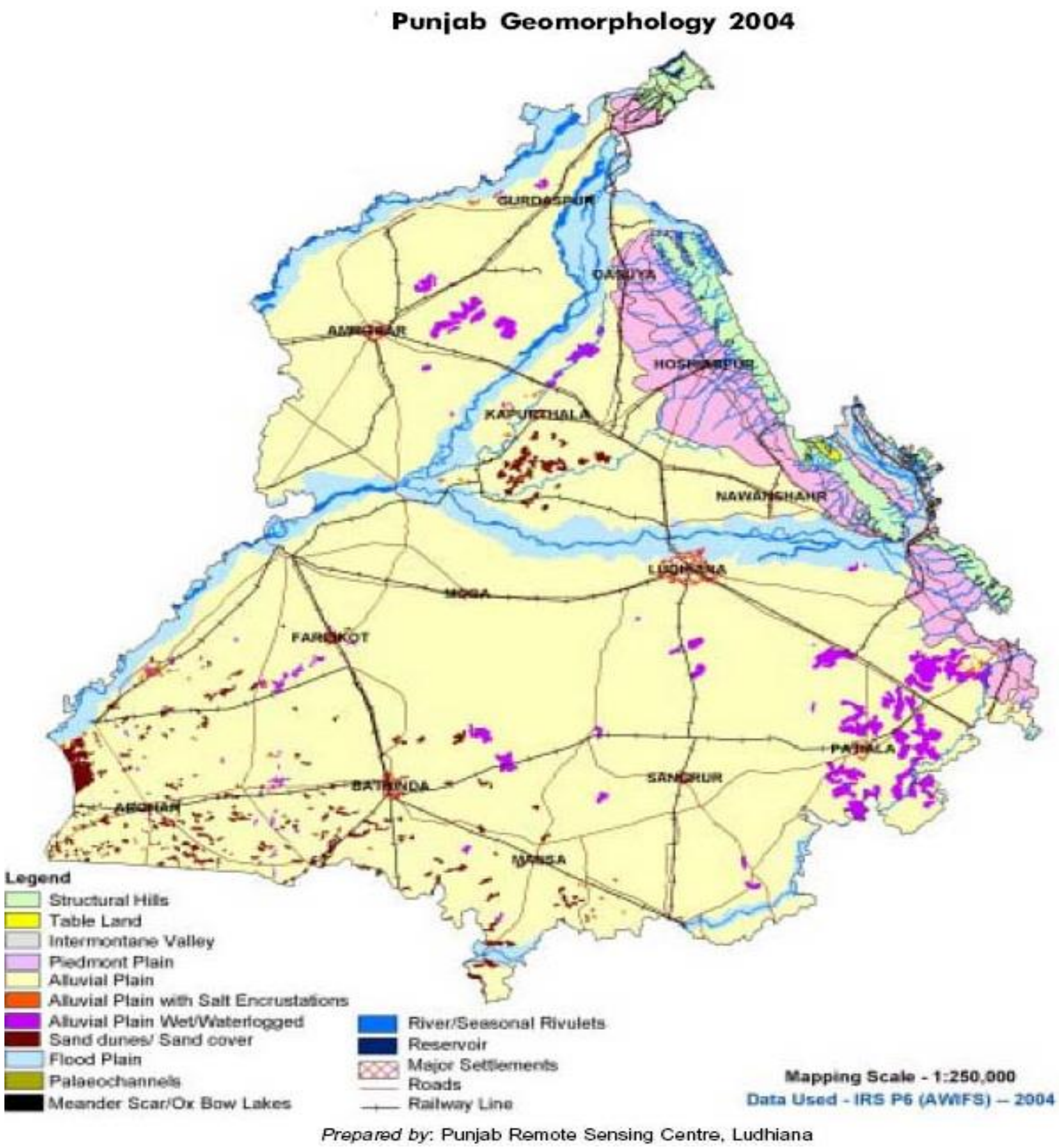

Figure 4.3: Geological map of Punjab showing geomorphology

- Beas lowland: Forms western boundary of the watershed, and separates the Beas river watershed from the Satluj river watershed.
- Sand dune infested tract: it constitutes only a small part of the Satluj watershed and present as localized pockets in the south and south western side.

- Floodplain of the Satluj: It is a new alluvium loam and sand covered, low lying, uneven, 10-15 km wide stretch of land along the Satluj river. It is separated from the sand dune infested tracts on the south and east sides by a low cliff. This tract is locally known as the *bet Satluj*.
- Upland plain: Most of the Satluj watershed area is upland plain. It is almost flat terrain and its elevation ranges from 240 m to 320 m MSL.
- Foothill plain: Adjoining area of the Shiwalik hills to their west with elevation ranging from 275 to 428 meters MSL is considered as the foothill plain. This area (also known as Kandi area) is densely infested with seasonal streams (locally known as *choes) and* has a badly dissected surface. It is the widest, about 24 km in the Hoshiarpur tahsil, and narrows down towards the north in the Dasuya tahsil, and towards the south in Garshankar and Balachaur tahsils of Nawashahr district.
- Anandpur Dun: It is an elongated valley enclosed by the Shiwalik Hills located on the eastern peripherals of the watershed. It runs from Nangal in the north to Kakrala village in the south over a distance of about 50 kilometers and has an average width of 10 km. Elevation range is between 278 and 358 meters, and the area has a north-south gradient of two meters per kilometer. The Satluj river enters this valley near Nangal, flows along its longer axis, and finally leaves it near Rupnagar.
- Hilly tract: It is situated in the northern margins of the watershed. It represents a transitional location between the up land plain of Central Punjab and the outer Himalayan Section of Himachal Pradesh. highest elevation point lies on the boundary between Garhshankar of Punjab and Una of Himachal Pradesh.

4.2.2 Soils

Soils of the watershed area vary with respect to texture, temperature, percent carbonates, drainage class and profile development, in addition to the presence of gravel or cobbles in some areas (Sharma, 2008). The soil types encountered in the watershed are shown in figures -4 and 5, and briefly described below:

- Aridic zone: A small fraction of soils in the south western parts of the watershed are aridic soils. These, according to Sehgal, 1974, developed under arid, semi arid and hot climatic conditions. These soils are light colored, and have pH in the range of 7.5 to 8.5 and conductivity in the range of 1 to 5 m.mhos/cm. Texture of the soil ranged from sandy loam to silty loam. The aridic soils have been grouped under the Hydrologic soil group B for hydrological studies.

- Sandy soils: These are confined to localized pockets (to sand dunes or sand bars). These soils have been grouped under the Hydrologic soil group A for the hydrological studies.
- Ustic zone: Most of the central part of the watershed has *Ustic soils. These soils* developed under sub-moist and less hot climatic conditions. These soils are saturated with bases. Their texture varied between sandy loam and clay loam. These soils have pH in the range of 7.5 to 8.5 and conductivity 1 to 2 m.mhos/cm. The Ustic soils have been grouped under the Hydrologic soil group C for the hydrological studies.
- Udic zone: Udic soils are confined only to the north east fringe of the watershed, the sub-humid and less hot foothills area of Punjab and Una district in Himachal Pradesh. These soils are reddish brown to olive brown in colour. Their pH varied from 6.5 to 7.5, and conductivity is below 0.5 m.mhos/cm. Texture of these soils ranged from sandy loam to clay loam. The Udic soils have been grouped under the Hydrologic soil group C for the hydrological studies.

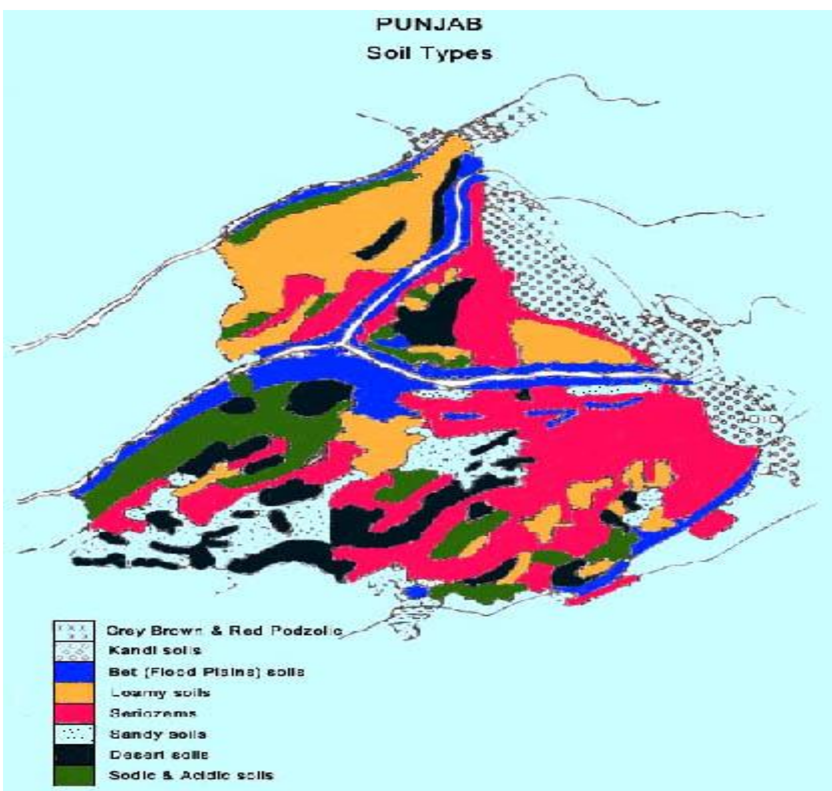

Figure 4.4: Geological map of the Punjab state showing soil types

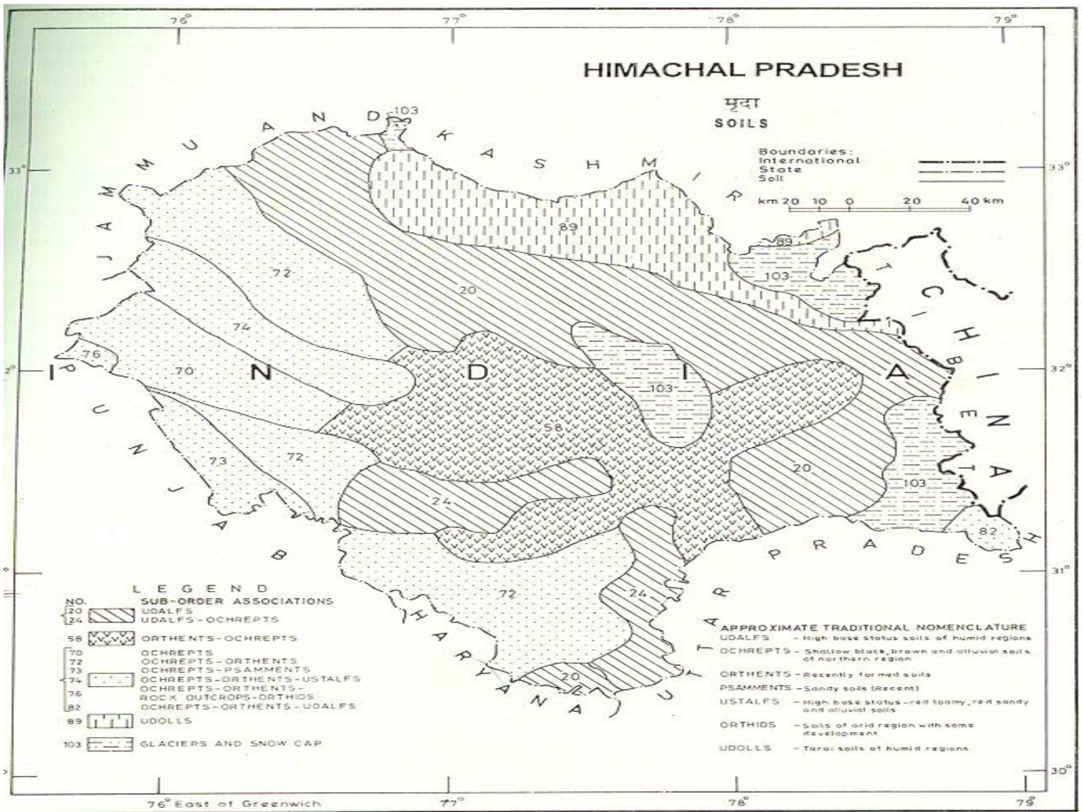

Figure 4.5: Geological map of the Himachal Pradesh state showing the soil types

4.2.3 Rainfall and temperature

The climate of the watershed is dominantly semi-arid and monsoon type. It is mainly influenced by the Himalayas in the north and by the Thar Desert in the south. Periodic circulation of the moist air masses from the south-east and north-west sectors causes occurrence of two wet periods alternating with dry periods. As the distance increases from the Himalayas the temperature also increases and rainfall decreases. In general, summers are hot and winters are cool (Sharma, 2008).

The watershed area experiences three distinct seasons, the hot season (from April to June), the rainy season (from July to September) and the winter season (from October to March). Highest temperatures (between 44.2° and 44.7°C) in the area are recorded in the June month and the lowest (between 0° and 2.2°C) in the January. The mean annual rainfall is 705 mm, which varies from 1200 mm to less than 300 mm. The major part of the rainfall occurs between the months of July and September.

4.2.4 Land use and land cover

Land use land cover (LULC) data developed by NRSC (2006) for the region was compiled for all the six sub-watersheds, and given in table-4.1.

Table 4.1: Land use and land cover classification of the different river sub-watersheds

Land use and Land Cover class (LULC Class)	**Area in km^2 (as % of the total area in parentheses)**					
	Buddha Nala sub-watershed	**East Bein river sub-watershed**	**Satluj river sub-watershed**	**Sirsa river sub-watershed**	**Siswan river sub-watershed**	**Swan river sub-watershed**
Cropland	914.3 *(77.7)*	3412.1 *(80)*	2189.2 *(71.7)*	232.3 *(35.1)*	284.4 *(59.5)*	533.5 *(42.7)*
Grasslands/ Grazing Lands	6.8 *(0.6)*	26.3 *(0.6)*	18.9 *(0.6)*	11.5 *(1.7)*	2.8 *(0.6)*	---
Mining	3.7 *(0.3)*	---	---	1.0 *(0.1)*	---	---
Gullied/Ravinous land	---	5.1 *(0.1)*	57.4 *(1.9)*	13.3 *(2.0)*	---	38.0 *(3.0)*
Fallow land	0.03 *(<0.1)*	3.5 *(0.1)*	0.1 *(<0.1)*	---	0.9 *(0.2)*	---
Deciduous	17.2 *(1.5)*	292.7 *(6.9)*	370.8 *(12.1)*	210.2 *(31.8)*	114.3 *(23.9)*	299.1 *(23.9)*
Forest Plantation	---	17.0 *(0.4)*	1.8 *(0.1)*	---	---	---
Plantation	7.6 *(0.6)*	21.9 *(0.5)*	11.6 *(0.4)*	1.6 *(0.2)*	1.2 *(0.3)*	2.8 *(0.2)*
Inland Wetland	2.0 *(0.2)*	---	0.7 *(<0.1)*	0.04 *(<0.1)*	---	2.5 *(0.2)*
Reservoirs/ Lakes/ Ponds	0.1 *(<0.1)*	1.1 *(<0.1)*	21.9 *(0.7)*	---	0.9 *(0.2)*	0.1 *(<0.1)*
River/ Stream/ Canals	20.0 *(1.7)*	96.1 *(2.3)*	89.3 *(2.9)*	18.4 *(2.8)*	13.4 *(2.8)*	73.2 *(5.9)*
Sandy Area	7.1 *(0.6)*	19.2 *(0.4)*	25.8 *(0.8)*	---	---	37.1 *(3.0)*
Scrub Forest	---	21.0 *(0.5)*	19.6 *(0.6)*	35.9 *(5.4)*	10.3 *(2.2)*	37.4 *(3.0)*
Scrub land	1.8 *(0.2)*	30.6 *(0.7)*	130.1 *(4.3)*	62.4 *(9.4)*	26.7 *(5.6)*	162.0 *(13.0)*
Rural	39.3 *(3.3)*	183.1 *(4.3)*	84.6 *(2.8)*	5.5 *(0.8)*	22.0 *(4.6)*	38.8 *(3.1)*
Urban	156.1 *(13.3)*	132.7 *(3.1)*	20.5 *(0.7)*	31.6 *(4.8)*	1.0 *(0.2)*	8.6 *(0.7)*
Salt affected land	---	1.5 *(<0.1)*	0.05 *(<0.1)*	---	---	---
Evergreen/ Semi-evergreen	---	---	8.7 *(0.3)*	34.7 *(5.2)*	---	2.5 *(0.2)*
Barren Rocky Area	---	---	1.9 *(0.1)*	3.6 *(0.6)*	---	14.5 *(1.2)*
Area of the sub-watershed (km^2)	1176	4264	3053	662	478	1250

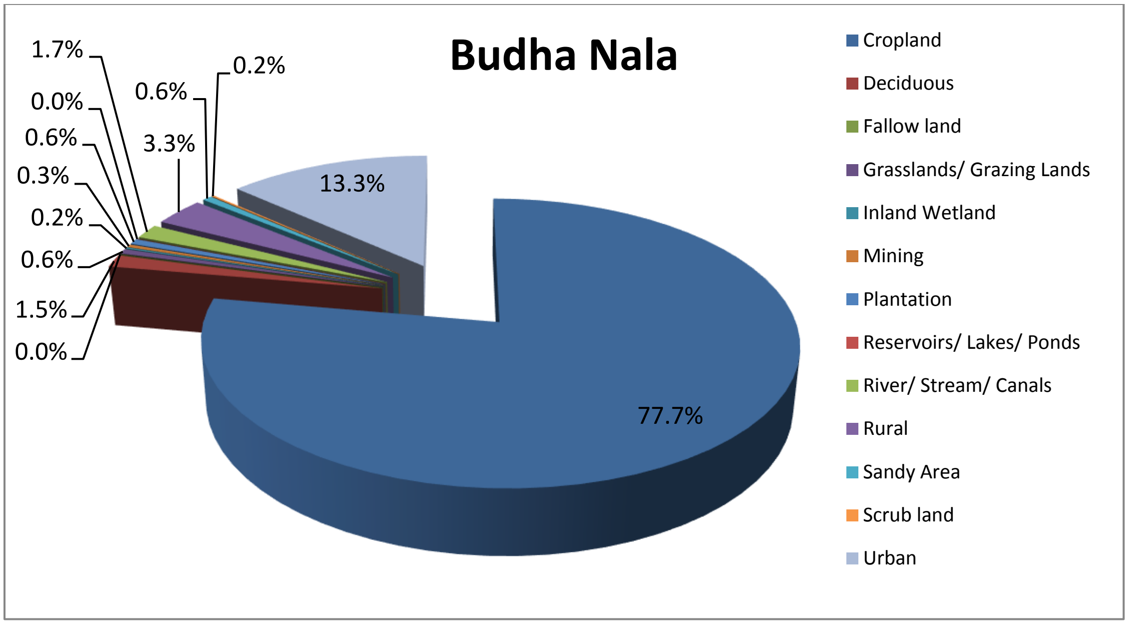

Figure 4.6: Composition of land use land cover class for Budha Nala sub-watershed

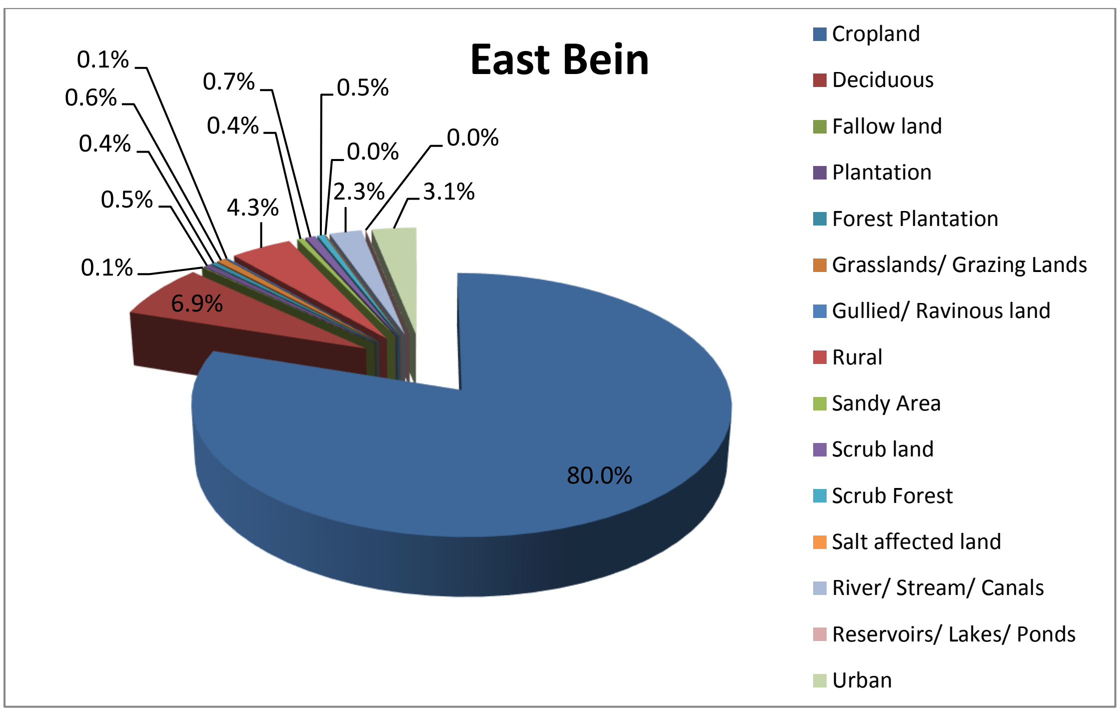

Figure 4.7: Composition of land use land cover class for East-Bein sub-watershed

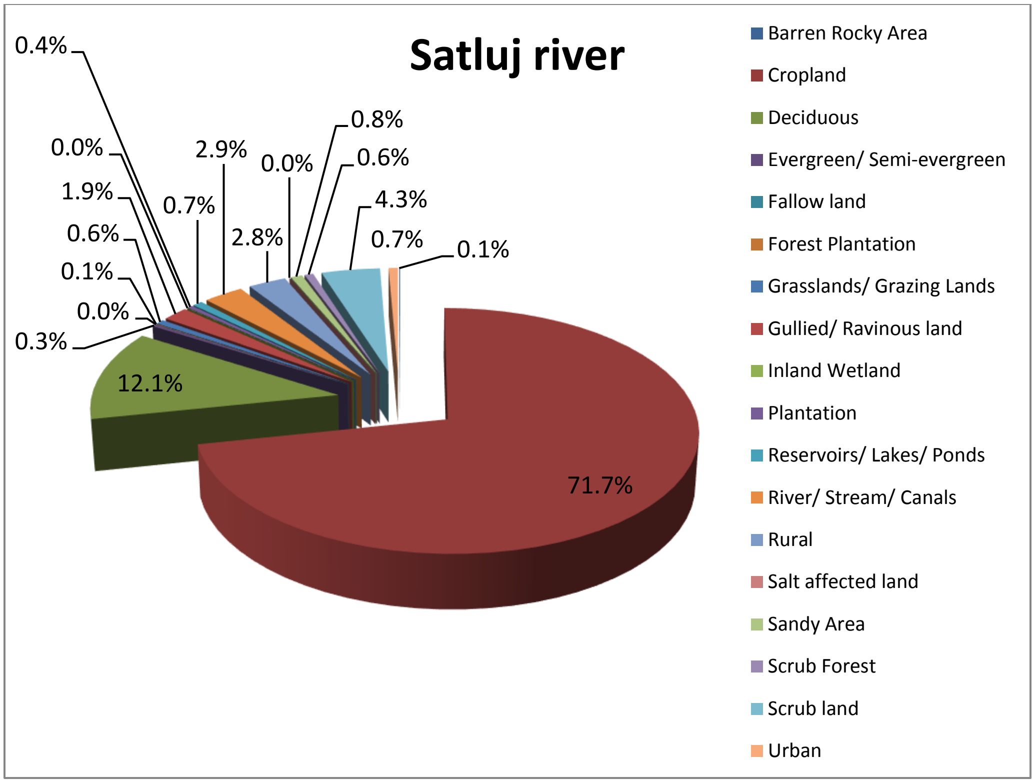

Figure 4.8: Composition of land use land cover class for Satluj river sub-watershed

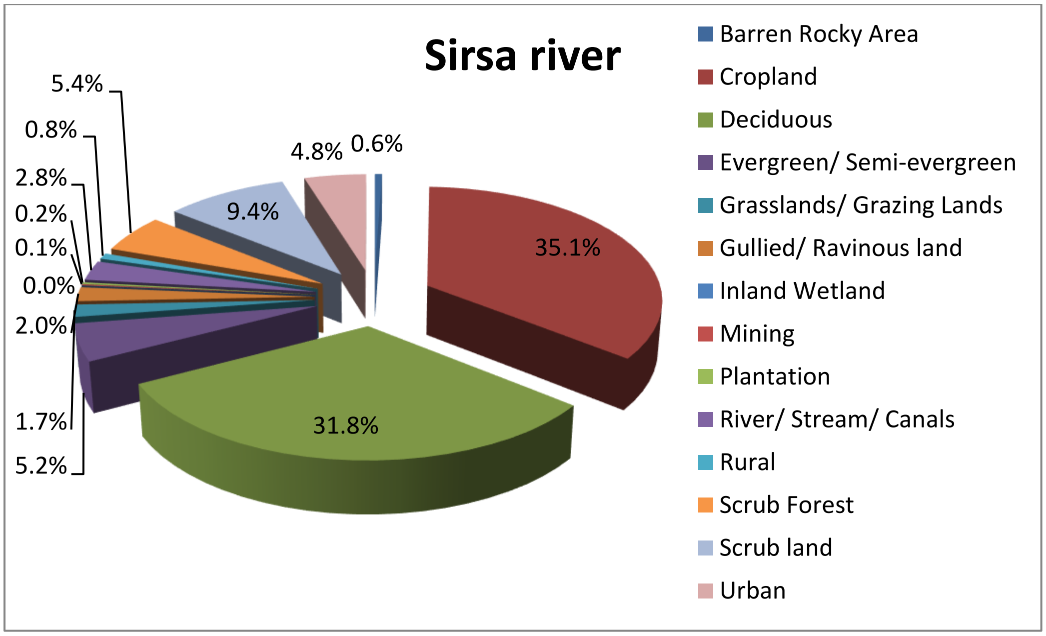

Figure 4.9: Composition of land use land cover class for Sirsa river sub-watershed

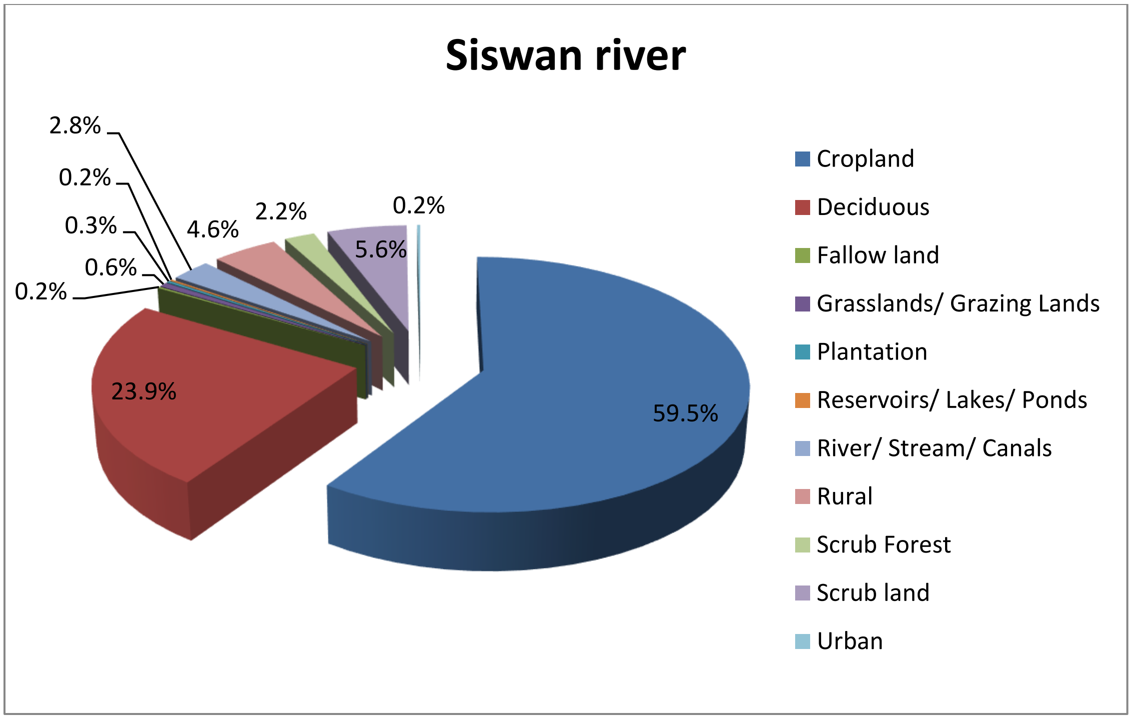

Figure 4.10: Composition of land use land cover class for Siswan river sub-watershed

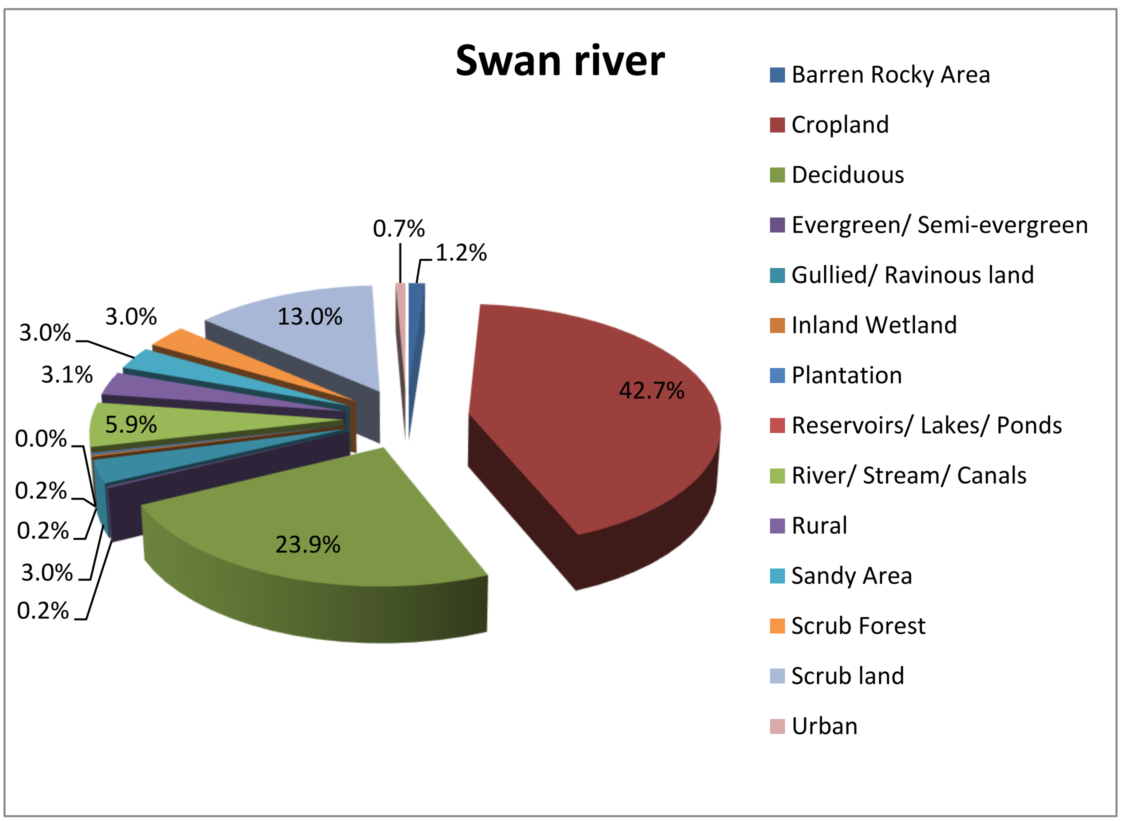

Figure 4.11: Composition of land use land cover class for Swan river sub-watershed

4.2.5 Demographics and human settlements

Census of India Directory (2011) revealed that south-western and western part of the watershed (Ludhiana and Jalandhar districts) are having the highest population densities of 975 and 831 persons/km^2 respectively and growing at 15% per decade and 11.16% per decade respectively. Central part of the watershed, which is comprised by districts of Hoshiarpur and Nawanshahar (S.B.S. Nagar) is having moderate population densities of 466 and 479 persons/km^2 respectively and the decadal population growth is 6.85% and 4.58% respectively. Northern part of the watershed (district Una of Himachal Pradesh) is having relatively lower population density (338 persons/km^2), but growing at faster rate (16.24% per decade). The eastern part of the watershed (district Rupnagar of Punjab and some part of district Solan of Himachal Pradesh) have population densities of 488 and 298 persons/km^2 respectively.

4.2.6 Point sources of pollution of the Satluj river

The municipal committees that fall within the satluj river watershed area and the sewage discharges they make into the river Satluj as estimated by the Punjab Pollution Control Board (PPCB), Patiala are given in **Appendix-C**. The large and medium scale industrial units discharging their effluents into the Satluj river as identified by the PPCB are given in **Appendix-D**.

4.3 Stormwater Assessments

For the watershed area both flow data and rainfall data was available for three years (January 2003 to December 2005) and this data was used in the storm water assessments.

For each of the sub-watersheds, storm water flows were quantified by NRCS Runoff Curve Number method. Area under each of the sub-watersheds was divided into 73.51 km2 (9.27 km x 7.93 km) size grids. For each of the grids, watershed characteristics, such hydrological soil group, land use and land cover, and slope of the land surface, were obtained. Runoff Curve Number (RCN) was then assigned for each of the land use and land cover types at the grid level. A curve numbers table (**Table-4.2**) deduced from the Curve Numbers tables of the TR-55 was used, and 'Fair' hydrologic condition was assumed in assigning the CN. Then Weighted Curve Number was found for each of the grids, and average weighted curve number was obtained for the sub-watersheds in question. Then using the following equations runoff volumes for different rainfall depths were computed for the sub-watersheds:

$$S = \frac{1000}{CN} - 10$$

Here S is potential maximum retention after runoff begins

CN is Curve Number

$$I_a = 0.2S$$

Here I_a Initial abstraction term

$$P = 25.4\left(\frac{200}{CN} - 2\right)$$

P is the maximum precipitation (in mm) uptill which no runoff will be created

$$Q_v = \frac{\left(\frac{P}{25.4} - I_a\right)^2}{\left(\frac{P}{25.4} - I_a + S\right)} \frac{A}{10^6}$$

Here P is precipitation in mm

A is area of the sub-watershed in km^2

Qv is surface runoff volume in km^3

Table 4.2: Curve Numbers used in the study

Land use and land cover type	Hydrologic condition	Hydrologic Soil Group		
		A	B	C
Urban	---	77	86	91
Rural	---	50	74	82
Crop land[-1]	---	98	98	98
Fallow land including mining	Poor	80	87	93
	Fair	71	81	89
	Good	62	74	85
Plantation	Poor	57	73	82
	Fair	43	65	76
	Good	32	58	72

Forest land	Poor	45	66	77
	Fair	36	60	73
	Good	30	55	70
Scrub land/forest	Poor	63	77	85
	Fair	55	72	81
	Good	49	68	79
Grassland/grazing land	Poor	68	79	86
	Fair	49	69	79
	Good	39	61	74
Water bodies (wetland, rivers/ streams, swamps, reservoirs and lakes) -2	---	98	98	98
Sandy Soil-3	---	50	50	50
Barron rock area-4	---	96	96	96
Salt affected land-5	---	94	94	94

Note:

-1: The crop land was considered as mostly under the flood irrigated paddy crop and are assigned with the CN of 98.

-2: Water bodies (wetland, rivers/streams, swamps, reservoirs and lakes) were considered as having water and assigned with the CN of 98

-3: Sandy soil was taken as highly pervious and assigned with the CN of 50

-4: Barron rock area is impervious and hence assigned with the curve number 96

-5: Salt affected land was taken as waterlogged impervious area and it was assigned with the CN of 94.

The surface runoff estimations for the six sub-watersheds are shown in **Table-4.3** and **Figure-4.12**.

Table 4.3: Runoff volume estimations for the sub-watersheds

Rainfall depth (in mm)	Runoff volume (in 1000 m^3)					
	Buddha nala sub-watershed	Satluj river sub-watershed	East bein river sub-watershed	Swan river sub-watershed	Sirsa river sub-watershed	Siswan river sub-watershed
5	0	0	1	0	0	0
10	2	5	8	0	0	0
15	6	13	20	2	1	0
20	10	23	35	4	2	1
30	20	46	69	10	5	3
40	30	72	106	19	9	6
65	58	142	205	43	22	15
95	92	230	328	76	39	27
135	138	350	496	123	64	45
180	191	485	686	177	92	65
230	249	637	898	238	124	88
290	319	819	1152	311	163	116
350	390	1002	1408	385	202	145

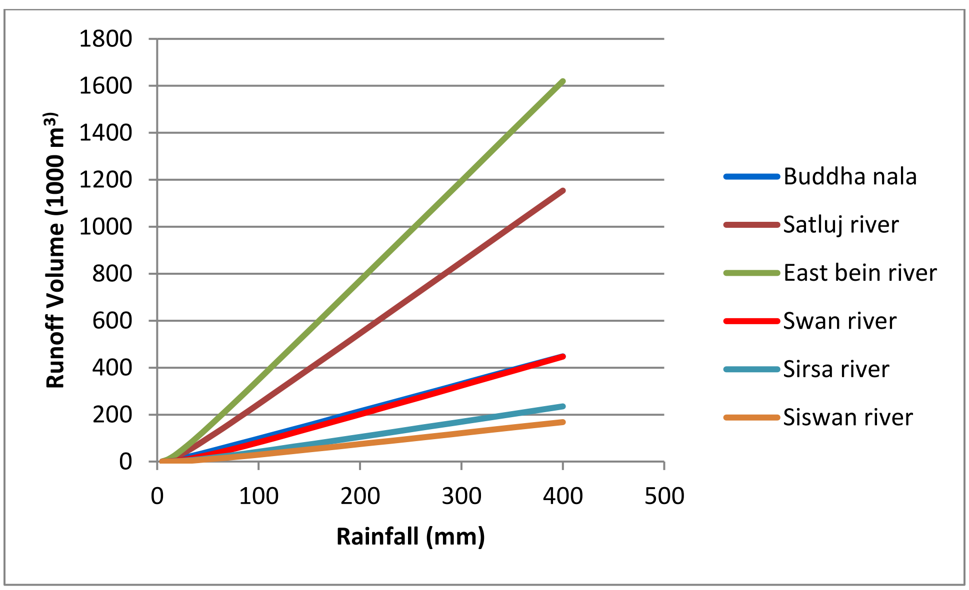

Figure 4.12: Surface runoff estimations for different sub-watersheds

Storm water flows were then assessed for the rainfall events for each of the sub-watersheds. One major limitation of this assessment is the assumption of the occurrence of the rainfall event of the same depth all across the sub-watershed. For the large heterogeneous sub-watersheds, the potential maximum retention after runoff begins (S) may be much higher than what was used in the assessments. The stormwater runoff assessments were made for three years period using the rainfall data available for the sub-watersheds. Please see **Appendix E to J** for the runoff assessments made for the sub-watersheds. In case of the East-Bein river sub-watershed, the Budha Nala sub-watershed and the Swan river sub-watershed, actual flows (monitored and available from the irrigation department for the period from January 2003 to December 2005) are shown along with the stormwater assessments in these tables for comparison.

When compared with the actual flows, for the Swan river, the Buddha Nala and the East-Bein sub-watersheds, stromwater flows were found not very significant. Further, the assessed stormwater flows appeared to be much higher than the swells observed in the actual flows. That is, the stromwater assessments have been mostly overestimations. This overestimation could be because of the following reasons:

- Heterogeneous nature of the sub-watershed might not have been properly incorporated into the NRCS Runoff Curve Number method storm runoff volume assessment. The potential maximum retention after runoff begins, S, might have been very much underestimated.
- About 70% of the watershed area was crop land and most of it was under flood irrigated paddy cultivation. For retaining the irrigated water leak proof bunds are provided to the paddy fields. These bunds might not have allowed any runoff to occur uptill certain threshold runoff depth. That is no runoff is created until the rainfall depth crossed certain threshold value. Relatively larger rainfall events might result in overflowing of the bunds and subsequent damage of the latter. As a consequence of this both the accumulated runoff water and the irrigated water of the paddy field might have flown down causing floods.
- During floods actual flow measurement at the outlet of the sub-watershed might not have been accurate and most often associated with negative error.

4.4 Relationship between the rainfall events and swells in flow rates observed at the sub-watershed outlets

Daily flow data was available for the outlets of the East-Bein river, Buddha Nala and Swan river sub-watersheds for the period, from January 2003 to December 2005. Rainfall data for this period for which the flow data is available for the three sub-watersheds in question was obtained. Swells in the flow at the sub-watershed outlet were obtained through subtracting 7-day moving average flow value from the actual flow. Since the hydraulic path lengths of the sub-watersheds are relatively larger, cumulative swells in flow on the day of the rainfall event and on the next day were considered. Since the rainfall events of beyond certain minimum depth only can generate runoff, rainfall events of >15 mm depth were only considered in this study. These swells were then correlated with the rainfall for knowing the extent to which the swells in flow are related with swells. Please see the results (correlation coefficient values obtained) in **Table-4.4**.

A strong correlation is supposed to exist if the flows at the outlet are mainly due to the stormwater runoff generated by the rainfall events. In none of the three cases any strong correlation was observed. Correlation coefficient value >0.5 was taken as an indication for significant contribution by stormwater flows to the actual flows in the river at the outlet of the sub-watershed. The results indicate that the water quality in the Swan river, Buddha Nala and in the East-Bein (and also in the Satluj river) is the least influenced by the storm water flows from the sub-watersheds.

Table 4.4: Correlation between Rainfall and Flow peaks (Actual flow – Moving average flow)

Station	**Correlation coefficient**
Budha Nala	-0.456
East-Bein river	-0.336
Swan river	-0.408

4.5 Development of Ecological Water Quality Index (WQI_E)

4.5.1 Parameter selection and assignment of weights

Potential water quality parameters identified for inclusion in the WQI_E are given in **Table-4.5**. These parameters included even the open lists of heavy metals parameters, and of pesticides and other toxic organic compounds parameters. If prescribed water quality criteria and/or water quality standards were existing for a specific parameter then that parameter was considered as a potential water quality parameter.

Table 4.5: List of selected parameters for WQI_E

Sub-index	Parameter group	Parameters
SI_{gp}	General parameters	Dissolved Oxygen % saturation, pH, Turbidity, Total Suspended Solids, Ammonical-N, Total-N[@], Total-P, BOD_5, $COD^2/8.33\times BOD_5$ ratio and Fluoride
SI_{hm}	Heavy Metals*	Iron, manganese, copper, zinc, lead, nickel, total chromium, hexavalent chromium, cadmium, arsenic, mercury, selenium, etc.
SI_{ptoc}	Pesticides and other toxic organic compounds**	α-benzene hexa chloride (BHC), β - BHC, γ - BHC, op – dichloro diphenyl trichloro ethane (DDT), pp – DDT, α - endosulphan, β – endosulphan, aldrin, dieldrin, carbaryl, malathian, methyl parathian, anilophos, chloropyriphos, etc.

@: Total Nitrogen included Ammonical-N, Nitrate-N and Nitrite-N, and organic-N was excluded

*: The list of heavy metals parameters is a open ended list. Still, 11 heavy metals (plus hexavalent chromium) mentioned by the NRCD, MOEF, GOI in its Notification S. O. 2151, 2005 "Uniform protocol for monitoring of rivers", were considered as important.

**: The list of pesticides and other toxic organic compounds is also an open ended list. Still, 10 pesticides mentioned by the NRCD, MOEF, GOI in its Notification S. O. 2151, 2005 "Uniform protocol for monitoring of rivers", were considered as important.

Many of the guidelines consider total Nitrogen as the sum of the inorganic forms of nitrogen present in water, like, ammonia, ammonium, nitrite and nitrate. Ammonia (NH_3) and ammonium (NH_4^+) forms are the reduced forms of inorganic nitrogen and their relative concentrations in water are governed by both temperature and pH of the water. Nitrate is more stable and more abundant in both soil and water environments, and it is an end product of nitrification of ammonical-N (reduced form of nitrogen). Nitrite (NO_2^-) is relatively unstable inorganic intermediate product of nitrification. In view of their co-occurrence and rapid inter-conversion, nitrite and nitrate are usually measured and considered together. Inorganic forms of nitrogen are primarily of concern. These have stimulatory effect on aquatic plants and algae. Ammonical nitrogen specially the free ammonia has toxic effects on most of the aquatic organisms. Organic nitrogen has no direct significance but bio-oxidation of organic matter converts the organic nitrogen into ammonical-N and influences the water quality.

Organic matter (both biodegradable and non-biodegradable but chemically oxidizable) concentration is measured as COD while biodegradable organic matter is measured as BOD. Here the BOD stated is actually BOD_5 at 20°C, and through the text BOD_5 at 20°C has been mentioned as BOD. Lower COD/BOD ratio is an indication that most of the COD is biodegradable organic matter. Higher COD/BOD ratio indicates that significant fraction of the organic matter is either slowly biodegrading or recalcitrant and even toxic. Very high COD/BOD ratio and higher COD (>450 mg/L) indicate that some hazardous organic substance must be contributing to the COD. Based on the water quality criteria and standards prescribed, the $COD^2/8.33\times BOD$ ratio had been decided for inclusion in the list of selected general parameters. In this case the 8.33 used is the ratio of the prescribed effluent COD to BOD ratio (CPCB, 2010).

The ten general parameters finally selected and the relative weights assigned to them are given in **Table-4.6**. Relative importance values or weights assigned to the parameters appear to be not that realistic. This is evident from the moderate variability (average standard error of 43.6%) observed in the expert opinion.

Table 4.6: Selected parameters with their corresponding weights

S. No.	Parameters	Final weights	Modified weights for 2001-02	Modified weights for 2005-11
1	BOD	0.153	0.155	0.172
2	DO% saturation	0.148	0.150	0.166
3	pH	0.116	0.117	0.130
4	$COD^2/8.33\times BOD$ ratio	0.114	0.115	0.128
5	Turbidity	0.097	0.098	---
6	TSS	0.096	0.098	0.108
7	Total-N	0.094	0.095	0.106
8	Total-P	0.092	0.093	0.103
9	Ammonical-N	0.078	0.079	0.088
10	Fluoride	0.012	---	---
	$\sum W$	1.000	1.000	1.000

4.5.2 Construction of transformation equations

Concentration ranges expected for all the potential general water quality parameters, and their sectionization and relating with the five sectors on the CESU (done on the basis of the review of the water quality criteria and standards prescribed) are given in **Table-4.7**. The PRC/TE developed for the potential water quality parameters are given in **Figure-4.13** and **Table-4.8**. Though water quality criteria and standards were used as the bases, some degree of subjectivity was forced into the development of PRC/TE specially for dividing the range of parameters' values into 5 sections. Differences in the criteria and standards prescribed among different nations and organizations also made this subjectivity inevitable. Sectionization of the 0-1 CESU into five sections (for relating with the actually measured values) has also been quite arbitrary, but done using the standard normal distribution curve as the basis.

Table 4.7: Concentration ranges of parameters and their corresponding CESU value/Quality

S. No.	**Parameters**	**Classification**				
		Excellent	Good	Moderate	Poor	Worst
		≥0.92	≥0.70	≥0.30	≥0.08	<0.08
1	DO% saturation	90-110	70-90 & 110-130	40-70 & >130	10-40	<10
2	pH	7.0-8.0	6.5-7.0 & 8.0-8.5	5.5-6.5 & 8.5-9.5	3.1-5.5 & 9.5-11.7	2.7-3.1 & 11.7-12.0
3	Turbidity	0-5	5-20	20-40	40-80	>80
4	TSS	0-10	10-30	30-100	100-250	>250
5	Ammonical-N	0-0.007	0.007-0.1	0.1-1.0	1.0-5.0	>5
6	Total-N	0-0.5	0.5-2.5	2.5-5.0	5-30	>30
7	Total-P	0-0.01	0.01-0.10	0.1-1.0	1-5	>5
8	BOD_5	0-2	2-5	5-15	15-30	>30
9	$COD^2/8.33\times BOD$ ratio	<15	15-40	40-100	100-250	>250
10	Fluoride	0-0.75	0.75-1.5	1.5-2.5	2.5-3.0	>3
14	Heavy metals/ Pesticides conc. Ratio	≤1	1-2	2-8	8-16	>16

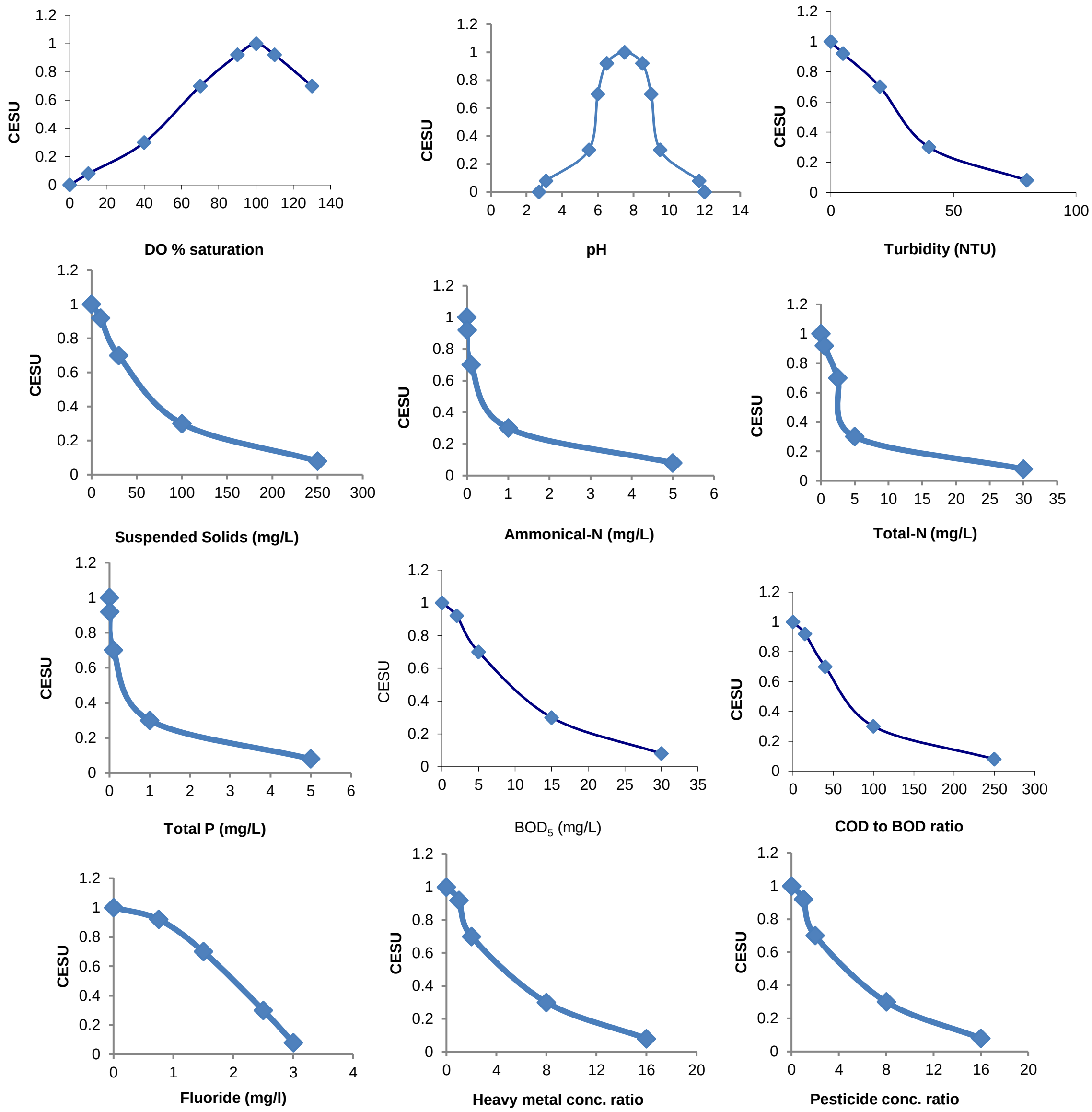

Figure 4.13: Assigned rating curves for the studied water quality parameters

Table 4.8: Parameter Transformation Equations (PTE)

Parameters	Concentration Range	Transformation Equation	Goodness of Fit Results			
			R^2	Chi^2		
				Value	DF	P=0.05
DO % saturation	0-100	$y = 0.002x^2 + 0.768x - 0.640$	0.995	1.346	5	11.07
	100-130	$y = -0.01x^2 + 1.3x + 70$	1	0	2	5.991
pH	2.7 – 5.5	$y = 41.05\ln(x) - 39.74$	0.994	1.290	2	5.991
	5.5 – 7.5	$y = -7.09x^2 + 128x - 460$	0.993	0.235	3	7.815
	7.5 – 9.5	$y = -7.09x^2 + 84.7x - 135.2$	0.993	0.235	3	7.815
	9.5 – 12.0	$y = -11.252x + 137.19$	0.977	3.270	2	5.991
Turbidity	0-80 (mg/L)	$y = 0.012x^2 - 2.193x + 102.5$	0.988	5.646	4	9.488
Suspended Solids	0 – 250 (mg/L)	$y = 96.012e^{-0.0102x}$	0.993	1.147	4	9.488
Ammonical-N	0 – 0.1 (mg/L)	$y = 97.13e^{-3.29x}$	0.973	0.175	2	5.991
	0.1 – 5.0 (mg/L)	$y = -15.9\ln(x) + 32.31$	0.995	0.458	2	5.991
Total-N	0 – 2.5 (mg/L)	$y = 2x^2 - 17x + 100$	1	0	2	5.991
	2.5 – 30 (mg/L)	$y = -25.1\ln(x) + 91.42$	0.99	1.090	2	5.991
Total-P	0-0.1 (mg/L)	$y = 97.66e^{-3.35x}$	0.982	0.119	2	5.991
	0.1-5.0 (mg/L)	$y = -15.9\ln(x) + 32.31$	0.995	0.458	2	5.991
BOD_5	0-5 (mg/L)	$y = -0.666x^2 - 2.666x + 100$	1	0.0	2	5.991
	5-30 (mg/L)	$y = 108.947e^{-0.087x}$	1	0.011	2	5.991
$COD^2/8.33\times BOD$ Ratio	0-250	$y = 100.4e^{-0.01x}$	0.990	1.781	4	9.488
Fluoride	0 – 3 (mg/L)	$y = -7.423x^2 - 9.128x + 100.9$	0.998	0.400	4	9.488
Heavy metal conc. ratio	0 - 16	$y = 101.9e^{-0.15x}$	0.998	0.828	4	9.488
Pesticides and toxic organics conc. ratio	0 - 16	$y = 101.9e^{-0.15x}$	0.998	0.828	4	9.488

4.5.3 Application of WQI_E for water quality evaluation of the Satluj river

The Satluj river water quality monitoring data obtained for the 8 monitoring stations along the main river for the periods indicated below was analyzed for the WQI_E:

- For the year April 2001 to March 2002: 9 general parameters (of the 10 ecological importance parameters) and 7 heavy metal parameters (Fe, Mn, Cu, Zn, Ni, Pb and Total Cr) were monitored monthly. Data on pesticides and other toxic organic compound parameters was not available.
- For the period April 2005 to March 2011: 8 general parameters (of the 10 ecological importance parameters) were monitored monthly. Data on heavy metals and pesticides and other toxic organic compounds parameters was not available.

In case of heavy metals and pesticides, when data was not available, the sub-index for these groups of parameters was taken as a unity in calculating the WQI_E. In case of general parameters, when data was not available for all the 10 selected parameters, relative weights of the parameters were adjusted while considering only the parameters for which the data was available (**Table -4.6**).

(a) Water quality of Satluj River:

Detailed descriptive statistical analysis of water quality monitoring data set of the Satluj river for the year 2001-02 is given in **Table-4.9** and for the year 2005-11 is given in **Table-4.10**.

Table 4.9: Water quality parameters with ranges, mean value and standard deviation at 8 different locations for the year 2001-02.

Parameters		SAT-1	SAT-2	SAT-3	SAT-4	SAT-5	SAT-6	SAT-7	SAT-8
Water Temperature (°C)	Mean	20.2	24.3	20.4	22.4	23.5	23.4	24.4	24.8
	S.D.	3.5	6.5	3.4	3.6	6.9	6.4	7.3	7.2
	Min.	14.8	14.8	15.5	17.5	11.9	12.5	12.5	14.2
	Max.	27.0	33.0	27.6	28.3	31.2	30.9	32.0	33.5
DO % saturation	Mean	85	131	93	94	90	91	17	30
	S.D.	5.9	38.9	13.4	3.8	4.4	4.8	16.1	21.6
	Min.	70	72	61	89	82	83	0	0
	Max.	94	201	110	101	96	100	39	52

Parameters		SAT-1	SAT-2	SAT-3	SAT-4	SAT-5	SAT-6	SAT-7	SAT-8
pH	Mean	7.93	8.32	7.96	7.92	7.92	7.92	7.29	7.63
	S.D.	0.34	0.35	0.21	0.28	0.31	0.24	0.30	0.26
	Min.	7.24	7.92	7.40	7.07	6.96	7.21	6.78	7.13
	Max.	8.67	8.95	8.20	8.19	8.18	8.14	7.72	7.97
Conductivity (µS/cm)	Mean	191	233	198	205	224	232	440	572
	S.D.	26	34	21	28	33	39	169	298
	Min.	142	163	155	151	172	180	265	116
	Max.	225	270	223	254	268	285	702	1190
TDS (mg/L)	Mean	138	178	162	164	190	179	344	414
	S.D.	20	29	27	30	38	30	140	164
	Min.	100	115	125	115	150	135	230	250
	Max.	170	210	215	210	275	235	625	800
SS (mg/L)	Mean	39	61	53	39	55	67	147	178
	S.D.	26	89	57	27	56	44	150	303
	Min.	5	5	10	10	5	5	5	15
	Max.	90	330	190	90	200	155	485	1110
Total Alkalinity (mg/L)	Mean	65.2	82.4	69.2	70.3	80.7	80.3	101.3	120.2
	S.D.	7.1	13.2	9.7	9.0	15.1	18.7	46.0	51.9
	Min.	54.0	58.5	53.0	54.0	64.5	67.0	64.7	68.0
	Max.	76.0	97.0	86.2	84.3	117.6	129.4	226.0	218.0
Total Hardness (mg/L)	Mean	97.7	105.1	87.5	91.7	99.3	102.3	131.7	162.0
	S.D.	15.3	17.0	13.9	13.9	16.7	19.9	34.8	57.6
	Min.	70.0	70.0	64.0	68.5	77.5	72.0	86.0	103.0
	Max.	127.0	123.0	112.0	112.0	123.0	126.0	200.0	268.0
Ammonical N (mg/L)	Mean	0.42	0.36	0.23	0.33	0.26	0.29	4.13	4.72
	S.D.	0.54	0.22	0.13	0.32	0.08	0.16	4.03	5.60
	Min.	0.08	0.08	0.08	0.08	0.14	0.06	0.20	0.17
	Max.	1.96	0.90	0.45	1.20	0.39	0.56	9.96	19.26
Nitrate+Nitrite N (mg/L)	Mean	0.73	3.00	0.84	0.77	0.65	0.59	2.18	2.90
	S.D.	1.45	2.83	1.26	1.11	0.95	0.86	2.35	2.36
	Min.	0.00	0.01	0.00	0.07	0.07	0.04	0.03	0.33
	Max.	5.19	10.75	4.68	4.21	3.60	3.27	9.03	9.32
Total Phosphorous (mg/L)	Mean	0.04	0.07	0.07	0.07	0.06	0.09	0.28	0.63
	S.D.	0.04	0.09	0.08	0.08	0.08	0.10	0.32	0.87
	Min.	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.12
	Max.	0.13	0.30	0.24	0.28	0.28	0.38	1.02	3.25
Chloride (mg/L)	Mean	3.1	5.0	3.3	5.0	6.2	7.2	37.9	53.4
	S.D.	1.8	2.6	2.1	3.2	3.7	4.2	29.5	36.8
	Min.	1.1	2.1	1.1	1.1	1.1	2.1	8.5	13.9
	Max.	6.6	11.1	6.8	11.8	12.7	15.6	97.0	115.4
Sulphate (mg/L)	Mean	29.2	31.3	32.0	28.2	29.0	26.9	38.8	42.3
	S.D.	12.2	13.3	12.2	11.1	14.3	13.7	14.4	14.6
	Min.	12.4	8.2	8.2	13.0	8.2	5.5	19.0	16.0
	Max.	52.3	49.4	49.4	46.5	50.6	46.5	62.0	65.8

Parameters		SAT-1	SAT-2	SAT-3	SAT-4	SAT-5	SAT-6	SAT-7	SAT-8
COD (mg/L)	Mean	20	28	24	14	33	33	108	85
	S.D.	29.3	34.0	27.4	18.9	29.4	28.3	70.3	56.2
	Min.	2	4	5	2	5	4	24	24
	Max.	102	118	102	70	98	90	222	225
BOD (mg/L)	Mean	1.1	1.6	1.0	1.3	1.4	1.4	26.0	18.2
	S.D.	0.4	0.8	0.2	0.4	0.7	0.7	21.2	15.2
	Min.	0.8	0.6	0.7	0.9	0.6	0.9	3.2	3.4
	Max.	2.1	3.5	1.6	2.0	3.4	3.2	63.5	47.5
Fecal Coliform (MPN/100 ml)	Mean	544	602	1,092	463	949	688	195,231	26,020
	S.D.	2,831	6,835	2,718	2,066	12,379	1,817	2,128,426	54,637
	Min.	30	30	127	52	90	90	6,000	706
	Max.	10,158	24,000	8,031	6,324	43,000	6,324	7,500,000	170,668
Fe (mg/L)	Mean	0.43	2.07	1.09	1.12	1.20	0.45	1.88	1.84
	S.D.	0.41	6.12	3.29	3.16	2.31	0.34	1.90	3.49
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
	Max.	1.40	21.37	11.53	11.06	8.40	0.99	6.49	11.48
Mn (mg/L)	Mean	0.14	0.19	0.17	0.04	0.40	0.38	0.07	0.06
	S.D.	0.20	0.29	0.16	0.06	0.57	0.61	0.14	0.13
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	0.40	0.71	0.32	0.14	1.34	1.46	0.32	0.29
Cu (mg/L)	Mean	0.03	0.02	0.01	0.02	0.01	0.03	0.01	0.01
	S.D.	0.04	0.03	0.02	0.04	0.02	0.05	0.02	0.02
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	0.11	0.09	0.07	0.11	0.08	0.16	0.07	0.08
Zn (mg/L)	Mean	0.57	0.47	0.49	0.41	0.38	0.57	0.55	0.67
	S.D.	0.28	0.27	0.50	0.27	0.29	0.31	0.33	0.43
	Min.	0.22	0.01	0.02	0.03	0.04	0.23	0.11	0.12
	Max.	1.01	1.04	1.50	0.88	0.89	1.11	1.06	1.56
Ni (mg/L)	Mean	0.01	0.07	0.00	0.01	0.01	0.05	0.04	0.02
	S.D.	0.03	0.22	0.01	0.02	0.02	0.15	0.05	0.02
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	0.10	0.78	0.03	0.07	0.06	0.52	0.16	0.06
Pb (mg/L)	Mean	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	S.D.	0.02	0.06	0.03	0.02	0.02	0.02	0.02	0.03
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	0.05	0.21	0.10	0.07	0.07	0.06	0.06	0.10
Cr (mg/L)	Mean	0.01	0.03	0.00	0.00	0.03	0.00	0.02	0.02
	S.D.	0.01	0.06	0.01	0.01	0.06	0.01	0.03	0.04
	Min.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max.	0.02	0.21	0.02	0.02	0.16	0.03	0.08	0.14

Table 4.10: Water quality parameters with ranges, mean value and standard deviation at 8 different locations for the year 2005-11.

Parameters		SAT-1	SAT-2	SAT-3	SAT-4	SAT-5	SAT-6	SAT-7	SAT-8
Water Temperature (°C)	Mean	18.7	22.0	18.3	21.5	21.6	21.8	22.9	23.9
	S.D.	2.14	4.30	2.39	2.67	5.98	5.81	5.95	6.30
	Min.	13.0	13.0	10.0	15.0	10.0	10.0	11.2	11.0
	Max.	27.0	33.0	27.6	29.4	32.8	32.7	33.8	35.0
DO % saturation	Mean	88	124	96	93	84	84	24	32
	S.D.	3.63	11.47	2.62	2.63	2.74	2.84	9.37	9.77
	Min.	68	61	61	75	44	30	0	0
	Max.	127	201	126	108	98	101	80	130
pH	Mean	7.56	7.91	7.74	7.75	7.76	7.68	7.37	7.47
	S.D.	0.15	0.15	0.10	0.10	0.11	0.10	0.12	0.10
	Min.	6.33	6.49	6.63	6.68	6.69	6.65	6.57	6.52
	Max.	8.67	9.05	8.47	8.28	8.44	8.30	8.23	8.26
Conductivity (µS/cm)	Mean	203	250	206	216	256	276	445	526
	S.D.	18.9	34.9	17.8	13.4	24.9	46.6	86.9	121.8
	Min.	119	157	136	151	152	170	187	116
	Max.	220	257	208	216	259	264	595	783
TDS (mg/L)	Mean	150	186	153	162	187	204	320	389
	S.D.	11	21	14	13	12	20	51	74
	Min.	85	100	80	92	100	120	105	150
	Max.	230	370	400	320	306	405	625	960
SS (mg/L)	Mean	34	44	48	85	111	117	208	189
	S.D.	8	20	12	83	75	51	94	69
	Min.	5	10	5	5	2	10	30	10
	Max.	170	150	310	235	575	320	640	385
Total Alkalinity (mg/L)	Mean	62.6	76.0	67.3	69.6	77.9	78.8	127.3	154.6
	S.D.	9.7	6.9	6.1	5.3	6.4	8.7	48.6	57.5
	Min.	25.0	52.9	52.9	54.0	54.9	56.8	64.7	68.0
	Max.	85.0	102.9	86.2	97.0	117.6	129.4	258.7	324.0
Total Hardness (mg/L)	Mean	101	112	101	102	107	108	137	159
	S.D.	8.3	8.0	8.6	4.1	7.9	7.0	21.7	25.6
	Min.	50	56	64	69	71	72	84	95
	Max.	175	140	160	141	206	152	212	268
Ammonical N (mg/L)	Mean	0.88	1.07	1.00	1.05	1.49	1.58	4.28	5.27
	S.D.	0.25	0.37	0.35	0.35	0.48	0.56	1.81	1.81
	Min.	0.08	0.06	0.08	0.06	0.06	0.06	0.06	0.11
	Max.	5.04	6.72	5.60	4.76	7.84	9.58	25.76	22.40
Nitrate+Nitrite N (mg/L)	Mean	0.74	1.91	0.85	0.72	0.83	0.81	1.25	1.80
	S.D.	0.32	0.57	0.32	0.30	0.27	0.27	0.43	0.51
	Min.	0.00	0.01	0.00	0.02	0.07	0.02	0.03	0.10
	Max.	5.19	10.75	5.86	5.84	5.90	5.90	9.03	9.32

Parameters		SAT-1	SAT-2	SAT-3	SAT-4	SAT-5	SAT-6	SAT-7	SAT-8
Total Phosphorous (mg/L)	Mean	0.25	0.21	0.22	0.25	0.32	0.36	0.67	0.83
	S.D.	0.13	0.08	0.16	0.11	0.18	0.19	0.25	0.33
	Min.	0.01	0.00	0.00	0.01	0.03	0.03	0.04	0.02
	Max.	2.75	2.07	3.75	2.79	4.66	4.91	3.78	3.85
Chloride (mg/L)	Mean	6.15	8.96	6.28	7.93	12.57	13.34	49.78	60.39
	S.D.	1.08	2.37	1.03	1.28	2.77	3.47	18.14	18.89
	Min.	0.93	1.85	0.94	1.10	1.10	2.10	4.25	5.67
	Max.	28.28	38.66	20.74	35.94	37.93	82.04	246.58	225.61
Sulphate (mg/L)	Mean	34.7	38.1	39.5	33.3	39.0	35.7	45.3	46.8
	S.D.	9.5	12.2	10.2	7.6	7.3	7.9	14.0	17.3
	Min.	23.2	20.8	26.5	22.0	28.4	25.4	25.5	27.4
	Max.	57.6	59.0	55.7	44.2	49.4	49.9	69.3	75.7
COD (mg/L)	Mean	11	21	14	17	24	29	111	106
	S.D.	5	7	6	6	5	6	28	41
	Min.	2	2	2	2	2	2	5	13
	Max.	35	75	40	105	72	72	430	470
BOD (mg/L)	Mean	1.2	1.7	1.1	1.3	2.6	3.3	25.1	21.3
	S.D.	0.2	0.3	0.3	0.2	1.4	2.1	12.1	10.1
	Min.	0.3	0.4	0.1	0.1	0.6	0.4	2.8	3.1
	Max.	4.7	5.6	4.3	3.5	35.0	48.0	126.8	113.8
Fecal Coliform (MPN/100 ml)	Mean	1,448	2,080	1,417	3,202	8,575	32,017	1,141,102	264,017
	S.D.	1,947	2,897	1,073	4,991	9,085	31,791	912,048	260,891
	Min.	20	20	20	52	30	35	2,800	400
	Max.	24,000	47,244	19,997	93,000	149,399	513,809	14,064,139	3,212,476

On the basis of results of descriptive statistical analysis, the following have been inferred:

- Temperature of water is influenced by season and it gradually increased from SAT-01 to SAT-08.
- DO % saturation gradually decreased from SAT-01 to SAT-08, but at SAT-02 super saturated conditions were observed. Hilly terrain and high algal growth were observed at this location, which may be the reason for this.
- Conductivity, TDS, SS, Total Alkalinity and Chloride gradually increased from SAT-01 to SAT-08. Standard deviation was observed on higher side at SAT-07 and SAT-08.
- pH, Total Hardness and Sulphate indicated not much variations throughout the stretch.
- Ammonical-N, Nitrate + Nitrite N and Total Phosphorous were also gradually increased from SAT-01 to SAT-08. At SAT-02, abnormal pattern was observed for these

parameters, which indicating the eutrophic conditions of the water body. This may be due to the effect of discharges of fertilizer industry located at upstream to this station.

- COD, BOD_5 and Fecal Coliform were also gradually increasing from SAT-01 to SAT-08.
- Heavy metal parameters analysed during 2001-02, also indicated no specific pattern of occurrence from SAT-01 to SAT-06, but indicated higher concentrations at SAT-07 and SAT-08 with higher standard deviation observed.

(b) Evaluation of WQI_E of Satluj River:

For the year April 2001 to March 2002, the WQI_E calculated, are given in **Table 4.11**. Values of SI_{gp} and SI_{hm} are also given in this table for comparison. WQI_E patterns along the river and their variability over the year are shown in **Figure 4.14.** Water quality at all the 8 stations has been found moderate with mean WQI_E score ranging from 46.97-62.29, however, mean SI_{gp} values were in the range of 66.40-90.41. This moderate quality was actually reflecting the very low SI_{hm} scores obtained for this period. WQI_E over the one year period (2001-02) at all the eight stations has been observed to be low in all those cases where the SI_{hm} were low. These results indicated that, at least for the Satluj river stretch, monthly monitoring of heavy metals is important.

Table 4.11: Comparison of SI_{gp}, SI_{hm} and WQI_E at various sampling stations during April 2001-March 2002

Station	$SI_{\text{general parameter}}$				$SI_{\text{heavy metals}}$				WQI_E			
	Min	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**	**Min**	**Max**	**Mean**	**Standard Deviation**
SAT-1	84.96	95.27	89.95	2.79	4.76	76.76	42.68	28.65	20.74	85.51	57.40	24.49
SAT-2	76.91	95.28	84.65	5.70	1.56	83.43	44.84	28.80	11.74	84.67	57.17	24.43
SAT-3	82.11	95.75	89.16	4.30	10.70	76.89	48.03	26.90	31.20	82.92	62.29	20.58
SAT-4	84.90	95.27	90.41	2.94	3.23	74.90	42.94	27.14	17.02	82.94	58.44	22.44
SAT-5	79.99	87.50	85.35	2.09	9.64	72.76	38.43	28.65	28.86	79.23	53.25	21.80
SAT-6	78.71	88.45	84.89	2.71	19.93	84.09	47.15	22.17	41.67	82.26	61.61	14.40
SAT-7	57.34	78.59	66.40	7.50	6.26	86.26	47.69	27.06	20.36	72.54	53.09	17.92
SAT-8	53.55	77.22	66.92	7.88	10.79	74.31	37.56	25.31	28.62	72.10	46.97	16.48

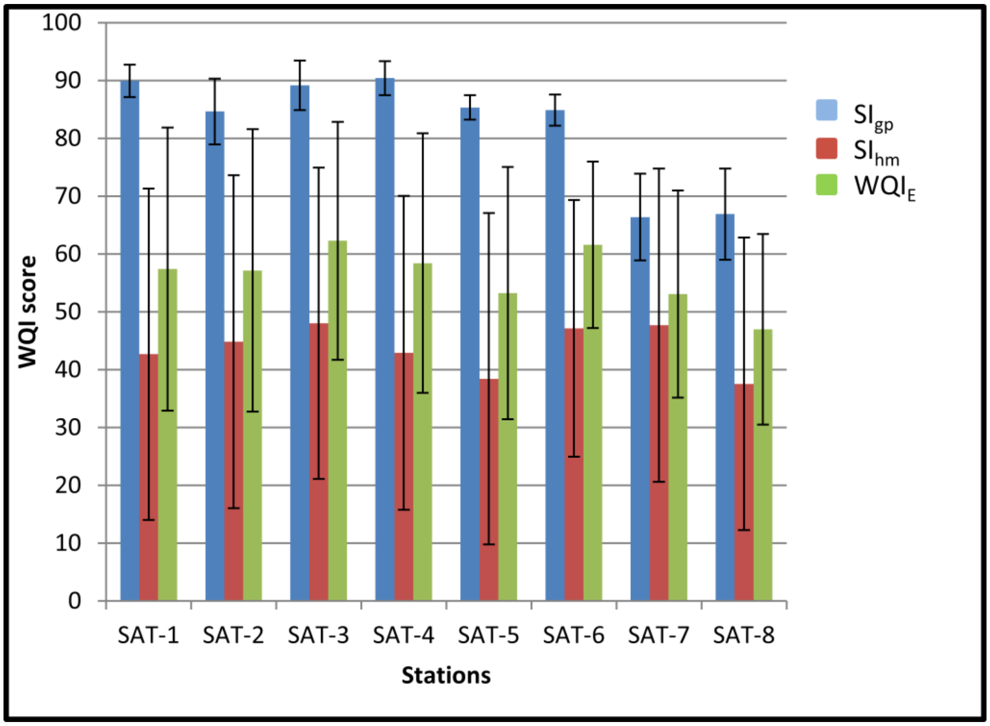

Figure 4.14: Comparision of SI_{gp}, SI_{hm} and WQI_E at different stations of river Satluj during April 2001-March2002

When looked from the general parameters angle the water quality was the lowest most of the time at SAT-7 and SAT-8 was the second lowest. This is along the expected lines and could be due to the Budha Nala and East-Bein discharges into the river upstream to SAT-7 and SAT-8 respectively. However, the WQI_E provided a distorted picture mainly because of the poor to worst water quality from heavy metals point of view. This again indicated the importance of monitoring the river for heavy metals as well. Among the heavy metals monitored, copper (Cu) was most often found as the maximum operator (65.6%). Other metals contributing were Mn (10.4%), Pb (9.4%), Fe (7.3%), Cr (5.2%) and Zn (2.1%) in the same order.

WQI_E calculated, for the period April 2005 to March 2011 for the 8 monitoring stations on the main Satluj river, are given in **Table 4.12**. Spatial and temporal trends of WQI_E along the river over the period are shown in **Figure 4.15**.

Table 4.12: Temporal and spatial variation in WQI_E at various sampling stations during 2005-11

Station	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
SAT-1	91.7 (1.8)	91.3 (2.0)	90.5 (1.9)	89.0 (2.2)	87.2 (2.3)	86.1 (2.2)
SAT-2	84.3 (3.9)	87.1 (3.9)	86.4 (4.5)	87.2 (4.0)	82.2 (4.1)	83.5 (3.3)
SAT-3	91.3 (2.4)	90.5 (2.8)	90.2 (2.1)	89.3 (2.9)	86.6 (2.2)	86.1 (2.9)
SAT-4	89.6 (4.2)	89.2 (2.8)	89.4 (2.4)	89.3 (2.7)	85.0 (2.9)	83.4 (3.4)
SAT-5	87.8 (2.5)	86.9 (2.7)	85.8 (2.6)	83.6 (3.9)	80.9 (2.9)	79.9 (4.7)
SAT-6	86.1 (3.2)	87.2 (2.7)	82.9 (3.3)	84.4 (3.6)	79.4 (4.6)	77.0 (4.7)
SAT-7	66.4 (11.4)	62.3 (10.3)	60.0 (10.8)	67.6 (14.1)	66.4 (4.8)	65.6 (6.7)
SAT-8	65.7 (10.7)	63.3 (9.6)	57.3 (10.0)	67.0 (12.1)	68.6 (3.1)	66.6 (5.0)

Note: Values in parenthesis are standard deviations.

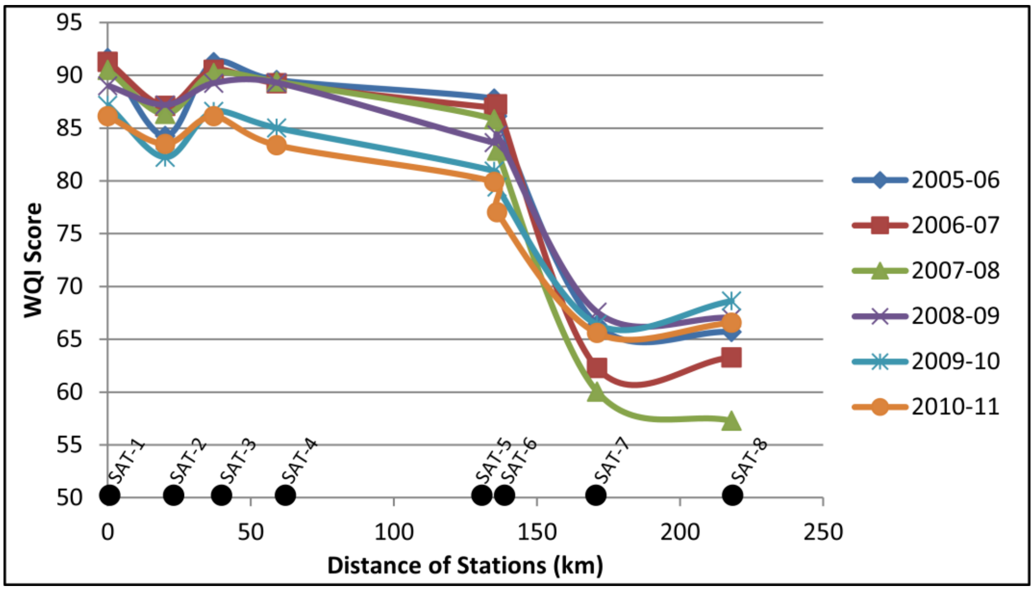

Figure 4.15: Temporal and spatial variation in WQI_E at various sampling stations during 2005-11

On the basis of the WQI_E, the Satluj river stretch can be divided into two sections: the river stretch upstream to SAT-6, and the river stretch downstream to SAT-6. The upstream stretch of the river carried relatively better quality water. The mean values of WQI score were in the range of good water quality (77.0-91.7) with lower standard deviations.

The downstream stretch of the river experienced steep decline in water quality upto SAT-7 and water quality slightly recovered beyond SAT-7. Mean values of WQI scores were in the range of moderate water quality (57.3-68.6) with higher standard deviations. This stretch experiences rapidly increasing flow of water. Municipal and industrial wastewater, including the treated effluent from the STPs of Phillaur and Ludhiana, in the form of Phillaur drain and Budha Nala was discharged into the river in this stretch. Water quality in this stretch of the river appears heavily depends on the effectiveness of sewage diversion and treatment by the STPs of both Phillaur and Ludhiana cities. WQI_E scores at various sampling stations of East-Bein river and major sources of pollution during 2005-11 are given in **Table-4.13**. The river water quality is apparently not much influenced by the discharges of the East-Bein, which carried municipal and industrial wastewater of Phagwara and Jalandhar cities into the river upstream to SAT-8. This could be because of the fact that the effluent of the East-Bein, though discharged into the river upstream to SAT-8, might not have properly mixed with the river water. The river water quality showed no significant temporal trends. Instead, the river water quality is randomly varying.

Table 4.13: Temporal and spatial variation in WQI_E at various sampling stations of East-Bein river and major sources of pollution during 2005-11

Station	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11
EB-1	47.6 (3.5)	52.1 (6.1)	59.4 (4.3)	67.9 (1.9)	60.5 (8.7)	53.8 (6.8)
EB-2	49.6 (4.7)	48.1 (3.8)	43.5 (6.1)	57.3 (2.6)	53.2 (6.7)	52.1 (6.6)
EB-3	56.8 (2.7)	47.6 (3.9)	42.1 (5.8)	56.9 (4.3)	53.6 (5.6)	49.9 (6.2)
EB-4	37.3 (4.8)	40.1 (3.2)	36.2 (3.9)	50.1 (4.8)	46.2 (6.4)	46.6 (5.6)
Source-1 (Swan River)	85.6 (8.5)	81.1 (7.6)	85.5 (5.9)	83.5 (6.1)	79.6 (4.4)	74.9 (6.5)
Source-2 (Phillaur drain)	65.0 (3.9)	55.5 (4.4)	62.9 (2.9)	51.3 (3.1)	60.6 (2.7)	54.1 (3.8)
Source-3 (Budha Nala)	41.1 (2.1)	41.9 (1.9)	42.6 (1.5)	43.2 (2.8)	41.3 (1.7)	41.6 (1.9)
Source-4 (Phagwara drain	44.4 (1.2)	41.6 (3.6)	36.6 (4.1)	41.7 (3.8)	42.7 (2.1)	43.1 (2.3)
Source-5 (Jalandhar drain)	38.9 (2.2)	43.9 (4.4)	39.8 (3.5)	40.9 (1.6)	39.6 (2.2)	40.6 (3.1)

4.6 Statistical analysis of water quality monitoring data

Objective of the study is to optimize the Satluj river water quality monitoring program through statistical analysis of the accumulated river water quality monitoring data from the currently implemented monitoring program. The study was believed to significantly reduce the number of monitoring stations, the frequency of sampling, and the number of monitoring parameters. The study used the monitoring data accumulated during a 7 years period (April 2004-March 2011).

4.6.1 Cluster Analysis (CA)

Cluster Analysis (CA) was applied to detect spatial similarities among the 8 monitoring stations and temporal similarities among the 12 months of monitoring at the individual stations. Results obtained from the CA of the monitoring stations are shown in **Figure-4.16**.

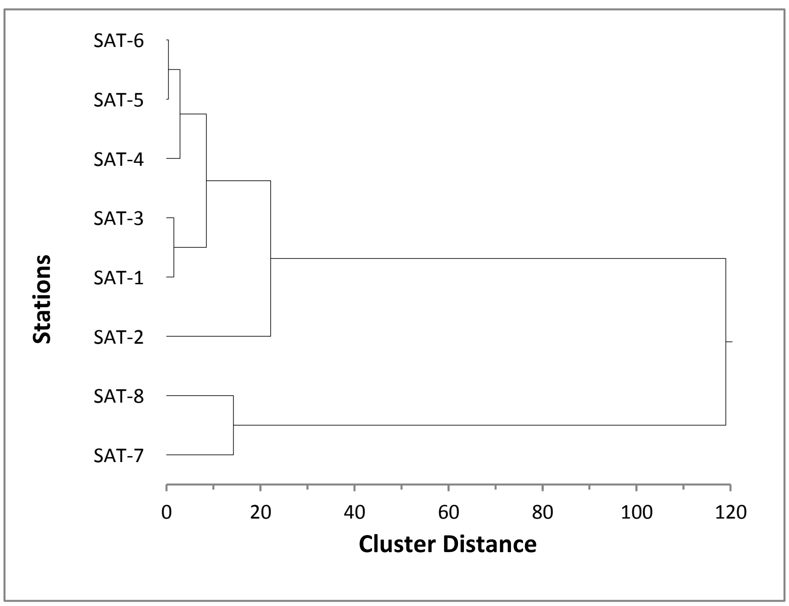

Figure 4.16: Cluster dendrogram showing similarity between different sampling stations of river Satluj.

Based on the similarities, the 8 monitoring stations were found can be grouped into 4 spatial groups (SGs). However, application of the condition, that only adjacent monitoring stations can be grouped together, resulted in grouping of the existing 8 monitoring stations into 6 SGs. The similarities detected among the sampling stations and the SGs indentified on the basis of the similarities are presented in **Table-4.14**. The minimum similarity of 0.881 was observed among the stations, SAT-7 and SAT-8. These stations were grouped together as special group SG-6. SAT-4 was showing very high similarity factor (0.976) with SAT-5 and SAT-6. This indicated the potential of grouping SAT-4, SAT-5 and SAT-6 into one spatial group. However, since SAT-4 represents the Ropar Ramsar Wetland site, SAT-4 was considered as a separate Spatial Group, SG-4.

Table 4.14: Clustering strategy and Spatial Groups.

<table>
<tr><th>Station</th><th>Similarity Factor</th><th>Spatial Group</th></tr>
<tr><td>SAT-1</td><td>0.986 (with SAT-3)</td><td>SG-1</td></tr>
<tr><td>SAT-2</td><td>0.815</td><td>SG-2</td></tr>
<tr><td>SAT-3</td><td>0.986 (with SAT-1)</td><td>SG-3</td></tr>
<tr><td>SAT-4</td><td>0.976 (with SAT-5 and SAT-6)</td><td>SG-4</td></tr>
<tr><td>SAT-5</td><td rowspan="2">0.997</td><td rowspan="2">SG-5</td></tr>
<tr><td>SAT-6</td></tr>
<tr><td>SAT-7</td><td rowspan="2">0.881</td><td rowspan="2">SG-6</td></tr>
<tr><td>SAT-8</td></tr>
</table>

CA was then applied on each of the 6 SGs independently for detecting temporal similarities and temporal grouping. Results obtained from the analysis are shown in **Figures-4.17a to f**. On the basis of the similarities among the 12 sampling months for each of the SG, temporal groups (TGs) were identified. Please see **Table-4.15a to f** for details on temporal grouping. Application of the condition that only the adjacent months of sampling events can be grouped, has marginally increased the number of TGs. Except in SG-5, close similarities were observed between March and May months in all the other 5 SGs. Since March and May are not two consecutive months, despite the similarities both the months were de-clustered.

From the cluster analysis, one can conclude that the number of monitoring stations can be reduced from the present 8 to 6 stations. The future six monitoring stations can be SAT-1, SAT-2, SAT-3, SAT-4, SAT-5 or SAT-6 and SAT-7 or SAT-8. Similarly, from the temporal cluster analysis one can conclude that the sampling frequency can be reduced to 8 per year for SG-1, 11 per year for SG-2, 9 per year for SG-3, 10 per year for SG-4, 10 per year for SG-5 and per year for SG-6. For example, in case of SG-1, sampling can be avoided during June or July, August or September, and during two months from October to December. Please see **Table-4.16** for details on the reduced sampling stations and sampling frequencies of the monitoring program. In summary, the sampling stations can be reduced from 8 to 6, and the total number of samplings over the year can be reduced to 57 from 96 (40.6% reduction).

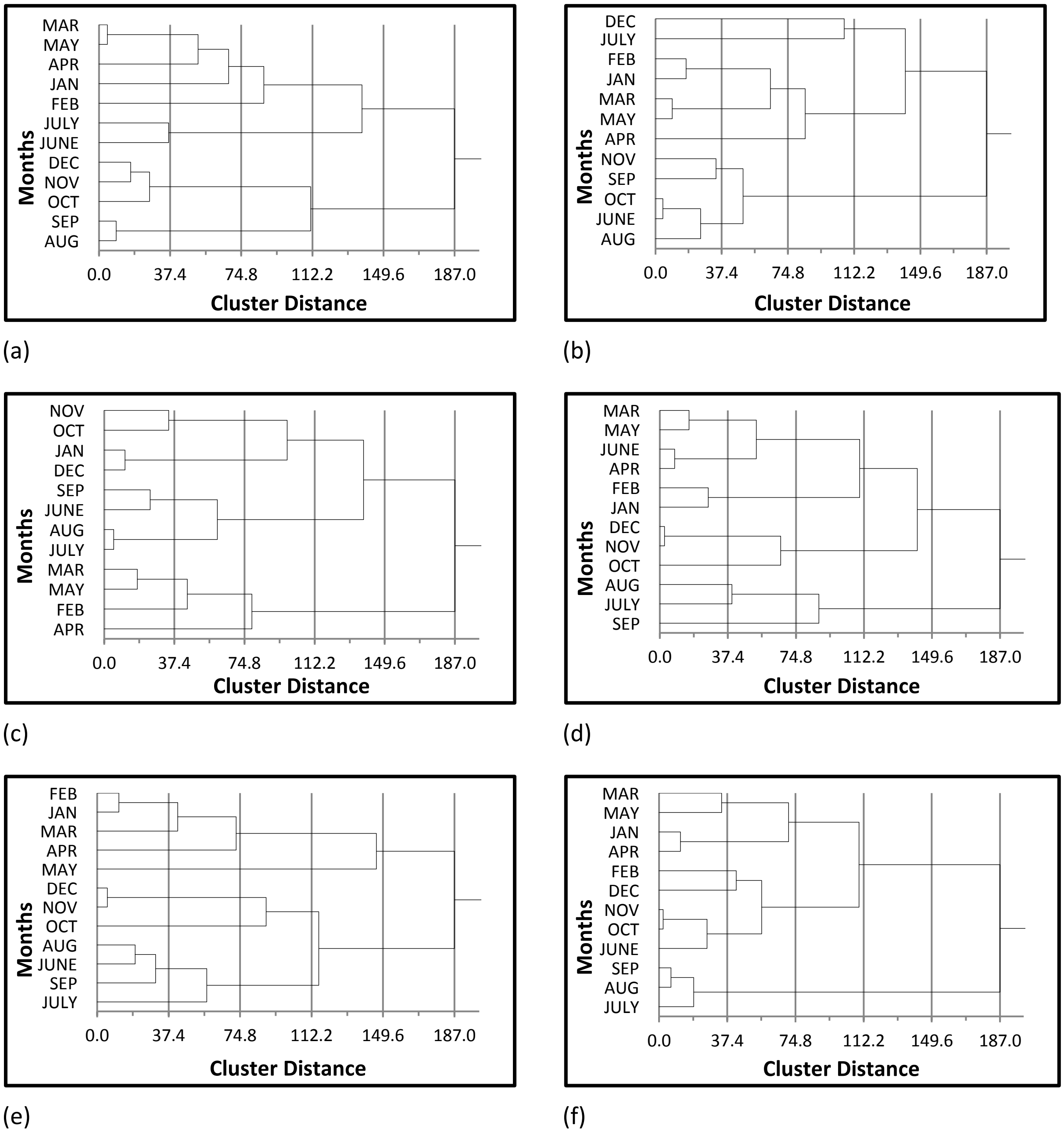

Figure 4.17: Cluster dendrogram showing similarity between different sampling months of Satluj river at sampling station (a) SAT-1 of Spatial Group-1, (b) SAT-2 of Spatial Group-2, (c) SAT-3 of Spatial Group-3, (d) SAT-4 of Spatial Group-4, (e) SAT-5 and SAT-6 of Spatial Group-5 and (f) SAT-7 and SAT-8 of Spatial Group-6.

Table 4.15a: Clustering strategy and Temporal Groups (TGs) for SG-1.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.635	0.536	0.976 (with May)	0.721	0.976 (with Mar)	0.804	0.804	0.951	0.951	0.857	0.911	0.911
Temporal Group	$G_{1,1}$	$G_{1,2}$	$G_{1,3}$	$G_{1,4}$	$G_{1,5}$	$G_{1,6}$		$G_{1,7}$		$G_{1,8}$		

Table 4.15b: Clustering strategy and Temporal Groups (TGs) for SG-2.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.907	0.907	0.949 (with May)	0.548	0.949 (with Mar)	0.977 (with Oct)	0.430 (with Dec)	0.863	0.817 (with Nov)	0.977 (with Jun)	0.817 (with Sep)	0.430 (with Jul)
Temporal Group	$G_{2,1}$		$G_{2,2}$	$G_{2,3}$	$G_{2,4}$	$G_{2,5}$	$G_{2,6}$	$G_{2,7}$	$G_{2,8}$	$G_{2,9}$	$G_{2,10}$	$G_{2,11}$

Table 4.15c: Clustering strategy and Temporal Groups (TGs) for SG-3.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.940	0.763	0.905 (with May)	0.579	0.905 (with Mar)	0.868 (with Sep)	0.973	0.973	0.868 (with Jun)	0.816	0.816	0.940
Temporal Group	$G_{3,1}$	$G_{3,2}$	$G_{3,3}$	$G_{3,4}$	$G_{3,5}$	$G_{3,6}$	$G_{3,7}$		$G_{3,8}$	$G_{3,9}$		$G_{3,1}$

Table 4.15d: Clustering strategy and Temporal Groups (TGs) for SG-4.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.857	0.857	0.914 (with May)	0.956 (with Jun)	0.914 (with Mar)	0.956 (with Apr)	0.788	0.788	0.532	0.644	0.986	0.986
Temporal Group	$G_{4,1}$		$G_{4,2}$	$G_{4,3}$	$G_{4,4}$	$G_{4,5}$	$G_{4,6}$	$G_{4,7}$	$G_{4,8}$	$G_{4,9}$	$G_{4,10}$	

Table 4.15e: Clustering strategy and Temporal Groups (TGs) for SG-5.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.939	0.939	0.774	0.611	0.218	0.893 (with Aug)	0.693	0.893 (with Jun)	0.836 (with Aug and Jun)	0.527	0.971	0.971
Temporal Group	$G_{5,1}$		$G_{5,2}$	$G_{5,3}$	$G_{5,4}$	$G_{5,5}$	$G_{5,6}$	$G_{5,7}$	$G_{5,8}$	$G_{5,9}$	$G_{5,10}$	

Table 4.15f: Clustering strategy and Temporal Groups (TGs) for SG-6.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Similarity Factor	0.937 (with Apr)	0.773	0.816 (with May)	0.937 (with Jan)	0.816 (with Mar)	0.859 (with Nov and Oct)	0.898	0.965	0.965	0.987	0.987	0.773
Temporal Group	$G_{6,1}$	$G_{6,2}$	$G_{6,3}$	$G_{6,4}$	$G_{6,5}$	$G_{6,6}$	$G_{6,7}$			$G_{6,8}$		$G_{6,9}$

Table 4.16: Sampling frequencies suggested on the basis of the cluster analysis

Months	SG-1	SG-2	SG-3	SG-4	SG-5	SG-6	Sampling Frequency
January	$G_{1,1}$		$G_{3,1}$			$G_{6,1}$	3
February	$G_{1,2}$	$G_{2,1}$	$G_{3,2}$	$G_{4,1}$	$G_{5,1}$	$G_{6,2}$	6
March	$G_{1,3}$	$G_{2,2}$	$G_{3,3}$	$G_{4,2}$	$G_{5,2}$	$G_{6,3}$	6
April	$G_{1,4}$	$G_{2,3}$	$G_{3,4}$	$G_{4,3}$	$G_{5,3}$	$G_{6,4}$	6
May	$G_{1,5}$	$G_{2,4}$	$G_{3,5}$	$G_{4,4}$	$G_{5,4}$	$G_{6,5}$	6
June	$G_{1,6}$	$G_{2,5}$	$G_{3,6}$	$G_{4,5}$	$G_{5,5}$	$G_{6,6}$	6
July		$G_{2,6}$		$G_{4,6}$	$G_{5,6}$		3
August	$G_{1,7}$	$G_{2,7}$	$G_{3,7}$	$G_{4,7}$	$G_{5,7}$	$G_{6,7}$	6
September		$G_{2,8}$	$G_{3,8}$	$G_{4,8}$	$G_{5,8}$		4
October		$G_{2,9}$		$G_{4,9}$	$G_{5,9}$	$G_{6,8}$	4
November	$G_{1,8}$	$G_{2,10}$	$G_{3,9}$				3
December		$G_{2,11}$	$G_{3,1}$	$G_{4,10}$	$G_{5,10}$	$G_{6,9}$	4
Sampling Frequency	8	11	9	10	10	9	**57**

4.6.2 Principal Component Analysis (PCA)

PCA was applied on the monitoring data for each of the 6 SGs independently. Monitoring data on the 17 parameters accumulated over the 7 year period, from April 2004 to March 2011, was standardized and used in the analysis. Results (loadings, Eigen values, variance contributions of each of the PCs and cumulative variance contributions) obtained from the analysis are presented in **Tables-4.17 to 4.22**. Within each of the PCs, the parameters were arranged in the decreasing order of their significant loading values.

PC Analysis had provided six PCs, with Eigen value >1, for the monitoring data of SG-1. The six PCs were explaining 91.18% of the total variance. The parameters with significant loadings and the contributions to the total variance, by each of the six PCs, are shown in **Table-4.17**. PC-1 was having significant loadings on 6 parameters and explaining 31.04% of total variance. PC-2 had significant loadings on 3 parameters, and accounted for 19.36% of the total variance. Similarly, PC-3 had 4 parameters with significant loadings and accounted for 15.53% of the total variance.

Table 4.17: Principal Component Analysis for Group-1 (SAT-1).

Explained Variance (Eigenvalues)						
	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
Eigenvalue	5.276	3.292	2.640	1.940	1.282	1.070
% of Variance	31.038	19.364	15.529	11.414	7.543	6.295
Cumulative %	31.038	50.402	65.931	77.345	84.888	91.183

Component Loadings

Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
EC	**-0.843**	-0.227	0.339	0.115	0.106	0.121
TN	**-0.835**	0.299	0.233	0.242	0.230	-0.195
Nitrate-N	**-0.823**	0.383	0.273	-0.112	-0.108	-0.196
Alk	**-0.754**	0.451	-0.349	-0.010	0.072	0.163
BOD_5	**-0.709**	-0.392	-0.369	0.136	-0.143	-0.319
DO%	**0.580**	0.316	0.498	0.070	-0.123	-0.016
FC	0.067	**0.867**	0.260	-0.343	0.060	0.079
Wtemp	0.382	**0.725**	-0.173	-0.252	0.141	-0.397
pH	-0.580	**0.713**	-0.200	-0.138	-0.057	0.082
TH	-0.373	0.136	**0.640**	-0.562	0.091	0.058
SS	-0.235	0.157	**0.598**	0.563	-0.434	-0.055
TP	0.516	0.160	**0.518**	0.278	-0.242	0.181
TDS	-0.477	-0.421	**0.507**	-0.282	-0.414	-0.154
Amm-N	-0.431	0.033	0.116	**0.687**	0.505	-0.020
COD	-0.439	0.047	-0.573	-0.145	**-0.587**	-0.054
Cl^-	-0.470	-0.471	0.112	-0.443	0.173	**0.554**
SO_4^{2-}	0.094	-0.539	0.323	-0.392	0.287	**-0.554**

PCA of the monitoring data of SG-1 had indicated that most of the data variance (>50%) was contained in the first two PCs. A Biplot developed between the PC-1 and the PC-2 (shown in **Figure-4.18**), for understanding the relationships among the parameters with significant loadings, indicated the following:

- Water temperature is closely and positively correlated with FC and DO%. Unless the water is least polluted this positive correlation among the parameters cannot be expected.
- Nitrogen and phosphorus were found negatively correlated, and both Amm-N and TP were found relatively less important to the concerned PCs. These indicate very little eutrophication of the water body. Further, the water body was least polluted by

biodegradable organic waste. Higher importance to NO_3-N, and almost similar level of importance to TN, and higher DO saturation levels also supplement this conclusion.

- pH, Alk, TH and SS are positively correlated and represent soil structure and natural source of these parameters are from soil weathering and subsequent run-off.

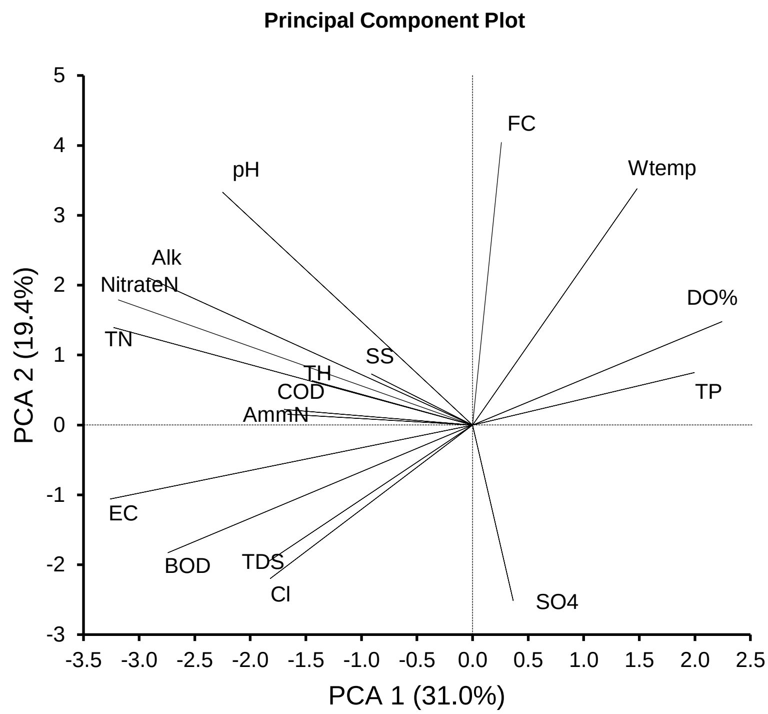

Figure 4.18: Principal Component Biplot for SG-1 (SAT-1).

PCA of SG-2 data set evolved 5 PCs with eigenvalue >1, explaining 86.71% of the total variance in respective water quality data (**Table-4.18)**. PC-1 has significant loadings on 7 parameters. This component was explaining 31.98% of total variance. PC-2 has significant loadings on 5 parameters and accounted for 20.71% of total variance. PC-3 accounted for 16.46% of total variance, has significant loadings on 2 parameters. PC-4 and PC-5 accounted for 9.28% and 8.28% of total variance respectively are comprised with 1 parameter each.

Table 4.18: Principal Component Analysis for Group-2 (SAT-2).

Explained Variance (Eigenvalues)					
	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**
Eigenvalue	5.436	3.521	2.798	1.578	1.408
% of Variance	31.978	20.711	16.459	9.281	8.280
Cumulative %	31.978	52.689	69.148	78.429	86.710

Component Loadings

Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**
EC	**-0.893**	0.260	-0.101	-0.094	-0.202
Nitrate-N	**-0.878**	0.056	0.151	0.007	0.115
TN	**-0.810**	0.193	0.274	0.351	0.242
Wtemp	**0.805**	0.225	0.233	0.143	0.431
TDS	**-0.750**	0.258	-0.303	-0.315	-0.023
BOD_5	**-0.695**	-0.042	0.507	-0.031	-0.315
Cl^-	**-0.666**	0.417	0.059	-0.499	-0.059
Alk	0.225	**0.840**	0.343	0.148	-0.144
pH	0.494	**0.757**	0.144	-0.232	-0.119
DO%	0.197	**0.749**	-0.449	0.005	0.321
FC	0.196	**-0.723**	0.620	-0.153	-0.008
SS	-0.504	**-0.537**	0.420	-0.039	0.468
TH	-0.354	-0.088	**-0.732**	0.426	-0.197
COD	0.078	0.425	**0.577**	-0.416	0.219
Amm-N	-0.357	0.324	0.338	**0.706**	0.223
SO_4^{2-}	-0.364	-0.036	-0.498	-0.243	**0.713**
TP	0.241	-0.419	-0.390	-0.251	0.052

PCA of the data related to SG-2 had indicated that most of the data variance was contained in the first two PCs. In view of this, a Biplot (**Figure-4.19**) was developed between PC-1 and PC-2 for understanding the relationships among the parameters with significant loadings. The following conclusions can be drawn from the close observation of the Biplot:

- pH, Alk and DO% are very closely and positively correlated indicating eutrophication problem or high algal activity. Algal activity is supposed to be strongly related to the eutrophication conditions (especially with TP). Further, intense algal activity is supposed to enhance DO, Alkalinity and pH. However, the TSS is not positively related with these parameters. This may be because of the attached growth of algae on the stony substratum of the shallow rapids.

- EC, TDS, Cl^-, NO_3-N and TN are positively correlated. These indicate discharges from the inorganic chemical industry. There are fertilizer and chloralkali industries on the upstream side discharging their effluent. Unexpectedly, the Amm-N was found less important. This may be because of its rapid conversion into NO_3-N and/or immediate assimilation by the algae.

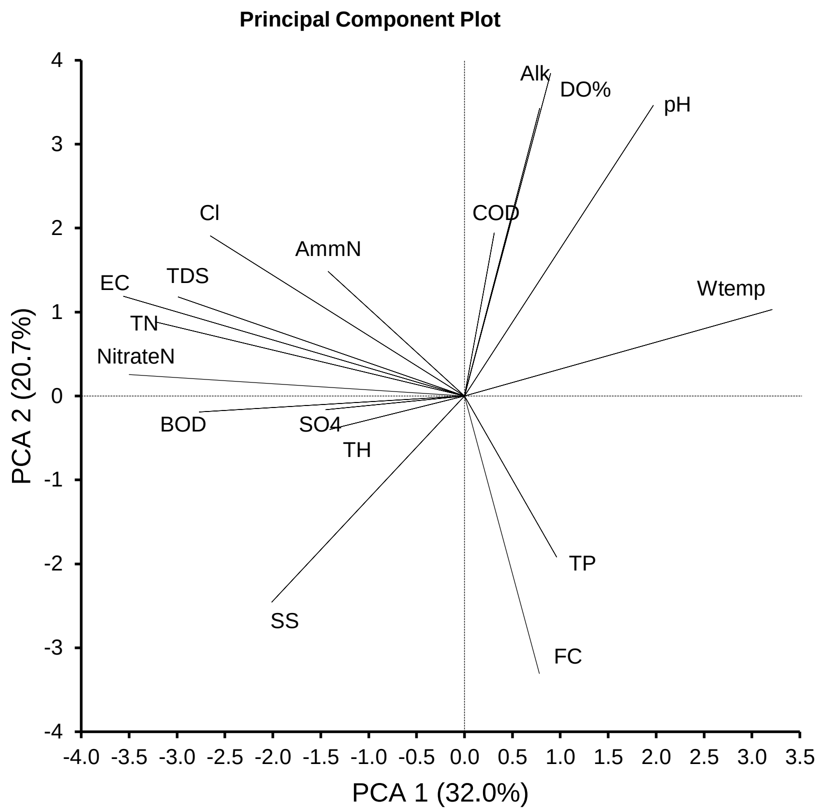

Figure 4.19: Principal Component Biplot for SG-2 (SAT-2).

PCA of SG-3 data set evolved 5 PCs with eigenvalue >1, explaining 85.38% of the total variance in respective water quality data (**Table-4.19)**. PC-1 has significant loadings on 8 parameters. This component was explaining 33.38% of total variance. PC-2 has significant loadings on 6 parameters and accounted for 23.58% of total variance. PC-3 accounted for 13.28% of total variance, has significant loadings on 2 parameters. PC-4 accounted for 8.68% of total variance and comprised with 1 parameter. PC-5 accounted for 6.51% of total variance and no significant parameter.

Table 4.19: Principal Component Analysis for Group-3 (SAT-3).

Explained Variance (Eigenvalues)

	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**
Eigenvalue	5.666	4.009	2.257	1.475	1.107
% of Variance	33.328	23.581	13.277	8.677	6.513
Cumulative %	33.328	56.909	70.186	78.864	85.376

Component Loadings

Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**
BOD_5	**0.850**	-0.318	-0.115	-0.150	0.087
Alk	**0.847**	0.459	0.089	-0.146	-0.003
EC	**0.793**	-0.236	-0.330	-0.172	-0.003
TN	**0.787**	0.405	-0.007	0.352	0.266
Nitrate-N	**0.691**	0.296	0.466	0.300	0.198
Amm-N	**0.682**	0.343	-0.450	0.250	0.326
TH	**0.616**	-0.278	-0.378	0.098	-0.469
TP	**-0.586**	-0.301	0.010	-0.224	0.478
DO%	-0.003	**-0.793**	0.009	-0.267	0.412
FC	-0.257	**0.768**	-0.144	-0.369	-0.157
SS	-0.071	**0.716**	-0.551	-0.008	-0.021
Wtemp	-0.630	**0.652**	0.265	0.031	-0.019
TDS	0.112	**-0.622**	0.344	0.159	-0.010
Cl^-	0.516	**-0.581**	0.154	-0.088	-0.390
COD	0.276	0.307	**0.777**	-0.298	-0.219
pH	0.592	0.330	**0.607**	-0.193	0.176
SO_4^{2-}	-0.372	-0.142	0.237	**0.835**	-0.096

PCA of the data related to SG-3 had indicated that most of the data variance was contained in the first two PCs. In view of this, a Biplot (**Figure-4.20**) was developed between PC-1 and PC-2 for understanding the relationships among the parameters with significant loadings. The following conclusions can be drawn from the close observation of the Biplot:

- Alkalinity, TN, Amm-N, NO_3-N and pH are positively correlated. TP is negatively correlated and DO% is unrelated with the above parameters. These results indicate eutrophication is there but not severe, apparently, limited by the low TP levels. Influence of eutrophication on DO is apparently countered by organic pollution of the water body, which is evident from the positive correlation among BOD_5, EC, TH and Cl^-. The water body is polluted by the domestic sewage.

- FC and SS are positively correlated and represent pollution from the discharge of untreated sewage (with fecal contamination) from both human and livestock sources.

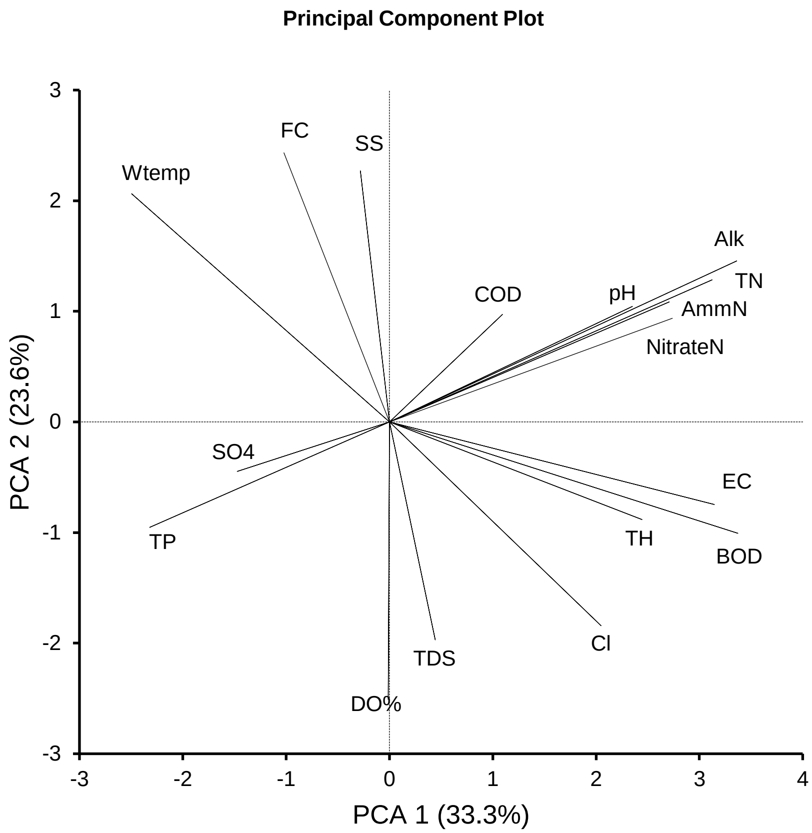

Figure 4.20: Principal Component Biplot for SG-3 (SAT-3).

PCA of SG-4 data set evolved 6 PCs with eigenvalue >1, explaining 91.68% of the total variance in respective water quality data (**Table-4.20)**. PC-1 has significant loadings on 6 parameters. This component was explaining 28.72% of total variance. PC-2 has significant loadings on 6 parameters and accounted for 20.3% of total variance. PC-3 accounted for 17.35% of total variance, has significant loadings on 3 parameters. PC-4 and PC-5 accounted for 10.28% and 7.82% of total variance respectively and comprised with 1 parameter each PC-6 accounted for 7.2% of total variance and no significant parameter.

Table 4.20: Principal Component Analysis for Group-4 (SAT-4).

Explained Variance (Eigenvalues)

	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
Eigenvalue	4.883	3.451	2.950	1.748	1.330	1.224
% of Variance	28.724	20.300	17.352	10.281	7.824	7.200
Cumulative %	28.724	49.024	66.376	76.656	84.481	91.681

Component Loadings

Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
FC	**-0.904**	0.213	-0.184	0.259	-0.075	0.028
COD	**-0.763**	0.384	0.205	-0.145	-0.210	-0.220
EC	**0.734**	0.219	-0.551	0.152	0.028	-0.211
DO%	**0.732**	-0.100	0.314	0.293	0.292	-0.421
Wtemp	**-0.698**	0.172	0.637	0.081	0.179	-0.148
SS	**-0.667**	0.338	0.055	0.190	0.077	0.546
pH	-0.208	**0.744**	0.144	-0.413	0.132	-0.261
Alk	0.182	**0.739**	-0.073	-0.419	-0.101	-0.427
TP	-0.180	**-0.680**	0.372	-0.069	-0.006	-0.106
TN	0.515	**0.649**	0.396	0.286	0.069	0.221
Nitrate-N	0.445	**0.618**	0.563	0.011	0.048	0.181
Amm-N	0.502	**0.580**	0.081	0.456	0.054	0.222
Cl^-	-0.185	-0.079	**-0.670**	0.408	0.544	-0.150
BOD_5	-0.486	0.485	**-0.657**	0.188	-0.016	-0.100
TH	0.343	0.222	**-0.640**	-0.140	-0.562	0.170
TDS	-0.458	0.144	0.092	**0.673**	-0.248	-0.394
SO_4^{2-}	0.231	-0.212	0.346	0.439	**-0.667**	-0.153

PCA of the data related to SG-4 had indicated that most of the data variance was contained in the first two PCs. In view of this, a Biplot (**Figure-4.21**) was developed between PC-1 and PC-2 for understanding the relationships among the parameters with significant loadings. The following conclusions can be drawn from the close observation of the Biplot:

- Alkalinity, NO_3-N, TN and Amm-N are showing positive correlation among themselves and negative correlation with the TP. Relatively greater importance of the TP indicates that eutrophication is there but very much limited by the TP.
- FC, COD, BOD_5 and SS are positively correlated. This indicates pollution of the water body by municipal sewage.

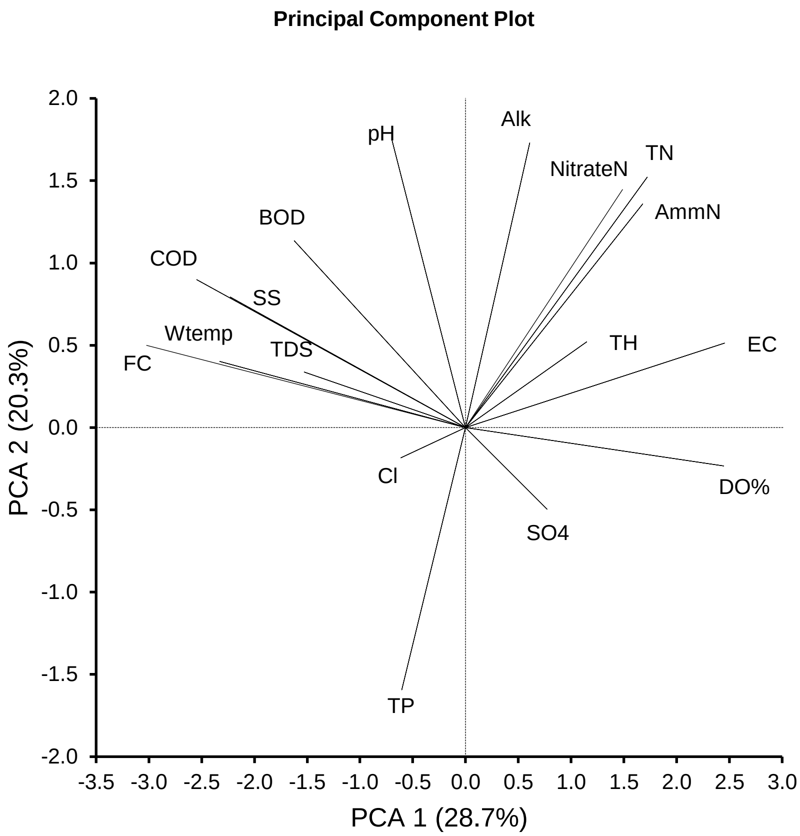

Figure 4.21. Principal Component Biplot for SG-4 (SAT-4).

PCA of SG-5 data set evolved 6 PCs with eigenvalue >1, explaining 87.75% of the total variance in respective water quality data (**Table-4.21)**. PC-1 has significant loadings on 8 parameters. This component was explaining 30.55% of total variance. PC-2 has significant loadings on 4 parameters and accounted for 22.91% of total variance. PC-3 accounted for 11.17% of total variance, has significant loadings on 3 parameters. PC-4, PC-5 and PC-6 accounted for 9.22%, 7.49% and 6.41% of total variance respectively and comprised with 1 parameter all.

Table 4.21: Principal Component Analysis for Group-5 (SAT-5 and SAT-6).

Explained Variance (Eigenvalues)						
	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
Eigenvalue	5.194	3.895	1.898	1.567	1.273	1.089
% of Variance	30.552	22.912	11.167	9.220	7.491	6.409
Cumulative %	30.552	53.464	64.631	73.851	81.341	87.750

Component Loadings

Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
TN	**0.836**	0.209	-0.034	0.236	0.306	0.210
Cl^{-}	**0.818**	-0.341	0.090	-0.002	-0.208	-0.132
EC	**0.786**	-0.577	-0.117	-0.070	-0.078	0.072
BOD_5	**0.770**	-0.174	-0.331	-0.342	-0.127	-0.051
Nitrate-N	**0.699**	0.183	-0.029	-0.323	0.086	0.502
Amm-N	**0.688**	0.141	0.011	0.528	0.347	0.012
COD	**0.630**	0.258	0.164	0.046	-0.570	0.009
FC	**-0.583**	-0.468	0.076	-0.399	0.041	-0.108
Wtemp	0.273	**0.815**	-0.085	0.081	0.019	-0.452
TH	0.231	**-0.794**	0.388	0.089	0.210	0.197
SS	-0.153	**0.792**	0.082	-0.321	0.129	-0.043
TDS	0.177	**-0.660**	-0.068	0.014	-0.458	-0.321
TP	0.136	0.223	**-0.849**	0.360	-0.156	-0.049
pH	0.357	0.603	**0.615**	-0.007	-0.192	-0.138
SO_4^{2-}	0.219	-0.235	**-0.522**	-0.353	0.441	-0.331
DO%	-0.546	-0.340	-0.016	**0.685**	-0.033	-0.005
Alk	0.491	-0.301	0.439	0.070	0.366	**-0.528**

PCA of the data related to SG-5 had indicated that most of the data variance was contained in the first two PCs. In view of this, a Biplot (**Figure-4.22**) was developed between PC-1 and PC-2 for understanding the relationships among the parameters with significant loadings. The following conclusions can be drawn from the close observation of the Biplot:

- EC, Cl^{-}, BOD, TN, Amm-N, NO_3-N and COD are positively correlated. DO% and FC are negatively correlated with the above parameters. SS is unrelated with the above. These indicate receipt of treated effluent (both industrial and municipal) by the river. Negative correlation with FC indicates the effluent received is treated, and negative correlation with DO% indicates significant biological activity and BOD_5 removal in the water body. Very important Cl^{-} and EC parameters indicate pollution with industrial effluent. Eutrophication is apparently not at all a problem. Higher importance to NO_3-N may also be an indication of pollution of the river by agricultural drainage.

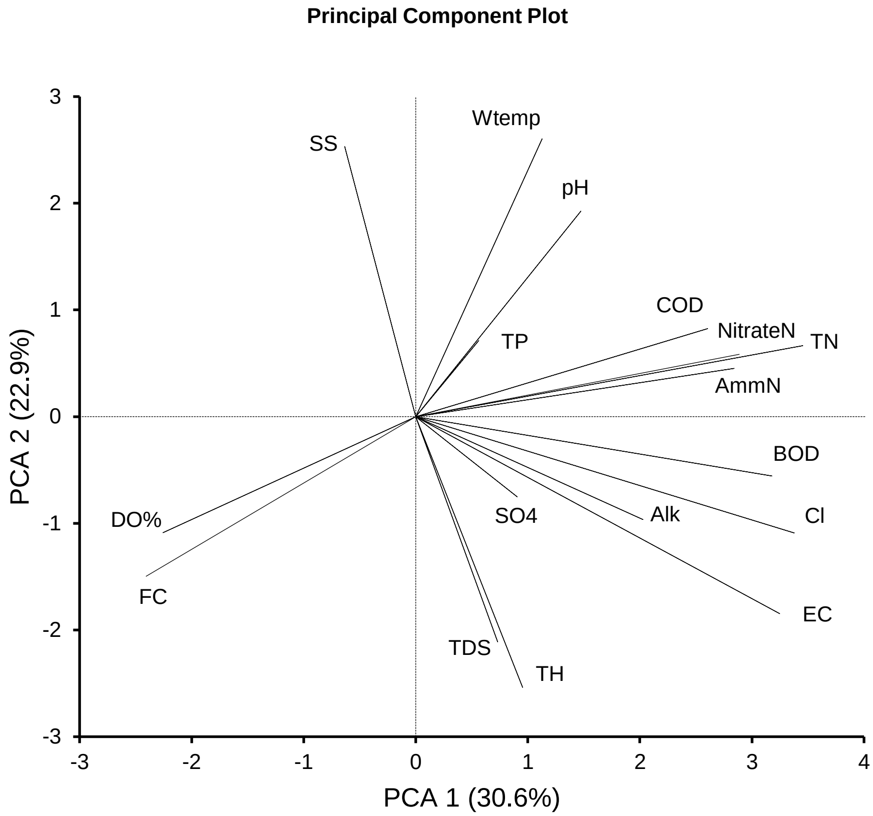

Figure 4.22. Principal Component Biplot for SG-5 (SAT-5 and SAT-6).

PCA of SG-6 data set evolved 4 PCs with eigenvalue >1, explaining 88.0% of the total variance in respective water quality data as seen in **Table-4.22**. PC-1 has significant loadings on 13 parameters. This component was explaining 58.43% of total variance. PC-2 has significant loadings on 2 parameters and accounted for 13.76% of total variance. PC-3 and PC-4 accounted for 9.19% and 6.62%of total variance and has significant loadings on 1 parameter each.

Table 4.22: Principal Component Analysis for Group-6 (SAT-7 and SAT-8).

Explained Variance (Eigenvalues)				
	PC 1	**PC 2**	**PC 3**	**PC 4**
Eigenvalue	9.933	2.340	1.561	1.126
% of Variance	58.432	13.766	9.185	6.624
Cumulative %	58.432	72.198	81.383	88.006

Component Loadings				
Variable	**PC 1**	**PC 2**	**PC 3**	**PC 4**
EC	**-0.965**	0.106	-0.186	0.059
DO%	**0.927**	-0.089	-0.158	-0.073
Amm-N	**-0.925**	0.298	-0.152	0.026
BOD_5	**-0.918**	0.103	0.193	0.095
TH	**-0.897**	0.043	0.304	0.129
TN	**-0.897**	0.320	-0.050	-0.203
TDS	**-0.890**	0.021	-0.288	0.082
Cl^-	**-0.885**	-0.066	0.218	0.294
Alk	**-0.883**	0.355	0.200	0.000
COD	**-0.843**	-0.117	0.198	0.103
SO_4^{2-}	**-0.632**	0.068	0.147	-0.440
pH	**0.630**	0.624	-0.004	0.163
TP	**-0.623**	0.317	-0.568	-0.338
FC	-0.396	**-0.807**	0.091	-0.146
Wtemp	0.500	**0.777**	-0.080	-0.178
SS	0.418	0.471	**0.719**	0.167
Nitrate-N	0.056	-0.048	0.511	**-0.729**

PCA of the data related to SG-6 had indicated that most of the data variance was contained in the first two PCs. In view of this, a Biplot (**Figure-4.23**) was developed between PC-1 and PC-2 for understanding the relationships among the parameters with significant loadings. The following conclusions can be drawn from the close observation of the Biplot:

- FC is negatively correlated with SS and unrelated with BOD_5, Amm-N, etc. This indicates that untreated municipal sewage discharge is not significant.
- Most of the parameters are flocked together and positively correlated, and DO% is negatively correlated. pH and SS have remained unrelated with other parameters. NO_3-N is not important. All these indicate that the river water is heavily polluted by both organic and inorganic matter, and the river water is anoxic.

Principal Component Plot

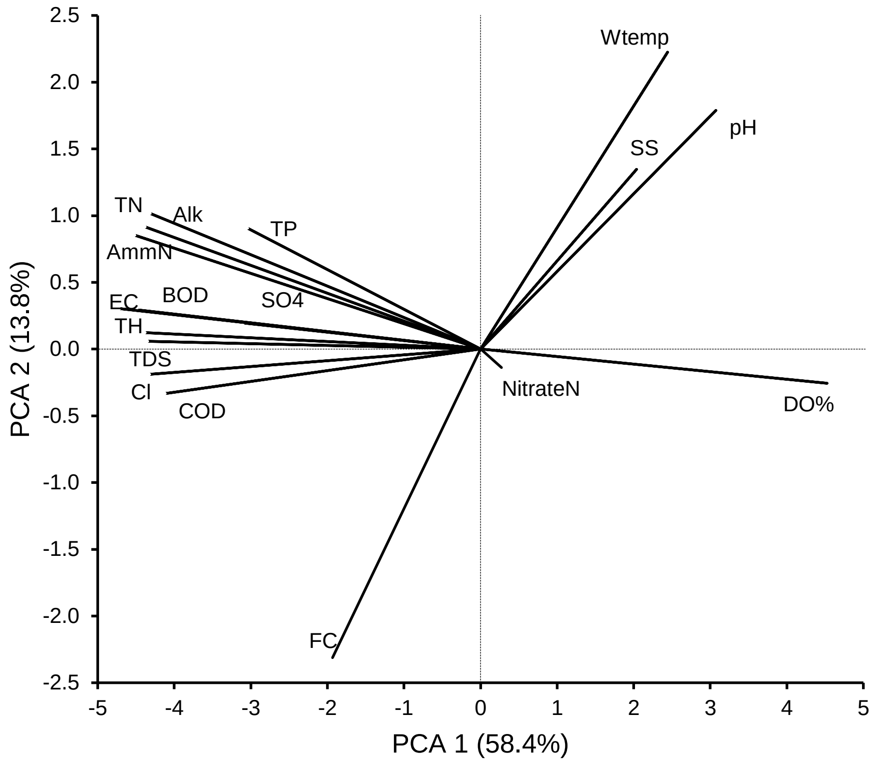

Figure 4.23. Principal Component Biplot for SG-6 (SAT-7 and SAT-8).

4.6.3 WQI approach for minimizing water quality parameters through use of PCA results

PCA results have been used for rationally minimizing the water quality parameters for which the collected water samples should be analyzed for each of the SGs. For deciding on the parameters to be considered as important, WQI approach was followed. The parameters listed under PC-1 and having >0.5 loadings were considered first to find the WQI value. Then the parameters of PC-1 and PC-2 with >0.5 loading were considered to find the WQI value. In the next case even the parameters of PC-3 were considered. This process of evaluation of WQI was continued till that PC at which all the 17 parameters have been considered in the WQI evaluation.

The obtained WQI values for increasing number of PCs were exposed to the test of hypothesis with the WQI value for all the 17 parameters. In this process, the minimum number of PCs, at which the null hypothesis was accepted, was taken as to include all the parameters of importance for the monitoring. Null hypothesis was the WQI value calculated for the parameters listed in the PCs considered is not different from the WQI value calculated for all the 17 parameters considered. If null hypothesis was accepted for PC-1 plus PC-2, then all the parameters with >0.5 loading and listed under PC-1 and PC-2 were taken as important and sufficient for the water quality monitoring at the SG under consideration.

The hypothesis test results obtained for the 6 SGs from the PCA results are presented in **Table-4.23a to f**. These results indicate the number of parameters that may be considered in the water quality monitoring for each of the SGs.

Table 4.23a: Test of Hypothesis for GWQI at SAT-1 of SG-1.

<table>
<tr><th rowspan="2">No. of Parameters</th><th rowspan="2">GWQI</th><th colspan="3">Test of Hypothesis ($p < 0.05$)</th></tr>
<tr><th>T</th><th>P</th><td rowspan="7">Critical T = 2.015
N = 6
Mean = 86.86
Standard Deviation = 1.654</td></tr>
<tr><td>6</td><td>86.75</td><td>0.168</td><td>0.437</td></tr>
<tr><td>9</td><td>89.69</td><td>- 4.186</td><td>0.004</td></tr>
<tr><td>13</td><td>87.34</td><td>- 0.760</td><td>0.256</td></tr>
<tr><td>14</td><td>84.65</td><td>3.277</td><td>0.011</td></tr>
<tr><td>15</td><td>86.18</td><td>1.012</td><td>0.179</td></tr>
<tr><td>17</td><td>86.57</td><td>0.437</td><td>0.341</td></tr>
</table>

<u>Hypothesis 1.1</u>

Ho: The GWQI calculated with 6 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 6 parameters

<u>Explanation</u>

Since the calculated T value was lesser than the critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-1 (SAT-1), there is no significant difference between the GWQI calculated from the 6 parameters with significant loading of PC-1 and the overall GWQI calculated from all the 17 parameters.

Table 4.23b: Test of Hypothesis for GWQI at SAT-2 of SG-2.

No. of Parameters	GWQI	Test of Hypothesis (p<0.05)		
		T	P	Critical T = 2.132 N = 5 Mean = 82.094 Standard Deviation = 1.922
7	81.45	0.749	0.248	
12	84.66	- 2.986	0.020	
14	83.46	- 1.590	0.094	
15	80.95	1.331	0.127	
17	79.95	2.495	0.034	

<u>Hypothesis 2.1</u>

Ho: The GWQI calculated with 7 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 7 parameters

<u>Explanation</u>

Since calculated T value is lesser than critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-2 (SAT-2), there is no significant difference between the GWQI calculated from the 7 parameters with significant loading of PC-1 and the overall GWQI calculated from all the 17 parameters.

Table 4.23c: Test of Hypothesis for GWQI at SAT-3 of SG-3.

No. of Parameters	GWQI	Test of Hypothesis (p<0.05)		
		T	P	Critical T = 2.353 N = 4 Mean = 82.33 Standard Deviation = 3.782
8	76.74	2.956	0.030	
14	83.29	- 0.508	0.323	
16	84.53	- 1.163	0.164	
17	84.76	- 1.285	0.145	

<u>Hypothesis 3.1</u>

Ho: The GWQI calculated with 8 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 8 parameters

Explanation

Since the calculated T value was greater than critical T value, the null hypothesis was rejected in favour of the alternative hypothesis.

Hypothesis 3.2

Ho: The GWQI calculated with 14 parameters listed under PC1 and PC2 cumulatively explain overall GWQI

Ha: The GWQI calculation should be done with more than 14 parameters

Explanation

Since calculated T value is lesser than critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-3 (SAT-3), there is no significant difference between the GWQI calculated from the 14 parameters with significant loading of PC-1 and PC-2, and the overall GWQI calculated from all the 17 parameters.

Table 4.23d: Test of Hypothesis for GWQI at SAT-4 of SG-4.

No. of Parameters	GWQI	Test of Hypothesis ($p<0.05$)		
		T	P	Critical T = 2.132 N = 5 Mean = 83.66 Standard Deviation = 2.018
6	86.40	- 3.029	0.019	
12	80.71	3.275	0.015	
15	83.59	0.084	0.468	
16	83.70	- 0.038	0.486	
17	83.93	- 0.293	0.392	

Hypothesis 4.1

Ho: The GWQI calculated with 6 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 6 parameters

Explanation

Since the calculated T value was greater than the critical T value, the null hypothesis was rejected in favour of the alternative hypothesis.

Hypothesis 4.2

Ho: The GWQI calculated with 12 parameters listed under PC1 and PC2 cumulatively explain overall GWQI

Ha: The GWQI calculation should be done with more than 12 parameters

Explanation

Since the calculated T value is greater than the critical T value the null hypothesis was rejected in favour of the alternative hypothesis.

Hypothesis 4.3

Ho: The GWQI calculated with 15 parameters listed under PC1, PC2 and PC3 cumulatively explain overall GWQI

Ha: The GWQI calculation should be done with more than 15 parameters

Explanation

Since the calculated T value is lesser than the critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-4 (SAT-4), there is no significant difference between the GWQI calculated from the 15 parameters with significant loading of PC-1, PC-2 and PC-3, and the overall GWQI calculated from all the 17 parameters.

Table 4.23e: Test of Hypothesis for GWQI at SAT-6 of SG-5.

No. of Parameters	GWQI	Test of Hypothesis ($p<0.05$)		
		T	P	Critical T = 2.132 N = 5 Mean = 66.44 Standard Deviation = 4.939
8	59.95	2.940	0.021	
12	63.15	1.491	0.105	
15	66.81	- 0.166	0.438	
16	71.06	- 2.090	0.052	
17	71.25	- 2.176	0.048	

Hypothesis 5.1

Ho: The GWQI calculated with 8 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 8 parameters

Explanation

Since the calculated T value is greater than the critical T, the null hypothesis was rejected in favour of the alternative hypothesis.

Hypothesis 5.2

Ho: The GWQI calculated with 12 parameters listed under PC1 and PC2 cumulatively explain overall GWQI

Ha: The GWQI calculation should be done with more than 12 parameters

Explanation

Since the calculated T value is lesser than the critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-5 (SAT-6), there is no significant difference between the GWQI calculated from the 12 parameters with significant loading of PC1 and PC2, and the overall GWQI calculated from all the 17 parameters.

Table 4.23f: Test of Hypothesis for GWQI at SAT-8 of SG-6.

No. of Parameters	GWQI	Test of Hypothesis ($p<0.05$)		
		T	P	Critical T = 2.353 N = 4 Mean = 66.27 Standard Deviation = 1.622
13	68.61	- 2.888	0.032	
15	65.73	0.663	0.277	
16	64.87	1.723	0.092	
17	65.86	0.502	0.325	

Hypothesis 6.1

Ho: The GWQI calculated with 13 parameters listed under PC1 explain overall GWQI

Ha: The GWQI calculation should be done with more than 13 parameters

Explanation

Since the calculated T value was greater than the critical T value, the null hypothesis was rejected in favour of the alternative hypothesis.

Hypothesis 6.2

Ho: The GWQI calculated with 15 parameters listed under PC1 and PC2 cumulatively explain overall GWQI

Ha: The GWQI calculation should be done with more than 15 parameters

Explanation

Since the calculated T value was lesser than the critical T value, the null hypothesis was not rejected. Conclusion is, in case of SG-6 (SAT-7 and SAT-8), there is no significant difference between the GWQI calculated from the 15 parameters with significant loading of PC1 and PC2, and the overall GWQI calculated from all the 17 parameters.

Please see **Table-4.24** for the parameters sufficient for the water quality monitoring identified through the WQI approach. Results indicated that the number of parameters to be monitored can be reduced to 69 from 102. The parameter reduction was maximum (61%) for the SG-1 and SG-2. The parameter reduction was not significant for the other SGs.

Table 4.24: Number of parameters significant for the water quality monitoring at different SGs.

Parameters	**SG-1**	**SG-2**	**SG-3**	**SG-4**	**SG-5**	**SG-6**	**Total**
Water Temperature	-	✓	✓	✓	✓	✓	**5**
Conductivity	✓	✓	✓	✓	✓	✓	**6**
DO% Saturation	✓	-	✓	✓	-	✓	**4**
pH	-	-	-	✓	-	✓	**2**
Suspended Solids	-	-	✓	✓	✓	-	**3**
Total Dissolved Solids	-	✓	✓	-	✓	✓	**4**
BOD_5	✓	✓	✓	✓	✓	✓	**6**
COD	-	-	-	✓	✓	✓	**3**
Ammonical-Nitrogen	-	-	✓	✓	✓	✓	**4**
Nitrate-Nitrogen	✓	✓	✓	✓	✓	-	**5**
Total Nitrogen	✓	✓	✓	✓	✓	✓	**6**
Total Phosphorous	-	-	✓	✓	-	✓	**3**
Chloride	-	✓	✓	✓	✓	✓	**5**
Total Hardness	-	-	✓	✓	✓	✓	**4**
Alkalinity	✓	-	✓	✓	-	✓	**4**
Sulphate	-	-	-	-	-	✓	**1**
Fecal Coliform	-	-	✓	✓	✓	✓	**4**
Total parameters	**6**	**7**	**14**	**15**	**12**	**15**	**69**

4.7 Water quality management programs and plans

4.7.1 The Satluj river water quality monitoring programs

River water quality monitoring program is one of the important aspects of the river water quality management programs. Its implementation involves spending money, resources and time. Outcome of the monitoring programs are supposed to support the planning and implementation of effective water quality management programs. The monitoring programs are also used to evaluate the effectiveness of the implemented river water quality management programs and assessment of the water quality management programs' goals and objectives. The monitoring program is supposed to monitor the river at appropriate monitoring stations at appropriate intervals for the selected appropriate parameters. The monitoring data is supposed to be communicated to the concerned persons and agencies associated with the river water quality management in easy to understand, simple and usable form.

The water quality monitoring program of the river Saluj was found can be optimized. The number of monitoring stations can be reduced from 8 to 6, similarly the frequency of sampling and the parameters to be monitored can be significantly reduced. Total number of samples to be collected can be reduced from 96 to 57, and the number of parameters to be monitored can be reduced on an average from 17 to 11.5. This optimization can significantly the cost of implementation of the Satluj river water quality monitoring program. Further, analysis of the monitoring data has indicated the need for monitoring the river water also for the heavy metals, pesticides and other toxic substances.

The river water quality monitoring data may be communicated, within reasonable time to the authorities concerned with the implementation of the Satluj River Action Plan, in the form of Water Quality Index (WQI) and sub-WQI. The communicated information may also include information on the maximum operators identified.

4.7.2 Stormwater management in the sub-watersheds of the Satluj river watershed

Stormwater flows from the catchments were found contributing not much to the Satluj river water flows and quality. However, it was suspected that due to about 70% of the catchments being crop land that too under flood irrigated paddy crop specially during the monsoon or the rainy season floods can occur in the catchments and the river whenever the rainfall crosses some threshold rainfall volume. These floods must be dramatically altering the Satluj river water quality. Hence, the Satluj River Action Plan implementing authority, as part of the river water quality management program focus on replacing the monsoon paddy crop requiring flood irrigation with alternate crops that require no flood irrigation. Such an action can significantly reduce the Curve Number of the watersheds. The curve number for the cropland because of the paddy crop was taken as 98 and this will be dramatically reduced and curtail the runoff volumes generated by the storm events. Further, such a measure can reduce the pollution loads (eutrophicating nutrients and pesticides) to the Satluj river and the Harike Wetland System.

4.7.3 Reduction of pollution loads into the river Satluj

Water quality in the Satluj river was found deteriorated downstream to SAT-6 station, and most of the flow in the river (at SAT-8, upstream of the Harike Wetland System) was contributed by the Buddha Nala and the East-Bein river sub-watersheds. Further, storm water component in the water drained by these two sub-watersheds is almost insignificant. Most of the water was urban sewage and industrial effluents. Biodegradable organic matter, nutrients, and heavy metals and toxic organic substances were the key pollutants in these waters.

The current Satluj River Action Plan of sewage diversion from the cities of the two sub-watersheds (Ludhiana, Jalandhar, Phagwara and Phillaur) for treatment and disposal of the treated effluent into the river Satluj is proving insufficient to tackle the river water and the Harike Wetland System pollution problems. The activity has been mainly taking care of the organic pollution. Removal or reduction of other pollutants were just coincidental. Removal of specially the heavy metals and toxic organic substances, and even to the nutrients may need emphasis in these actions. In addition to what has been done by the individual point sources of pollution (the multitude of large and medium scale industries discharging effluent into the river) towards pollution reduction, the Satluj River Action Plan can focus on the run of the river treatment systems on both the Buddha Nala and the East-Bein rivers on the downstream side specially for tackling the heavy metals and other toxic substances and nutrient pollution problems.

Over the decades both the Buddha Nala and the East-Bein river have accumulated sediments of heavy metals and other toxic substances. Dredging removal of these sediments is needed, otherwise these sediments can prove long lasting sources of pollution to the Satluj river and to the Harike Wetland System.

4.7.4 Water flow regulations in the river Satluj

Allowing a minimum base flow of original river water in the Satluj river specially downstream the Ropar Headworks, and occasional controlled flooding of the Satluj river flood plains by the original river water discharges from the Ropar Head-Works (and Nangal Head-works) can ensure healthy riverine ecosystem on the river Satluj. Further, such flow regulations in the river can help in the protection and conservation of the river's pollution assimilation and self-cleansing capabilities.

Water conservation measures, specially, in the urban human settlements and by the industrial units, specially of the three sub-watersheds (the East-Bein, The Buddha Nala and the Satluj Flood Plain), are also important in the Satluj river water quality management. Such measures can reduce the water and pollution loads by these watersheds to the river Satluj.

Chapter – 5

CONCLUSIONS

The water quality monitoring program needs optimization to minimize its implementation cost. The program may have to include monitoring for heavy metals, pesticides and other toxic substances. Water quality monitoring data must be communicated, within reasonable time to the authorities implementing the Satluj River Action Plan, in the form of WQI and sub-WQI. The information should include information on the maximum operators identified.

While the smaller rainfall events are believed to contribute insignificant storm water flows, the larger rainfall events on the other hand result in floods with storm water flows much higher than the expected from the effective rainfall. For mitigating this problem, the monsoon paddy crop requiring flood irrigation may be replaced with alternate crops that require no flood irrigation and significantly drop the Curve Number.

Water quality in the Satluj river is found deteriorated downstream to SAT-6 station, and most of the flow in the river (at SAT-8, upstream of the Harike Wetland System) is contributed by the Budha Nala and the East Bein sub-watersheds. Strom water component in the water drained by these two sub-watersheds is almost insignificant, and most of the water is urban sewage and industrial effluents. Biodegradable organic matter, nutrients, and heavy metals and toxic organic substances are the key pollutants in these waters. The current Satluj River Action Plan of sewage diversion of the sub-watersheds' cities (Ludhiana, Jalandhar, Phagwara and Phillaur) for treatment and introduction of the treated effluent into the Satluj river is proving insufficient to tackle the pollution problem. The plan is mainly taking care of the organic pollution. Attention must be paid to the heavy metals and toxic organic substances, and even to the nutrients. In addition to what is being done by the individual point sources of pollution, run of the river treatment systems may be required on both the Buddha Nala and the East-Bein rivers on the downstream side specially for tackling the heavy metals and other toxic substances and the nutrients.

Over the decades both the Budha Nala and the East Bein have accumulated sediments of heavy metals and other toxic substances. Dredging removal of these sediments is needed, otherwise these can prove long lasting sources of pollution of the Satluj river water.

Allowing a minimum base flow of original river water in the Satluj river specially at the Ropar head-works, and occasional controlled flooding of the Satluj river flood plains by the discharges from the Ropar head-works can ensure a healthy riverine ecosystem and maintain the river's pollution assimilation and self-cleansing capabilities.

Water conservation measures, specially, in the urban human settlements and by the industrial units specially of the three sub-watersheds (the East-Bein, The Budha Nala and the Satluj Flood Plain) is also important in the Satluj river water quality management.

Existing WQIs are found not suitable for the effective communication of water quality data. These focus mostly on general parameters and not use specific. Use of indicators rather than attributes of water quality as parameters, not considering the parameters like heavy metals and pesticides, lack of rating curves for many of the water quality parameters, and lack of flexibility to include or exclude parameters have been some of the limitations associated with the existing WQIs. Water quality index specific to the ecological use of water (WQI_E) has been developed and applied to the Satluj river water quality monitoring data in the present study.

All the parameters for which prescribed ecological water quality criteria and standards exist have been selected for inclusion in the WQI. Three sub-indices (SI_{gp}, SI_{hm} and SI_{ptoc}) developed for expressing the water quality for the three groups of parameters, were aggregated by geometric mean method for obtaining the WQI_E.

Developed WQI_E is open to allow the flexibility of inclusion or exclusion of any parameter. Application of the WQI_E to the monitoring data available has indicated the importance of including the heavy metal parameters in the WQI. When heavy metals were not considered the water quality of the river Satluj was found to be good, while the actual water quality was not that high. Lack of data on pesticides did not allow assessment of importance of incorporating pesticides and other toxic organic compounds parameters in the WQI_E. The WQI_E, together with the SI_{hm} and SI_{ptoc}, will be of immense help in deciding the strategies and programs for the river water quality management, specially, through source control of pollution. The WQI_E scores estimated will also be useful to ascertain suitability of the water for the conservation of ecological status of rivers.

The present study used the monitoring data accumulated over seven years for the optimization of the Satluj river water quality monitoring program. Advanced statistical techniques, cluster analysis and principal component analysis, were effectively used for minimizing the number of sampling stations, and the frequency of sampling from the individual stations, and for reducing the number of parameters for which the samples from different stations should be analyzed.

The sampling stations, the frequency of sampling and the number of parameters all have been significantly reduced. The sampling stations were reduced to six from the existing eight. The frequency of sampling was reduced to 9.5/year from 12/year, but the reduction was not same or similar for all the six stations. The parameters were reduced to 11.5 from 17, and the parameters to be analyzed also showed variations among the sampling stations. While one of the sations (SG-1) required only 6 parameters, another station (SG-6) required 15 parameters. Further, the sets of parameters were different for different stations.

Expert opinion analysis (using pair-wise comparison technique), by the experts well acquainted with the Satluj river and its water quality, was used in the study for the selection of parameters and assigning relative importance values. The study has shown that even the results of principal component analysis can be comfortably used for the selection of parameters and assigning relative importance values. The only problem suspected with this is, it fails to provide any use specific water quality indices, as it only takes into account the water quality variability with time.

The study, however, fails to establish whether the number of stations are enough or need any additional stations, or whether the frequency of sampling is enough or needs enhancement, or whether the parameters tested are sufficient or need increasing.

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Appendix-A

Guidelines for Filling the Response Sheets
(Pair-wise Comparison of Parameters for Relative Importance)

Three Response Sheets (RS-1, RS-2 and RS-3) are attached herewith, for your assignment of relative importance values (to the **Common Water Quality Parameters[@]** selected for inclusion in our Water Quality Indexing exercise) through pair-wise comparison of the parameters.

Response Sheet- includes 11 parameters selected for the Ecological Water Quality Index (WQI_E)

The response sheet is a matrix table of 1 to n rows and 1 to n columns of the selected set of parameters. What all you need to do is filling the empty matrix cells with your scores assigned to each of the parameters of the rows on pair-wise comparison with each of the parameters of the columns. To avoid ambiguity, only the cells above the diagonal of the matrix table are given in the response sheets.

Through pair-wise comparison of a parameter of a row with a parameter of a column, your may decide on the score (any one of the following) and enter the same along with sign in the corresponding matrix cell:

+2	Of the two parameters compared, the **parameter of the row** is '**Much More Important'** than the **parameter of the column.**
+1	Of the two parameters compared, the **parameter of the row** is '**More Important'** than the **parameter of the column.**
0	Of the two parameters compared, the **parameter of the row** is '**As Important As'** the **parameter of the column**.
-1	Of the two parameters compared, the **parameter of the row** is '**Less Important'** than the **parameter of the column**.
-2	Of the two parameters compared, the **parameter of the row** is '**Very Less Important'** than the **parameter of the column**.

Please find on the hind side of this sheet a sample filled response sheet for assistance in filling the response sheets RS-1, RS-2 and RS-3. In this sample sheet, as examples, comparisons of pH with Ammonical-N, Alkalinity with Hardness, Hardness with Iron, Ammonical-N with Fecal Coliform and Nitrate-N with Chloride are shown through encircling the scores. A score of '**+2**', for comparison of pH with Ammonical-N, indicates that pH is rated as '**Much More Important'** than Ammonical-N. A score of '**-1**', for comparison of Nitrate-N with Chloride, indicates that Nitrate-N is rated as '**Less Important'** than Chloride. A score of '0', for comparison of Alkalinity with Hardness, indicates that Alkalinity is rated as '**As Important As**' Hardness.

@: In addition to the common parameters, heavy metals and pesticides (and other toxic organic compounds) have also been considered in the Water Quality Indexing through sub-indexing (S_{Ihm} and SI_{ptoc}).

Fig-1: Example for assignment of relative importance through pair-wise comparison of parameters

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
		pH	Conductivity	Turbidity	TDS	Alkalinity	Hardness	Ammonical-N	Nitrate-N	Fluoride	Iron	Chloride	Sulfate	Fecal Coliform	Water Temperature
1	pH		+1	-1	+1	+1	+2	+2	+1	+1	+1	-1	+2	+1	+1
2	Conductivity			-1	0	+1	+1	+2	+2	+1	+1	+1	+1	-1	0
3	Turbidity				+1	+1	+1	+2	+1	+2	+2	+1	+1	-1	0
4	TDS					+1	+1	+1	+1	+2	+2	+1	+1	-1	0
5	Alkalinity						0	0	+1	+2	+2	+1	+1	-1	+1
6	Hardness							0	+1	+1	+1	0	0	-1	+1
7	Ammonical-N								0	+1	+1	-1	0	-2	0
8	Nitrate-N									+1	0	-1	0	-2	0
9	Fluoride										0	-1	-1	-2	-1
10	Iron											-1	0	-2	+1
11	Chloride												+1	-1	0
12	Sulfate													-2	0
13	Fecal Coliform														+2
14	Water Temperature														

Response Sheet

RS: Relative importance scores through pair-wise comparison of selected parameters for Ecological WQI (WQI_E)

		A	B	C	D	E	F	G	H	I	J
		DO	pH	Turbidity	TSS	Ammonical-N	Total-N	Total-P	BOD_5	COD/BOD_5 ratio	Fluoride
1	DO										
2	pH										
3	Turbidity										
4	TSS										
5	Ammonical-N										
6	Total-N										
7	Total-P										
8	BOD_5										
9	COD/BOD_5 ratio										
10	Fluoride										

Personal Information (To be filled by the participant)

Name

Designation

Institute/Organization

Address

E-mail

Area of Interest

Any Suggestion If you want to exclude any of the selected parameters or, include any additional parameter, please indicate.

	Exclusion	Inclusion
$WQI_{M/I}$		
WQI_{E}		
WQI_{I}		

Signature:

Date:

Appendix-B

AMMONICAL NITROGEN

Units Used for Analytical Results: mg/l N

Normal Method(s) of Analysis: Colorimetric (Manual; Nessler's Reagent), Digestion, Distillation, Titrimetry.

Occurrence/Origin: Ammonia is generally present in natural waters, though in very small amounts, as a result of microbiological activity which causes the reduction of nitrogen-containing compounds. When present in levels above 0.1 mg/l N, sewage or industrial contamination may be indicated.

Health/Sanitary Significance: From the viewpoint of human health the significance of ammonia is marked because it indicates the possibility of sewage pollution and the consequent possible presence of pathogenic micro-organisms.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008			Ammonia, mg/l NH_4^+	①
	EU Drinking Water Directive [98/83/EC]		0.5	Ammonia, mg/l NH_4^+	
	Vietnam WQ Standard, Level 1		0.1	Ammonium as N	
	South African WQ Guidelines		**0 - 1.0 (TWQR)**	Target water quality range	②
			1.0 - 2.0		③
			2.0 - 10.0		④
			> 10.0		⑤
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	50	Free Ammonia 5	
		Public Sewers	50		
		Marine Coastal Areas	50	Free Ammonia 5	
	EU Surface Water Directive (75/440 EEC)	A-1	0.2		⑥
		A-2	1.5		
		A-3	4		
	Vietnam WQ Standard, Level 2		0.2	Ammonium as N	
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.5	Ammonium as N	
	South African WQ Guidelines		**≤ 5 (TWQR)**	Criteria are based on Total Inorganic Nitrogen (NH_3, NH_4^+, NO_2^-, NO_3^-)	Table:1
			5-30		Table:2
			> 30		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		≤1.2	Free Ammonia as N	
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	(G) < 0.04	Limits are for Total Ammonium	⑦
			(I) <1		
		(Cyprinid)	(G) < 0.2		
			(I) <1		
	Vietnam WQ Standard, Level 2		0.2	Ammonium as N	

	South African WQ Guidelines				⑧
	Canadian Environmental Quality Guidelines				Table:3
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① No health-based guideline value was recommended, but the Guidelines stated that ammonia could cause taste and odour problems at concentrations above 35 and 1.5 mg/litre, respectively.

② No health or aesthetic effects.

③ Possibility of taste and odour complaints from consumers.

④ Consumer complaints of objectionable taste and odours likely. Disinfection by chlorine can be compromised.

⑤ Unacceptable in domestic water. Danger of formation of nitrite. Likelihood of fish deaths in aquaria. Chlorination is severely compromised.

⑥ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑦ G [value] Guide [advisory] value in EU Directives; I [value] Mandatory [imperative] value in EU Directives.

⑧ The TWQR and criteria for un-ionised ammonia in aquatic ecosystems are :

TWQR and Criteria	**Un-ionised Ammonia Concentration (μg -N/L)**
Target Water Quality Range (TWQR)	*≤ 7*
Chronic Effect Value (CEV)	15
Acute Effect Value (AEV)	100

Table 1: Effects of Total Inorganic Nitrogen on Crop Yield and Quality and Ground Water Contamination

Concentration Range (mg/L)	Crop Yield and Quality	Ground Water Contamination
Target Water Quality Range ≤ 5	***The unintended nitrogen application should, at normal irrigation applications, be low enough not to affect even sensitive crops such as grapes and most fruit trees***	***The unintended nitrogen application should, at normal irrigation applications, be low enough so that most of it would be utilised by the irrigated crop and little be available for leaching to ground water***
5-30	Sensitive crops increasingly likely to be affected (depending on magnitude of irrigation application). Other crops remain largely unaffected in the lower concentration range, but are increasingly affected as concentration increases	Likelihood of ground water contamination increases, depending on actual volume of irrigation water applied and uptake by irrigated crop
> 30	Most crops are affected. A limited range of crops can utilise the nitrogen applied. Severe restrictions are placed on the utilisation of these waters	Increasingly serious likelihood of ground water contamination

Table 2: Effects of Total Inorganic Nitrogen on Irrigation Equipment

Concentration Range (mg/L)	Effects on Irrigation Equipment
Target Water Quality Range ≤0.5	***Oligotrophic conditions. No nuisance growth of aquatic plants or blue-green algal blooms in irrigation structures (canals and storage dams)***
0.5 - 2.5	Mesotrophic conditions. Occasional growth of nuisance plants and blue-green algae in irrigation structures
2.5 - 10	Eutrophic conditions. Frequent growth of nuisance plants and blue-green algal blooms in irrigation structures, in the absence of other limiting growth factors
> 10	Hypertrophic conditions. Almost continuous growth of nuisance plants and blue-green algal blooms in irrigation structures in the absence of other growth-limiting factors

Table-3: Water quality guidelines for total ammonia for the protection of aquatic life (mg/L NH_3).

Temp.	**pH**							
(ºC)	**6**	**6.5**	**7**	**7.5**	**8**	**8.5**	**9**	**10**
0	231.0	73.0	23.10	7.320	2.330	0.749	0.250	0.042
5	153.0	48.3	15.30	4.840	1.540	0.502	0.172	0.034
10	102.0	32.4	10.30	3.260	1.040	0.343	0.121	0.029
15	69.7	22.0	6.98	2.220	0.715	0.239	0.089	0.026
20	48.0	15.2	4.82	1.540	0.499	0.171	0.067	0.024
25	33.5	10.6	3.37	1.080	0.354	0.125	0.053	0.022
30	23.7	7.5	2.39	0.767	0.256	0.094	0.043	0.021

Note:

Measurements of total ammonia in the aquatic environment are often expressed as mg/L total ammonia-N. The present guideline values (mg/L NH_3) can be converted to mg/L total ammonia-N by multiplying the corresponding guideline value by 0.8224.

BORON

Units Used for Analytical Results: mg/l B
Normal Method(s) of Analysis: Colorimetric (Curcumin); Atomic Absorption Spectrometry.
Occurrence/Origin: Naturally occurring trace element. Used in cleaning compounds and in alloys.
Health/Sanitary Significance: Although excessive amounts of boron can cause nervous problems, the element is not considered a problem in drinking water. It has been identified as a danger to crops when present in irrigation water at the 1 - 2 mg/l concentration range.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.5		①
	EU Drinking Water Directive [98/83/EC]		1		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	2		②
		A-2	2		
		A-3	2		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		<2		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		≤ 0.5 (TWQR)		Table:1
	Canadian Environmental Quality Guidelines				③
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		29	short term	
			1.5	long term	
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① The guideline is designated as provisional because it will be difficult to achieve in areas with high natural boron levels with the treatment technology available.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Boron on Crop Yield and Appearance

Concentration Range (mg/L)	**Crop Yield and Appearance**
Target Water Quality Range ≤ 0.5	Should prevent the accumulation of boron to toxic levels (through root uptake) in all but the most sensitive plants
0.5 - 1.0	Crops very sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases
1.0 - 2.0	Crops sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases
2.0 - 4.0	Crops moderately sensitive to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases
4.0 - 6.0	Crops moderately tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases
6.0 - 15.0	Crops tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases
> 15.0	Crops very tolerant to boron accumulate toxic levels (through root uptake). They start to display symptoms of foliar injury and/or yield decreases

③ Canadian Environmental Quality Guidelines for Protection of Agriculture are as follows:

● 500 µg/L for blackberries

● 500-1000 µg/L for peaches, cherries, plums, grapes, cowpeas, onions, garlic, sweet potatoes, wheat barley, sunflowers, mung beans, sesame, lupins, strawberries, Jerusalem artichokes, kidney beans, and lima beans

● 1000-2000 µg/L for red peppers, peas, carrots, radishes, potatoes, and cucumbers

● 2000-4000 µg/L for lettuce, cabbage, celery, turnips, Kentucky bluegrass, oats, corn, artichokes, tobacco, mustard, clover, squash, and muskmelons

● 4000-6000 µg/L for sorghum, tomatoes, alfalfa, purple vetch, parsley, red beets, and sugar beets

● 6000 µg/L for asparagus

CALCIUM

Units Used for Analytical Results: mg/l Ca

Normal Method(s) of Analysis: Titration (Calcium Hardness); Atomic Absorption Spectrometry.

Occurrence/Origin: Occurs in rocks, bones, shells etc. Very abundant.

Health/Sanitary Significance: High levels may be beneficial (see below) and waters which are rich in calcium (and hence are very hard) are very palatable.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<75	Permissible limit 200	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 32 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		②
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Encrustation in water supply structure and adverse effects on domestic use.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Calcium on Personal Hygiene, Household Distribution Systems and Water Heating Appliances

Calcium Range (mg/L as Ca)	Effects
Target Water Quality Range 0 - 32	***No health effects. No scaling evident. Possible corrosive effects < 16 mg/L***
32 - 80	No health effects. Increased scaling problems. Lathering of soap impaired
> 80	No health effects. Severe scaling problems. Lathering of soap severely impaired

CHLORIDE

Units Used for Analytical Results: mg/l Cl

Normal Method(s) of Analysis: Titration (Mohr Method: Silver Nitrate).

Occurrence/Origin: Chloride exists in all natural waters, the concentrations varying very widely and reaching a maximum in sea water (up to 35,000 mg/l Cl). In fresh waters the sources include soil and rock formations, sea spray and waste discharges. Sewage contains large amounts of chloride, as do some industrial effluents.

Health/Sanitary Significance: Chloride does not pose a health hazard to humans and the principal consideration is in relation to palatability.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<250		①
	CPCB, Class A		<250		
	CPCB, Class C		<600		
	WHO, 2008				②
	EU Drinking Water Directive [98/83/EC]		250		
	Vietnam WQ Standard, Level 1		250		
	South African WQ Guidelines		**0 - 100 (TWQR)**	Target water quality range	③
			100 - 200		④
			200 - 600		⑤
			600 - 1200		⑥
			> 1200		⑦
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	250		⑧
		A-2	250		
		A-3	250		
	Vietnam WQ Standard, Level 2		400		
Irrigation	CPCB, Class E		<600		
	Vietnam WQ Standard, Level 3		600		
	South African WQ Guidelines		**≤ 100 (TWQR)**	Target water quality range	Table:1
	Canadian Environmental Quality Guidelines				Table:2
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		400		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this limit taste, corrosion and palatibility are affected.

② No health-based guideline value is proposed for chloride in drinking-water. However, chloride concentrations in excess of about 250 mg/litre can give rise to detectable taste in water.

③ No aesthetic or health effects. The threshold for corrosion acceleration in domestic appliances is at 50 mg/l.

④ No aesthetic or health effects. Possible increase in the corrosion rate in domestic appliances.

⑤ Water has a distinctly salty taste, but no health effects Likelihood of noticeable increase in corrosion rates in domestic appliances.

⑥ Water has objectionable salty taste and will not slake thirst Likelihood of rapid corrosion in domestic appliances.

⑦ Water unacceptably salty. Nausea and disturbance of the electrolyte balance can occur, especially in infants, where fatalities due to dehydration may occur.

⑧ A1, A2 or A3, depending on the (increasing) degree of treatment.

Table-1: Effects of Chloride on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Quality
Target Water Quality Range < 100	***Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, even when chloride uptake is through foliar absorption, that is, crop foliage is wetted***
< 140	Should prevent the accumulation of chloride to toxic levels in all but the most sensitive plants, when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage
140 - 175	Only slight problems with the accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage
100 - 175	Crops sensitive to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display foliar injury and yield decreases
175 - 350	Some problems with the accumulation of chloride to levels toxic to moderately sensitive crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface, thereby excluding wetting of crop foliage
	Crops moderately sensitive to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display symptoms of foliar injury and yield decreases
350 - 700	All moderately sensitive crops and most moderately tolerant crops accumulate chloride to levels toxic to crops when chloride uptake is through root absorption, that is, water is applied to the soil surface thereby excluding wetting of crop foliage
	Crops moderately tolerant to foliar absorption accumulate toxic levels of chloride when crop foliage is wetted. They display symptoms of foliar injury and yield decreases
>700	Increasing problems with the accumulation of chloride to levels toxic to crops can be expected when chloride uptake is through root absorption, that is, water is applied to the soil surface thereby excluding wetting of crop foliage
	Crops tolerant to foliar absorption increasingly accumulate toxic levels of chloride when crop foliage is wetted. They display symptoms of foliar injury and yield decreases

Note:

Crop tolerance to chloride, when crop foliage is wetted by sprinkler irrigation, is not well established. Very little local confirmation of internationally published experiments has taken place. The indicated concentration ranges apply to daytime sprinkling under conditions that are not too hot or too dry.

Table-2: Canadian Environmental Quality Guidelines for Chloride are as follows:

Foliar damage
= 100-178 mg/L for almond apricots and plums
= 178-355 mg/L for grapes, peppers, potatoes and tomatoes
= 355-710 mg/L for alfalfa, barley, corn, and cucumbers
>710 mg/L for cauliflower, cotton, safflower, sesame, sorghum, sugar beets, and sunflowers
Rootstocks
= 180-600 mg/L for stone fruit (peaches, plums, etc.)
= 710-900 mg/L for grapes
Cultivars
= 110-180 mg/L for strawberries
= 230-460 mg/L for grapes
= 250 mg/L for boysenberries, blackberries, and raspberries

DISSOLVED OXYGEN

Units Used for Analytical Results: mg/l O_2
Normal Method(s) of Analysis: Winkler Titration, Electrometric [DO Meter].
Occurrence/Origin: Natural characteristic of clean waters.
Health/Sanitary Significance: Slight organoleptic significance only, but critical for survival of fish.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		≥6		
	CPCB, Class C		≥4		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		88-112	% saturation	
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	≥60	% saturation	①
		A-2	≥50	% saturation	
		A-3	≥30	% saturation	
	Vietnam WQ Standard, Level 2		75-88, 112-125	% saturation	
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		50-75, 125-150	% saturation	
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		≥4		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	50% ≥9 , 100% ≥7	(Imperative Value) 50% ≥9	②
		(Cyprinid)	50% ≥8 , 100% ≥5	(Imperative Value) 50% ≥7	③
	Vietnam WQ Standard, Level 2		75-88, 112-125	% saturation	
	South African WQ Guidelines		**80-120 (TWQR)**	% saturation	**Table-1**
	Canadian Environmental Quality Guidelines		5.5-9.5		④
Outdoor Bathing, Recreational Use	CPCB, Class B		≥5		
	EU Bathing Water Directive (76/160/EEC)		70-120	% saturation	
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① A1, A2 or A3, depending on the (increasing) degree of treatment.

② The I value for salmonid water contains the provision: "When the oxygen concentration falls below 6 mg/l, Member States shall implement the provisions of Article 7 [3] [of the Directive]. The competent authority must prove that this situation will have no harmful consequences for the balanced development of the fish population."

③ The I value for cyprinid water contains the provision: "When the oxygen concentration falls below 4 mg/l, Member States shall implement the provisions of Article 7 [3] [of the Directive]. The competent authority must prove that this situation will have no harmful consequences for the balanced development of the fish population."

Table-1: Criteria for dissolved oxygen concentrations (in terms of percentage saturation).

Criteria for dissolved oxygen concentrations (in terms of percentage saturation) are given in terms of the Minimum Allowable Values (MAV), in the table below. These concentrations provide limits which will ensure protection of aquatic biota from the adverse effects of oxygen depletion.

The MAV will protect sensitive life stages which may last for only a few days, and take into account the resilience of aquatic organisms to short-duration oxygen depletion.

TWQR and Criteria	**Concentration**	**Condition**	**Application**
Target Water Quality Range	***80 % - 120 % of saturation***	***06h00 sample or lowest instantaneous concentration recorded in a 24 hour period***	***Will protect all life stages of most southern African aquatic biota - endemic to, or adapted to, aerobic warm water habitats. Always applicable to aquatic ecosystems of high conservation value.***
Minimum Allowable Values	> 60 % (Sub lethal)	7-day mean minimum	The 7-day mean minimum *and* the 1- day minimum should apply together.
	> 40 % (Lethal)	1-day minimum	Violation of these minimum values is likely to cause acute toxic effects on aquatic biota.

④ Lowest acceptable dissolved oxygen concentration:

for warm water biota: early life stages = 6 mg/L, for warm water biota: other life stages = 5.5 mg/L.

for cold water biota: early life stages = 9.5 mg/L, for cold water biota: other life stages = 6.5 mg/L.

CONDUCTIVITY

Units Used for Analytical Results: µS/cm
Normal Method(s) of Analysis: Electrometric.
Occurrence/Origin: Reflects mineral salt content of water.
Health/Sanitary Significance: No direct significance.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		2500		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 700 (TWQR)**	Target water quality range	Table:1
			700 - 1500		
			1500 - 3000		
			3000 - 4500		
			> 4500		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	1000		1
		A-2	1000		
		A-3	1000		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		2250		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		**400 (TWQR)**	Target water quality range	2
			400 - 900		3
			900 - 2700		4
			2700 - 5400		5
			> 5400		6
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		1000		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

Table-1: Effects of EC on Human Health, Aesthetics, Household Distribution Systems and Water Heating Appliances

EC Range (µS/cm)	Aesthetic/Economic Effects	Health Effects
0 - 700	**The taste threshold for dissolved salts in water is in the region of 45 mS/m (300 mg/L TDS), hence a slight salty taste may be detected above this concentration. The threshold varies according to the salt composition.**	**No health effects associated with the electrical conductivity of water are expected < 45 mS/m (300 mg/L TDS)**
	Water with extremely low TDS concentrations may be objectionable because of its flat, insipid taste. No effects on plumbing or appliances	***The upper limit of this range takes into account the higher water consumption which may be expected in hot climates***
700 - 1500	Water has a noticeable salty taste, but is well tolerated. No effects on plumbing or appliances	No health effects are likely
1500 - 3000	Water has a marked, salty taste and would probably not be used on aesthetic grounds if alternative supplies are available Some effects on plumbing and appliances, such as increased corrosion or scaling, may be expected	Consumption of water does not appear to produce adverse health effects in the short term
3000 - 4500	Water tastes extremely salty Corrosion and/or scaling of pipes and appliances will increase	Short-term consumption may be tolerated, but with probable disturbance of the body's salt balance
> 4500	Water tastes extremely salty and bitter. Effects such as corrosion and/or scaling increase	Short-term consumption leads to disturbance of the body's salt balance. At high concentrations, noticeable short-term health effects can be expected

① Al, A2 or A3, depending on the (increasing) degree of treatment.

② Should ensure that salt-sensitive crops can be grown without yield decreases when using low frequency irrigation systems. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided.

③ A 95 % relative yield of moderately salt-sensitive crops can be maintained by using a low-frequency irrigation system. A leaching fraction of up to 0.1 may be required and wetting of the foliage of sensitive crops should be avoided.

④ A 90 % relative yield of moderately salt-tolerant crops can be maintained by using a low-frequency application system. A leaching fraction of up to 0.15 may be required and wetting of the foliage of sensitive crops should be avoided.

⑤ A 80 % relative yield of moderately salt-tolerant crops can be maintained provided that a high-frequency irrigation system is used. A leaching fraction of up to 0.2 may be required and wetting of the foliage of sensitive crops should be avoided.

⑥ These waters can still be used for irrigation of selected crops provided sound irrigation management is practiced and yield decreases are acceptable. However, the management and soil requirements become increasingly restrictive and the likelihood of sustainable irrigation decreases rapidly.

ENTEROCOCCUS

Units Used for Analytical Results: Number of organisms/100 ml sample
Normal Method(s) of Analysis: Most Probable Number (MPN: Multiple Tube Method).
Occurrence/Origin: Sewage and similar wastes.
Health/Sanitary Significance: Indicators of possible presence of pathogenic micro-organisms.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0	Absent	
	EU Drinking Water Directive [98/83/EC]		0	Absent	
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	200		①
		A-2	2000		
		A-3	10000		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		<300		②
	South African WQ Guidelines	Full-contact recreation (swimming)	**0 - 30 (TWQR)**	Target water quality range	③
			30 - 60		④
			60 - 100		⑤
			> 100		⑥
		Intermediate contact recreation	**0 - 230 (TWQR)**	Target water quality range	⑦
			230 - 700		⑧
			> 700		⑨
		Non-contact recreation			⑩

N.A. = Not Available

① Al, A2 or A3, depending on the (increasing) degree of treatment.

② To be conformed with by 95% or more of samples and not to be exceeded by any two consecutive samples in any case.

③ Low risk of gastrointestinal illness indicated. Not expected to exceed a risk of typically < 8 cases/1 000 swimmers.

④ Slight risk of gastrointestinal effects expected. Negligible effects expected if isolated instances only.

⑤ Some risk of gastrointestinal effects, particularly if this occurs frequently. Risk is minimal if only isolated samples fall in this range. Resampling should be conducted if individual results > 100/100 ml are recorded.

⑥ Risks of health effects increase as faecal streptococci levels increase. The volume of water which needs to be ingested in order to cause ill effects decreases as the faecal streptococci density increases.

⑦ Health effects indicated. If water contact is extensive, such as may occur for novice waterskiing or novice windsurfing and if full-body immersion is likely to occur, refer to the more stringent criteria proposed for full-contact recreation.

⑧ Limited contact associated with a risk of gastrointestinal illness.

⑨ Expected increasing risk of gastrointestinal illness as faecal streptococci levels increase.

⑩ Provided no contact with water occurs and this restriction is clearly signposted, public health risks due to possible disease transmission, as indicated by faecal streptococci levels, are not of concern. Health effects should not result from rare accidental water contact.

FAECAL COLIFORM

Units Used for Analytical Results: Number of organisms/100 ml sample.

Normal Method(s) of Analysis: Most Probable Number (MPN: Multiple Tube Method).

Occurrence/Origin: Faecal coliforms originate in human and animal waste. Total coliforms include faecal and also other bacteria with similar properties which originate in soil and are nonfaecal.

Health/Sanitary Significance: Indicators of possible presence of pathogenic micro-organisms.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		0	Absent	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0	Absent	
	EU Drinking Water Directive [98/83/EC]		0	Absent	
	Vietnam WQ Standard, Level 1		20		
	South African WQ Guidelines		**0 (TWQR)**	Target water quality range	②
			0-10		③
			10-20		④
			>20		⑤
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	1000		⑥
		A-2	5000		
		A-3	40000		
	Vietnam WQ Standard, Level 2		50		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		100		
	South African WQ Guidelines		**<1 (TWQR)**	Target water quality range	⑦
			1-1000		⑧
			>1000		⑨
	Canadian Environmental Quality Guidelines		100		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		50		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		<1000		⑩
			<2000		⑪
	South African WQ Guidelines	Full-contact recreation (swimming)	**0 - 130**	Target water quality range	⑫
			130 - 600		⑬
			600 - 2 000		⑭
			> 2 000		⑮
		Intermediate contact recreation	**0 - 1 000**	Target water quality range	⑯
			1 000 - 4 000		⑰
			> 4 000		⑱
		Non-contact recreation			⑲

N.A. = Not Available

① Throughout the year, 95% of samples should not contain any coliform organisms in 100 ml, No sample should contain E. Coli in 100 ml, No sample should contain more than 10 Coliform organisms per 100 ml, Coliform organisms should not be detectable in 100 ml of any 2 consecutive samples.

② Negligible risk of microbial infection.

③ Slight risk of microbial infection with continuous exposure; negligible effects with occasional or short-term exposure.

④ Risk of infectious disease transmission with continuous exposure; slight risk with occasional exposure.

⑤ Significant and increasing risk of infectious disease transmission. As faecal coliform levels increase, the amount of water ingested required to cause infection decreases.

⑥ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑦ Irrigation water can be applied with any irrigation method to any crop with little likelihood that this will lead to the spread of human pathogens.

⑧ Likelihood of contamination from vegetables and other crops eaten raw and of milk from cows grazing on pastures will result in the transmission of human pathogens Fruit trees and grapes may be irrigated provided that the fruits are not wetted Crops and pastures not consumed raw can be irrigated with any method provided crops and pastures are allowed to dry before harvesting and grazing.

⑨ Provided water treatment quality is equivalent to or better than primary and secondary treated waste water, and that no contact is allowed to take place with humans, water can be used in irrigation for the production of fodder, tree plantations, nurseries, parks, etc.

⑩ To be conformed with by 80% or more of samples and not to be exceeded by any two consecutive samples in any case.

⑪ To be conformed with by 95% or more of samples and not to be exceeded by any two consecutive samples in any case.

⑫ Risk of gastrointestinal effects expected. The presence of faecal coliforms indicate a possible risk to health, but the absence of indicators does not guarantee no risk.

⑬ Risk of gastrointestinal illness indicated at faecal coliforms levels which occasionally fall in this range. Risk increases if the geometric mean or median levels are consistently in this range.

⑭ Noticeable gastrointestinal health effects expected in the swimmer and bather population. Some health risk, if single samples fall in this range, particularly if such events occur frequently. Four out of five samples should contain < 600 faecal coliforms/100 ml, or 95 % of faecal coliform analyses should be < 2 000/100 ml.

⑮ As the faecal coliform count increases above this limit, the risk of contracting gastrointestinal illness increases. The volume of water ingested in order to cause adverse effects decreases as the faecal coliform density increases.

⑯ Health effects are indicated for intermediate contact with recreational water. If water contact is extensive, such as may occur for novice waterskiing or novice windsurfing and if full body immersion is likely to occur, the more stringent criteria proposed for full-contact recreation may be more appropriate.

⑰ It may be expected that limited contact with water of this quality is associated with a risk of gastrointestinal illness. The upper limit of this range corresponds to the limit recommended by the Australian guidelines for at least four out of five samples collected over 30 days.

⑱ Intermediate recreational contact with water can be expected to carry an increasing risk of gastrointestinal illness as faecal coliform levels increase.

⑲ Provided no contact with water occurs, public health risk due to possible disease transmission, as indicated by faecal coliform concentrations, is not of concern.

FLUORIDE

Units Used for Analytical Results: mg/l F

Normal Method(s) of Analysis: Colorimetric (after distillation); Specific Ion Electrode.

Occurrence/Origin: Occurs naturally in quite rare instances; arises almost exclusively from fluoridation of public water supplies and from industrial discharges.

Health/Sanitary Significance: Health studies have shown that the addition of fluoride to water supplies in levels above 0.6 mg/l F leads to a reduction in tooth decay in growing children and that the optimum beneficial effect occurs around 1.0 mg/l.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<1	Permissible limit 1.5	①
	CPCB, Class A		<1.5		
	CPCB, Class C		<1.5		
	WHO, 2008		1.5		
	EU Drinking Water Directive [98/83/EC]		1.5		
	Vietnam WQ Standard, Level 1		1		
	South African WQ Guidelines		0 - 1 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<2		
		Public Sewers	<15		
		Marine Coastal Areas	<15		
	EU Surface Water Directive (75/440 EEC)	A-1	1		②
		A-2	1.7		
		A-3	1.7		
	Vietnam WQ Standard, Level 2		1.5		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		1.5		
	South African WQ Guidelines		≤ 2 (TWQR)		Table:2
	Canadian Environmental Quality Guidelines		1		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		1.5		
	South African WQ Guidelines		≤ 0.75 (TWQR)		Table:3
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		<1.5		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Fluoride may be kept as low as possible. High fluoride may cause fluorosis.

② Al, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Fluoride on Aesthetics and Human Health

Fluoride Range (mg/L)	Effects
Target Water Quality Range 0 - 1.0	***The concentration in water necessary to meet requirements for healthy tooth structure is a function of daily water intake and hence varies with annual maximum daily air temperature. A concentration of approximately 0.75 mg/L corresponds to a maximum daily temperature of approximately 26 °C – 28 °C. No adverse health effects or tooth damage occurs***
1.0 - 1.5	Slight mottling of dental enamel may occur in sensitive individuals. No other health effects are expected
1.5 - 3.5	***The threshold for marked dental mottling with associated tooth damage due to softening of enamel is 1.5 mg/L***
	Above this, mottling and tooth damage will probably be noticeable in most continuous users of the water. No other health effects occur
3.5 - 4.0	Severe tooth damage especially to infants' temporary and permanent teeth; softening of the enamel and dentine will occur on continuous use of water. ***Threshold for chronic effects of fluoride exposure***, manifested as skeletal effects. Effects at this concentration are detected mainly by radiological examination, rather than overt
4.0 - 6.0	Severe tooth damage especially to the temporary and permanent teeth of infants; softening of the enamel and dentine will occur on continuous use of water. Skeletal fluorosis occurs on long-term exposure
6.0 - 8.0	Severe tooth damage as above. Pronounced skeletal fluorosis occurs on long-term exposure
> 8.0	Severe tooth damage as above. Crippling skeletal fluorosis is likely to appear on long-term exposure
> 100	Threshold for onset of acute fluoride poisoning, marked by vomiting and diarrhoea
> 2 000	The lethal concentration of fluoride is approximately 2 000 mg/L

Note: It is recommended that the concentration of fluoride in potable water never exceed 4.0 mg/L, due to the likelihood of skeletal fluorosis with crippling, as well as the loss of teeth.

Table 2: Effects of Fluoride on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield, Crop Quality and Soil Sustainability
Target Water Quality Range ≤ 2.0	***No adverse effects on crops***
2.0 - 15.0	Maximum acceptable as concentration for fine textured neutral to alkaline soils
> 15.0	Acceptable for irrigation only over the short term on a site-specific basis

Table 3: The TWQR and criteria for dissolved fluoride in aquatic ecosystems are:

TWQR and Criteria	Fluoride concentration (µg/L)
Target Water Quality Range (TWQR)	***≤ 750***
Chronic Effect Value (CEV)	1 500
Acute Effect Value (AEV)	2 540

MAGNESIUM

Units Used for Analytical Results: mg/l Mg
Normal Method(s) of Analysis: Titration with EDTA; Atomic Absorption Spectrometry.
Occurrence/Origin: Major constituent of geological formations.
Health/Sanitary Significance: Indirect (in conjunction with Sulphate, q.v.).

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<30	Permissible limit 100	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 30 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		②
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Encrustation in water supply structure and adverse effects on domestic use.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Magnesium on Aesthetics and Human Health

Magnesium Range (mg/L as Mg)	Effects
Target Water Quality Range 0 - 30	***No bitter taste. No scaling problems. No health effects***
30 - 50	No bitter taste. Slight scaling problems may occur. No health effects
50 - 70	No bitter taste; No health effects; Scaling problems
70 - 100	Slight bitter taste. Taste threshold for magnesium is ≈70 mg/L. Scaling problems. Diarrhoea in sensitive users
100 - 200	Water aesthetically unacceptable because of bitter taste. Increased scaling problems. Diarrhoea in most new users if sulphate present
200 - 400	Severe scaling problems. Diarrhoea in all new users
> 400	Severe scaling problems. Diarrhoea in all new users. Health problems may occur

NITRATE NITROGEN

Units Used for Analytical Results: mg/l N or mg/l NO_3^-
Normal Method(s) of Analysis: Manual/Automated Colorimetry ; Specific Ion Electrode.
Occurrence/Origin: Oxidation of ammonia: agricultural fertiliser run-off.
Health/Sanitary Significance: Hazard to infants above 11 mg/l N [50 mg/l NO_3].

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<45	mg/l NO_3^-	①
	CPCB, Class A		<20	mg/l NO_3^-	
	CPCB, Class C		<50	mg/l NO_3^-	
	WHO, 2008		50	mg/l NO_3^-	② ③
	EU Drinking Water Directive [98/83/EC]		50	mg/l NO_3^-	④
	Vietnam WQ Standard, Level 1		2	Nitrate (as N)	
	South African WQ Guidelines		**0 - 6 (TWQR)**	Criteria are based on NO_2^- + NO_3^-	⑤
			6-10		⑥
			10-20		⑦
			> 20		⑧
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<10		
		Public Sewers	N.A.		
		Marine Coastal Areas	<20		
	EU Surface Water Directive (75/440 EEC)	A-1	50	mg/l NO_3^-	⑨
		A-2	50	mg/l NO_3^-	
		A-3	50	mg/l NO_3^-	
	Vietnam WQ Standard, Level 2		5	Nitrate (as N)	
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		10	Nitrate (as N)	
	South African WQ Guidelines		**≤ 5 (TWQR)**	Criteria are based on Total Inorganic Nitrogen (NH_3, NH_4^+, NO_2^-, NO_3^-)	Table:1
			5-30		Table:2
			> 30		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		5	Nitrate (as N)	
	South African WQ Guidelines			Criteria are based on Total Inorganic Nitrogen (NH_3, NH_4^+, NO_2^-, NO_3^-)	Table:3
	Canadian Environmental Quality Guidelines		13	Interim guideline.	⑩
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this methaemoglobinemia occurs.

② To protect against methaemoglobinaemia in bottle-fed infants (short-term exposure).

③ (Guideline value for combined nitrate plus nitrite) The sum of the ratios of the concentrations of each to its guideline value should not exceed 1.

④ The Directive specifies that "Member States must ensure that the condition that [nitrate]/50 + [nitrite]/3 < 1, the square brackets signifying the concentrations in mg/l for nitrate (NO_3) and nitrite (NO_2), is complied with and that the value of 0.10 mg/l for nitrites is complied ex water treatment works."

⑤ No adverse health effects.

⑥ Rare instances of methaemoglobinaemia in infants; no effects in adults. Concentrations in this range generally well tolerated.

⑦ Methaemoglobinaemia may occur in infants. No effects in adults.

⑧ Methaemoglobinaemia occurs in infants. Occurrence of mucous membrane irritation in adults.

⑨ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑩ For protection from direct toxic effects; the guidelines do not consider indirect effects due to eutrophication.

Guidelines are expressed in mg nitrate/L. These values are equivalent to 2.935 mg nitrate-nitrogen/L for freshwater.

Table 1: Effects of Total Inorganic Nitrogen on Crop Yield and Quality and Ground Water Contamination

Concentration Range (mg/L)	Crop Yield and Quality	Ground Water Contamination
Target Water Quality Range ≤ 5	***The unintended nitrogen application should, at normal irrigation applications, be low enough not to affect even sensitive crops such as grapes and most fruit trees***	***The unintended nitrogen application should, at normal irrigation applications, be low enough so that most of it would be utilised by the irrigated crop and little be available for leaching to ground water***
5-30	Sensitive crops increasingly likely to be affected (depending on magnitude of irrigation application). Other crops remain largely unaffected in the lower concentration range, but are increasingly affected as concentration increases	Likelihood of ground water contamination increases, depending on actual volume of irrigation water applied and uptake by irrigated crop
> 30	Most crops are affected. A limited range of crops can utilise the nitrogen applied. Severe restrictions are placed on the utilisation of these waters	Increasingly serious likelihood of ground water contamination

Table 2: Effects of Total Inorganic Nitrogen on Irrigation Equipment

Concentration Range (mg/L)	Effects on Irrigation Equipment
Target Water Quality Range ≤0.5	***Oligotrophic conditions. No nuisance growth of aquatic plants or blue-green algal blooms in irrigation structures (canals and storage dams)***
0.5 - 2.5	Mesotrophic conditions. Occasional growth of nuisance plants and blue-green algae in irrigation structures
2.5 - 10	Eutrophic conditions. Frequent growth of nuisance plants and blue-green algal blooms in irrigation structures, in the absence of other limiting growth factors
> 10	Hypertrophic conditions. Almost continuous growth of nuisance plants and blue-green algal blooms in irrigation structures in the absence of other growth-limiting factors

Table-3: The criteria for Total Inorganic Nitrogen in aquatic ecosystems are:

Average Summer Inorganic Nitrogen Concentration (mg/l)	Effects	*Target Water Quality Range*
< 0.5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or the presence of blue-green algal blooms.	• *Inorganic nitrogen concentrations should not be changed by more than 15 % from that of the water body under local unimpacted conditions at any time of the year; and* • *The trophic status of the water body should not increase above its present level, though a decrease in trophic status is permissible (see Effects); and* • *The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.*
0.5 - 2.5	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.	
2.5 - 10	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.	
> 10	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.	

Note: The inorganic nitrogen concentration for a specific system must be based on the existing trophic status of the system. It is undesirable to allow inorganic nitrogen concentrations to rise to a level which will change the trophic status of the system. A Target Water Quality Range should be derived only after case- and site-specific studies.

pH

Units Used for Analytical Results: pH units
Normal Method(s) of Analysis: Electrometry [pH electrode].
Occurrence/Origin: Physical characteristic of all waters/solutions.
Health/Sanitary Significance: None - except that extreme values will show excessive acidity/alkalinity, with organoleptic consequences.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		6.5-8.5		①
	CPCB, Class A		6.5-8.5		
	CPCB, Class C		6.5-8.5		
	WHO, 2008		6.5-9.2		
	EU Drinking Water Directive [98/83/EC]		6.5-9.5		
	Vietnam WQ Standard, Level 1		6.0-8.5		
	South African WQ Guidelines		< 4.0		②
			4.0-6.0		③
			6.0-9.0 (TWQR)	Target water quality range	④
			9.0-11.0		⑤
			>11.0		⑥
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	5.5-9.0		
		Public Sewers	5.5-9.0		
		Marine Coastal Areas	5.5-9.0		
	EU Surface Water Directive (75/440 EEC)	A-1	5.5-8.5		⑦
		A-2	5.5-9.0		
		A-3	5.5-9.0		
	Vietnam WQ Standard, Level 2		6.0-8.5		
Irrigation	CPCB, Class E		6.5-8.5		
	CPCB (Schedule-VI)	Land for Irrigation	5.5-9.0		
	Vietnam WQ Standard, Level 3		5.5-9.0		
	South African WQ Guidelines		< 6.5		Table:1
			6.5 - 8.4 (TWQR)	Target water quality range	
			> 8.4		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		6.5-8.5		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	6.0-9.0		
		(Cyprinid)	6.0-9.0		
	Vietnam WQ Standard, Level 2		6.0-8.5		
	South African WQ Guidelines				⑧
	Canadian Environmental Quality Guidelines		6.5-9.0		
Outdoor Bathing, Recreational Use	CPCB, Class B		6.5-8.5		
	EU Bathing Water Directive (76/160/EEC)		6.0-9.0		
	South African WQ Guidelines	Full-contact recreation (swimming)	0 - 5.0		⑨
			5.0 - 6.5		⑩
			6.5 - 8.5 (TWQR)	Target water quality range	⑪
			8.5 - 9.0		⑫

			> 9.0		⑬
		Intermediate contact recreation			⑭
		Non-contact recreation			⑮

N.A. = Not Available

① Beyond this range the water will affect the mucous membrane and/or water supply system.

② Severe danger of health effects due to dissolved toxic metal ions. Water tastes sour.

③ Toxic effects associated with dissolved metals, including lead, are likely to occur at a pH of less than 6 Water tastes slightly sour.

④ No significant effects on health due to toxicity of dissolved metal ions and protonated species, or on taste are expected.

Metal ions (except manganese) are unlikely to dissolve readily unless complexing ions or agents are present.

Slight metal solubility may occur at the extremes of this range. Aluminium solubility begins to increase at pH 6, and amphoteric oxides may begin to dissolve at a pH of greater than 8.5. Very slight effects on taste may be noticed on occasion.

⑤ Probability of toxic effects associated with deprotonated species (for example, ammonium deprotonating to form ammonia) increases sharply. Water tastes bitter at a pH of greater than 9.

⑥ Severe danger of health effects due to deprotonated species. Water tastes soapy at a pH of greater than 11.

Table-1: Effects of pH on Crop Yield and Quality, Sustainability of the Soil and Irrigation Equipment

pH Range	**Crop Yield and Quality**	**Sustainability**	**Irrigation Equipment**
< 6.5	Increasing problems with foliar damage when crop foliage is wet. This could give rise to yield reduction or a decrease in the quality of marketable materials	Increasing problems with the availability of several micro- and macro-nutrients in toxic concentrations are experienced in this range over the long term	Increasing problems with corrosion of metal and concrete in irrigation equipment are experienced in this range. Practically no problems experienced with clogging of drip irrigation systems
Target Water Quality Range 6.5 - 8.4	***Even when crop foliage is wetted, this should not cause foliar damage in plants which will result in a yield reduction or a decrease in the quality of marketable products.***	***Soil pH within this range does not present major problems with either unavailability of plant nutrients or toxic levels of elements.***	***Mostly no major problem with either corrosion or encrustation of irrigation equipment is experienced within this range (see Total Hardness). Slight to moderate problems with the clogging of drip irrigation systems.***
> 8.4	Increasing problems with foliar damage affecting yield or decrease in visual quality of visual marketable products are experienced in this range.	Increasing problems with the unavailability of several micro- and macro-nutrients are experienced within this range over the long term.	Increasing problems with encrustation of irrigation pipes and clogging of drip irrigation systems are experienced in this range.

⑦ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑧ pH values should not be allowed to vary from the range of the background pH values for a specific site and time of day, by >0.5 of a pH unit, **or** by > 5 %, **and should be assessed by whichever estimate is the more conservative.**

⑨ Severe eye irritation occurs. Skin, ear and mucous membrane irritation likely. Adverse aesthetic taste effects expected, if water accidentally swallowed.

⑩ Swimming in water of this pH is generally acceptable. Some eye irritation occurs. Skin, ear and mucous membrane irritation unlikely.

⑪ Minimal eye irritation occurs. The pH of water is well within the buffering capacity of the lachrymal fluid of the human eye. Skin, ear and mucous membrane irritation absent.

⑫ Swimming is acceptable. Some eye irritation expected. Skin, ear and mucous membrane irritation may occur. Adverse aesthetic taste effects expected if water swallowed accidentally.

⑬ Eye irritation becomes increasingly severe as pH values become more extreme. Skin, ear and mucous membrane irritation occurs. Adverse aesthetic taste effects expected, if water accidentally swallowed.

⑭ Since intermediate contact recreation may involve some degree of direct contact with water, including occasional full-body immersion, the same criteria as those given for full contact recreation are recommended. However, the extent of water contact should be taken into account and where contact is only slight or infrequent, the criteria may be less stringently applied.

⑮ If the water body is used exclusively for non-contact recreation, the effect of pH on human health is not relevant.

SUSPENDED SOLIDS

Units Used for Analytical Results: mg/l solids (Dried at stated temperature).
Normal Method(s) of Analysis: Gravimetric (Dried at stated temperature after filtration).
Occurrence/Origin: Natural deposition in or discharges to water.
Health/Sanitary Significance: No direct significance.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		20		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	100		
		Public Sewers	600		
		Marine Coastal Area	100	For process waste water	
				For cooling water effluent 10% above total suspended matter of influent	
	EU Surface Water Directive (75/440 EEC)	A-1	50		①
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		30		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	200		
	Vietnam WQ Standard, Level 3		50		
	South African WQ Guidelines		**≤ 50 (TWQR)**	Target water quality range	②
			50 - 100		③
			> 100		④
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	<25		
		(Cyprinid)	<25		
	Vietnam WQ Standard, Level 2		30		
	South African WQ Guidelines				⑤

	Canadian Environmental Quality Guidelines				⑥
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Al, A2 or A3, depending on the (increasing) degree of treatment.

② Practically no problems with the clogging of drip irrigation emitters.

③ Slight to moderate problems with the clogging of drip irrigation emitters.

④ Increasingly severe problems with the clogging of drip irrigation emitters.

⑤ The TWQR for TSS in aquatic ecosystems are as follows:

Background TSS concentrations in all aquatic ecosystem are < 100 mg/l.

Target Water Quality Range

Any increase in TSS concentrations must be limited to < 10 % of the background TSS concentrations at a specific site and time.

⑥ The CCME guidelines are as follows:

clear flow

Maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d).

high flow

Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is ≥ 250 mg/L.

SULPHATE

Units Used for Analytical Results: mg/l SO_4
Normal Method(s) of Analysis: Turbidimetric (Barium Sulphate).
Occurrence/Origin: Rocks, geological formations, discharge and so on.
Health/Sanitary Significance: Excess sulphate has a laxative effect, especially in combination with magnesium and/or sodium.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<200	May be extended up to 400 provided Mg does not exceed 30	①
	CPCB, Class A		<400		
	CPCB, Class C		<400		
	WHO, 2008				②
	EU Drinking Water Directive [98/83/EC]		250		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 200 (TWQR)**	Target water quality range	③
			200 - 400		④
			400 - 600		⑤
			600 - 1 000		⑥
			> 1 000		⑦
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	N.A.		
		Public Sewers	N.A.		
		Marine Coastal Areas	N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	200		⑧
		A-2	200		
		A-3	200		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		<1000		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing,	CPCB, Class B		N.A.		
	EU Bathing Water Directive		N.A.		

Recreational Use	(76/160/EEC)				
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this causes gastro intestinal irritation when magnesium or sodium are present.

② No health-based guideline is proposed for sulfate. However, because of the gastrointestinal effects resulting from ingestion of drinking-water containing higher than 500 mg/l sulfate, the health authorities may be notified of source of water.

③ No health or aesthetic effects are experienced.

④ Tendency to develop diarrhoea in sensitive and some non-adapted individuals. Slight taste noticeable.

⑤ Diarrhoea in most non-adapted individuals. Definite salty or bitter taste.

⑥ Diarrhoea in most individuals. User-adaptation does not occur. Pronounced salty or bitter taste.

⑦ Diarrhoea in all individuals. User-adaptation does not occur. Very strong salty and bitter taste.

⑧ Al, A2 or A3, depending on the (increasing) degree of treatment.

ALKALINITY

Units Used for Analytical Results: mg/l $CaCO_3$

Normal Method(s) of Analysis: Titration with Sulphuric Acid.

Occurrence/Origin: The alkalinity of a natural water is generally due to the presence of bicarbonates formed in reactions in the soils through which the water percolates. It is a measure of the capacity of the water to neutralise acids and it reflects its so-called buffer capacity (its inherent resistance to pH change). A poorly-buffered water will have a low or very low alkalinity and will be susceptible to pH reduction by, for example, "acid rain." At times, however, river alkalinity values of up to 400 mg/l $CaCO_3$ may be found; they are without significance in the context of the quality of the water.

Health/Sanitary Significance: There is little known sanitary significance attaching to alkalinity (even up to 400 mg/l CaCO3), though unpalatability may result in highly alkaline waters.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<200	Permissible limit 600	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		②
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this limit taste becomes unpleasent.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

TOTAL DISSOLVED SOLIDS

Units Used for Analytical Results: mg/l solids (Dried at stated temperature).
Normal Method(s) of Analysis: Gravimetric (Dried at stated temperature after filtration).
Occurrence/Origin: Natural or added solutes present in a water.
Health/Sanitary Significance: Principally organoleptic implications.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		500	Permissible limit is 2000	①
	CPCB, Class A		500		
	CPCB, Class C		1500		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 450 (TWQR)**	Target water quality range	Table:1
			450 - 1 000		
			1 000 - 2 000		
			2 000 - 3 000		
			> 3 000		
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		②
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		2100		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		500-3500		③
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines				④
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this palatability decreases and may cause gastro intestinal irritation.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table-1: Effects of TDS on Human Health, Aesthetics, Household Distribution Systems and Water Heating Appliances

TDS Range (mg/L)	Aesthetic/Economic Effects	Health Effects
Target Water Quality Range 0 - 450	**The taste threshold for dissolved salts in water is in the region of 45 mS/m (300 mg/L TDS), hence a slight salty taste may be detected above this concentration. The threshold varies according to the salt composition.**	**No health effects associated with the electrical conductivity of water are expected < 45 mS/m (300 mg/L TDS)**
	Water with extremely low TDS concentrations may be objectionable because of its flat, insipid taste. No effects on plumbing or appliances	***The upper limit of this range takes into account the higher water consumption which may be expected in hot climates***
450 - 1 000	Water has a noticeable salty taste, but is well tolerated. No effects on plumbing or appliances	No health effects are likely
1 000 - 2 000	Water has a marked, salty taste and would probably not be used on aesthetic grounds if alternative supplies are available Some effects on plumbing and appliances, such as increased corrosion or scaling, may be expected	Consumption of water does not appear to produce adverse health effects in the short term
2 000 - 3 000	Water tastes extremely salty Corrosion and/or scaling of pipes and appliances will increase	Short-term consumption may be tolerated, but with probable disturbance of the body's salt balance
> 3 000	Water tastes extremely salty and bitter. Effects such as corrosion and/or scaling increase	Short-term consumption leads to disturbance of the body's salt balance. At high concentrations, noticeable short-term health effects can be expected

③ Canadian Water Quality Guidelines (CCREM 1987) of TDS for Irrigation:

- 500 mg/L for strawberries, raspberries, beans, and carrots
- 500-800 mg/L for boysenberries, currants, blackberries, gooseberries, plums, grapes, apricots, peaches, pears, cherries, apples, onions, parsnips, radishes, peas, pumpkins, lettuce, peppers, muskmelons, sweet potatoes, sweet corn, potatoes, celery, cabbage, kohlrabi, cauliflower, cowpeas, broadbeans, flax, sunflowers, and corn.
- 800-1500 mg/L for spinach, cantaloupe, cucumbers, tomatoes, squash, brussels, sprouts, broccoli, turnips, smooth brome, alfalfa, big trefoil, beardless wildrye, vetch, timothy, and crested wheat grass
- 1500-2500 mg/L for beets, zucchini, rape, sorghum, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, reed canary grass, birdsfoot trefoil, perennial ryegrass
- 3500 mg/L for asparagus, soybeans, safflower, oats, rye, wheat, sugar beets, barley, barley hay, and tall wheat grass

④ The TWQR for TDS is stated in terms of case- and site-specific TDS concentrations. In all cases, local conditions should be determined (i.e. TDS concentrations, variability and seasonal changes) before water quality criteria are set.

<u>Target Water Quality Range</u>

TDS concentrations should not be changed by > 15 % from the normal cycles of the water body under unimpacted conditions at any time of the year; **and**

The amplitude and frequency of natural cycles in TDS concentrations should not be changed.

TOTAL HARDNESS

Units Used for Analytical Results: $mg/l\ CaCO_3$
Normal Method(s) of Analysis: Titration with EDTA.
Occurrence/Origin: Rock formations - limestone etc.
Health/Sanitary Significance: Hardness is a natural characteristic of water which can enhance its palatability and consumer acceptability for drinking purposes. Health studies in several countries in recent years indicate that mortality rates from heart diseases are lower in areas with hard water.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<300	Permissible limit 600	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines				②
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		③
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)			④
		(Cyprinid)			
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Encrustation in water supply structure and adverse effects on domestic use.

② Total hardness should be limited to between 50 - 100 mg/l as CaCO3 , where possible. It should however be noted that many USA cities allow for a final water total hardness value of up to 150 mg CaCO3 /l in order to limit sludge production and chemical costs of treatment.

③ A1, A2 or A3, depending on the (increasing) degree of treatment.

④ There are no limits for hardness as such in this Directive, but Annex II contains data on the relationship between hardness and the acceptable levels of dissolved copper and total zinc in salmonid and cyprinid waters.

TOTAL KJELDAHL NITROGEN

Units Used for Analytical Results: mg/l N

Normal Method(s) of Analysis: Colorimetric (Manual; Nessler's Reagent), Digestion, Distillation, Titrimetry.

Occurrence/Origin: Principally from organic matter naturally present (e.g. from peat, falling leaves etc.) or added in discharges.

Health/Sanitary Significance: No direct significance but parameter is an indication of the overall purity of a water.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<100		
		Public Sewers	N.A.		
		Marine Coastal Areas	<100		
	EU Surface Water Directive (75/440 EEC)	A-1	1		①
		A-2	2		
		A-3	3		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)				②
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① A1, A2 or A3, depending on the (increasing) degree of treatment.

② Sampling to be carried out "where an investigation …shows, or there are other grounds for believing, that there has been a deterioration in the quality of waters ... or, in the case of Nitrogen Kjeldahl..., that there is a tendency towards eutrophication."

TOTAL COLIFORM

Units Used for Analytical Results: Number of organisms/100 ml sample.

Normal Method(s) of Analysis: Most Probable Number (MPN: Multiple Tube Method).

Occurrence/Origin: Faecal coliforms originate in human and animal waste. Total coliforms include faecal and also other bacteria with similar properties which originate in soil and are nonfaecal.

Health/Sanitary Significance: Indicators of possible presence of pathogenic micro-organisms.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<10		①
	CPCB, Class A		50		②
	CPCB, Class C		5000		②
	WHO, 2008		0		
	EU Drinking Water Directive [98/83/EC]		0		
	Vietnam WQ Standard, Level 1		2500		
	South African WQ Guidelines		**0-5 (TWQR)**	Target water quality range	③
			5-100		④
			>100		⑤
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	5000		⑥
		A-2	25000		
		A-3	100000		
	Vietnam WQ Standard, Level 2		5000		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		7500		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		1000		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		5000		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		500		
	EU Bathing Water Directive (76/160/EEC)		<5000		⑦
			<10000		⑧
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Throughout the year, 95% of samples should not contain any coliform organisms in 100 ml, No sample should contain E. Coli in 100 ml, No sample should contain more than 10 Coliform organism per 100 ml, Coliform organisms should not be detectable in 100 ml of any 2 consecutive samples.

② If the coliform is found to be more than the prescribed tolerance limits, the criteria for coliform shall be satisfied if not more than 20 percent of samples show more than the tolerance limit specified, and not more than 5 percent of samples show values more than 4 times the tolerance limits. Further, the faecal coliform should not be more than 20 percent of the coliform.

③ Negligible risk of microbial infection.

④ Indicative of inadequate treatment, post treatment contamination or growth in the distribution system. Risk of infectious disease transmission with continuous exposure and a slight risk with occasional exposure.

⑤ Indicative of poor treatment, post treatment contamination or definite growth in the water distribution system. Significant and increasing risk of infectious disease transmission.

⑥ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑦ To be conformed with by 80% or more of samples and not to be exceeded by any two consecutive samples in any case.

⑧ To be conformed with by 95% or more of samples and not to be exceeded by any two consecutive samples in any case.

TOTAL PHOSPHORUS

Units Used for Analytical Results: mg/l P
Normal Method(s) of Analysis: Digestion, followed by determination of the resultant orthophosphate.
Occurrence/Origin: Natural or added organic matter (wastes, vegetation etc.)
Health/Sanitary Significance: Indirect - indicates overall water quality.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		0.1	Orthophosphate (as P)	
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<5	Dissolved P	
		Public Sewers	N.A.		
		Marine Coastal Areas	N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		①
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		0.2	Orthophosphate (as P)	
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.3	Orthophosphate (as P)	
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)			②
		(Cyprinid)			
	Vietnam WQ Standard, Level 2		0.2	Orthophosphate (as P)	
	South African WQ Guidelines				Table:1
	Canadian Environmental Quality Guidelines				③
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① A1, A2 or A3, depending on the (increasing) degree of treatment.

② In the cases other than lakes, limit values of 0.2 mg/l for salmonid and of 0.4 mg/l for cyprinid waters, expressed PO_4 [corresponding to 0.062 and 0.124 mg/l as P, respectively], may be regarded as indicative in order to reduce eutrophication".

③ Canadian Guidance Framework for Phosphorus provides Trigger Ranges for Total Phosphorus (µg/L):

- ultra-oligotrophic <4
- oligotrophic 4-10
- mesotrophic 10-20
- meso-eutrophic 20-35
- eutrophic 35-100
- hyper-eutrophic >100

Table-1: The Criteria for the Inorganic Phosphorus concentration are as follows:

Average Summer Inorganic Phosphorus Concentration (µg/l)	**Effects**	**Target Water Quality Range**
< 5	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or blue-green algae.	● Inorganic phosphorus concentrations should not be changed by > 15 % from that of the water body under local, unimpacted conditions at any time of the year; **and** ● The trophic status of the water body should not increase above its present level, though a *decrease* in trophic status is permissible; **and** ● The amplitude and frequency of natural cycles in inorganic phosphorus concentrations should not be changed.
5-25	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.	
25 - 250	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, with nuisance growth of aquatic plants and blooms of bluegreen algae; algal blooms may include species which are toxic to man, livestock and wildlife.	
> 250	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.	

Note: The inorganic phosphorus concentration for a specific system must be based on the existing trophic status of the system. It is undesirable to allow inorganic phosphorus concentrations to rise to a level which will change the trophic status of the system. A Target Water Quality Range should be derived only after case- or site-specific studies.

TURBIDITY

Units Used for Analytical Results: Jackson Turbidity Unit [JTU]; Nephelometric Turbidity Units [NTU]
Normal Method(s) of Analysis: Turbidimeter or Nephelometer.
Occurrence/Origin: Clay particles, sewage solids, silt and sand washings, organic and biological sludges etc.

Health/Sanitary Significance: Direct health effects depend on the precise composition of the turbidity-causing materials, but there are other implications, as discussed below.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<5		①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]			Acceptable to consumers and no abnormal change	②
	Vietnam WQ Standard, Level 1		5		
	South African WQ Guidelines		**0 - 1 (TWQR)**	Target water quality range	③
			1-5		④
			5-10		⑤
			> 10		⑥
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		⑦
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		20		
Irrigation	CPCB, Class E		N.A.		
	Vietnam WQ Standard, Level 3		30		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		20		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines				⑧
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Above 5 consumer acceptance decreases.

② In the case of surface water treatment, Member States should strive for a parametric value not exceeding 1.0 NTU (nephelometric turbidity units) in the water ex treatment works.

③ ***No turbidity visible. No adverse aesthetic effects regarding appearance, taste or odour and no significant risks of associated transmission of infectious micro-organisms. No adverse health effects due to suspended matter expected.***

④ No turbidity visible. A slight chance of adverse aesthetic effects and infectious disease transmission exists.

⑤ Turbidity is visible and may be objectionable to users at levels above 5 NTU. Some chance of transmission of disease by micro-organisms associated with particulate matter, particularly for agents with a low infective dose such as viruses and protozoan parasites.

⑥ Severe aesthetic effects (appearance, taste and odour). Water carries an associated risk of disease due to infectious disease agents and chemicals adsorbed onto particulate matter. A chance of disease transmission at epidemic level exists at high turbidity.

⑦ A1, A2 or A3, depending on the (increasing) degree of treatment.

⑧ Canadian Environmental Quality Guidelines for Turbidity are as follows:

clear flow

Maximum increase of 8 NTUs from background levels for a short-term exposure (e.g., 24-h period). Maximum average increase of 2 NTUs from background levels for a longer term exposure (e.g., 30-d period).

high flow or turbid waters

Maximum increase of 8 NTUs from background levels at any one time when background levels are between 8 and 80 NTUs. Should not increase more than 10% of background levels when background is > 80 NTUs.

WATER TEMPERATURE

Units Used for Analytical Results: Degrees Celsius [°C].
Normal Method(s) of Analysis: Measurement in the field with Thermometer.
Occurrence/Origin: Generally climatologically influenced (in the absence of thermal discharges).
Health/Sanitary Significance: None.

WATER USE	STANDARD		Desirable Limit	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.	
	CPCB, Class A		N.A.	
	CPCB, Class C		N.A.	
	WHO, 2008		N.A.	
	EU Drinking Water Directive [98/83/EC]		N.A.	
	Vietnam WQ Standard, Level 1		N.A.	
	South African WQ Guidelines		N.A.	
Surface Water	CPCB (Schedule-VI)	Inland Surface Water		①
		Public Sewers	N.A.	
		Marine Coastal Areas		①
	EU Surface Water Directive (75/440 EEC)	A-1	25	②
		A-2	25	
		A-3	25	
	Vietnam WQ Standard, Level 2		N.A.	
Irrigation	CPCB, Class E		N.A.	
	CPCB (Schedule-VI)	Land for Irrigation	N.A.	
	Vietnam WQ Standard, Level 3		N.A.	
	South African WQ Guidelines		N.A.	
	Canadian Environmental Quality Guidelines		N.A.	
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.	
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)		③, ④
		(Cyprinid)		③, ④
	Vietnam WQ Standard, Level 2		N.A.	
	South African WQ Guidelines			⑤
	Canadian Environmental Quality Guidelines		N.A.	
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.	
	EU Bathing Water Directive		N.A.	

	(76/160/EEC)			
	South African WQ Guidelines		N.A.	

N.A. = Not Available

① Shall not exceed 5 °C above the receiving water temperature.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

③ Temperature measured downstream of a point of thermal discharge [at the edge of the mixing zone] must not exceed the unaffected temperature by more than 1.5°C in salmonid waters and 3.0 °C in cyprinid waters. "Derogations limited in geographical scope may be decided by Member States in particular conditions if the competent authority can prove that there are no harmful consequences for the balanced development of the fish population."

④ Thermal discharges must not cause the temperature downstream of the point of thermal discharge [at the edge of the mixing zone] to exceed the following: 21.5°C/10°C in salmonid waters and 28°C/10°C in cyprinid waters.

⑤ Water temperature should not be allowed to vary from the background average daily water temperature considered to be normal for that specific site and time of day, by > 2 EC, or by > 10 %, whichever estimate is the more conservative. The TWQR for water temperature should be stated in terms of the case- and site-specific "natural" temperature regime. In all cases, local conditions should be determined (including diel and seasonal variability) before a water quality objective for an aquatic ecosystem is set. The 90th and 10th percentile values should be used to establish the "natural" temperature range.

SODIUM

Units Used for Analytical Results: mg/l Na

Normal Method(s) of Analysis: Flame Photometry ; Atomic Absorption Spectrometry.

Occurrence/Origin: Abundant constituent of rocks and soils.

Health/Sanitary Significance: Causes hypertension if taken in excess.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008				①
	EU Drinking Water Directive [98/83/EC]		200		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		**0 - 100 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)		N.A.		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		②
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.	Sodium Absorption Ratio (26)	
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		**≤ 70 (TWQR)**		Table:2
				Sodium Absorption Ratio (2.0)	Table:3
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① No health based guideline value is proposed. However, concentrations in excess of 200 mg/litre may give rise to unacceptable taste.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Sodium on Aesthetics and Human Health

Sodium Range (mg/L)	Effects
Target Water Quality Range 0 - 100	***No aesthetic or health effects***
100 - 200	Faintly salty taste. ***Threshold for taste. No health effects.***
200 - 400	Slightly salty taste. Undesirable for persons on a sodium restricted diet
400 - 600	Distinctly salty taste. No health effects in healthy adults with short-term use. Undesirable for infants or persons on a sodium-restricted diet
600 - 1 000	Very salty taste. Health effects may be expected. Very undesirable for infants or persons on a sodium-restricted diet.
1 000 - 5 000	Highly salty taste. Likelihood of nausea and vomiting. Highly undesirable for infants or persons on a sodium- restricted diet.
> 5 000	Extremely salty taste becoming bitter. Severe health effects with disturbance of electrolyte balance. Extremely undesirable for infants or persons on a sodium-restricted diet.

Table 2: Effects of Sodium on Foliar Crop Yield and Quality

Concentration Range *(mg/L)*	Crop Yield and Quality
Target Water Quality Range ≤ 70	***Should prevent the accumulation of sodium to toxic levels in all but the most sensitive plants, even when crop foliage is wet***
70 - 115	Crops sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decrease
115 - 230	Crops moderately sensitive to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases
230 - 460	Crops moderately tolerant to foliar absorption accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases
> 460	Crops tolerant to foliar absorption increasingly accumulate toxic levels of sodium when crop foliage is wetted. They display symptoms of foliar injury and yield decreases

Table 3: Effects of the SAR on Crop Yield and Quality

SAR Range	Crop Yield and Quality
Target Water Quality Range ≤ 2.0	***Should prevent sodium toxicity from developing in plants sensitive to sodium, provided that irrigation water is applied to the soil surface (that is, crop foliage is not wetted), limiting sodium uptake to that through the roots***
2.0 - 8.0	The most sodium-sensitive crops absorb toxic levels of sodium through roots (that is, crop foliage is not wetted). Crops vary in sensitivity
8.0 - 15.0	Sodium-sensitive crops absorb toxic concentrations of sodium through roots (that is, if crop foliage is not wetted). Crops vary in sensitivity
> 15.0	All sodium-sensitive crops absorb toxic levels of sodium through root uptake (that is, crop foliage is not wetted). Crops that are more tolerant of sodium increasingly absorb toxic concentrations of sodium through root uptake. A number of economically important crops can be irrigated without developing sodium toxicity

ARSENIC

Units Used for Analytical Results: mg/l As

Normal Method(s) of Analysis: Atomic Absorption Spectrometry.

Occurrence/Origin:

This element is very widely distributed throughout the earth's crust, according to the WHO Guidelines, which state that "it is introduced into water through the dissolution of minerals and ores, from industrial effluents, and from atmospheric deposition: concentrations in ground water in some areas are sometimes elevated as a result of erosion from natural sources. The average daily intake of inorganic arsenic in water is estimated to be similar to that from food; intake from air is negligible." Arsenic is used in the glass and semiconductor industries and as a fungicide in timber processing. A major US emission source is coal-fired power plant.

Health/Sanitary Significance: Very toxic to humans, some arsenical compounds are carcinogens, hence much of the concern regarding them, but there are a variety of other effects on health. The WHO states that inorganic arsenic is a documented human carcinogen, and that a relatively high incidence of skin and possibly other cancers that increase with dose and age has been observed in populations ingesting water containing high concentrations of arsenic.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.01		①
	CPCB, Class A		<0.05		
	CPCB, Class C		<0.2		
	WHO, 2008		0.01		②
	EU Drinking Water Directive [98/83/EC]		0.01		
	Vietnam WQ Standard, Level 1		0.01		
	South African WQ Guidelines		0 - 0.01 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<0.2		
		Public Sewers	<0.2		
		Marine Coastal Areas	<0.2		
	EU Surface Water Directive (75/440 EEC)	A-1	0.05		③
		A-2	0.05		
		A-3	0.1		
	Vietnam WQ Standard, Level 2		0.02		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	<0.2		
	Vietnam WQ Standard, Level 3		0.05		
	South African WQ Guidelines		≤ 0.1 (TWQR)		Table:2
	Canadian Environmental Quality Guidelines		0.1		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.02		
	South African WQ Guidelines		≤ 0.01 (TWQR)		Table:3
	Canadian Environmental Quality Guidelines		0.005		

Outdoor Bathing, Recreational Use	CPCB, Class B		<0.2		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this, the water becomes toxic.
② The guideline value is designated as provisional in view of the scientific uncertainties.
③ A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Arsenic on Human Health

Arsenic Range (µg/L)	Effects
Target Water Quality Range 0 - 10	***No health effects expected; ideal concentration range***
10 - 200	Tolerable concentration, but low risk of skin cancer in highly sensitive individuals over long term
200 - 300	Increasing possibility of mild skin lesions over long term. Slight possibility of induction of skin cancer over long term.
300 - 600	Possible adverse, chronic effects in sensitive individuals; brief exposure has no effect; skin lesions, including hyperpigmentation, will begin to appear on long-term exposure
600 - 1 000	Symptoms of chronic poisoning such as skin lesions, including hyperpigmentation, will appear on long-term exposure
1 000 - 10 000	Cancer or death will result from chronic poisoning
> 10 000	Death will result from acute poisoning

Note: It is recommended that the concentration of arsenic in potable water should never exceed 200 µg/L, but ideally should not exceed the TWQR.

Table 2: Effects of Arsenic on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield	Crop Quality
Target Water Quality Range ≤ 0.1	Depending on plant species, nutrient solutions containing 0.5 - 10 mg/L can induce arsenic toxicity. Only a fraction of the total arsenic in soil is available to plants	Yield reduction and crop failure are the main effects of arsenic contaminated soils. Generally arsenic does not accumulate in edible parts of plants to levels that are dangerous to consumers (root crops such as potatoes and radishes have been shown to concentrate arsenic)
0.10 - 2.0	Maximum concentration acceptable for fine textured neutral to alkaline soils	
> 2.0	Acceptable for irrigation only over the short term on a site-specific basis	

Table 3: The TWQR and criteria for the total Arsenic concentration in aquatic ecosystems are:

TWQR and Criteria	Arsenic concentration (µg/L)
Target Water Quality Range (TWQR)	**≤ 10**
Chronic Effect Value (CEV)	20
Acute Effect Value (AEV)	130

CADMIUM

Units Used for Analytical Results: mg/l Cd

Normal Method(s) of Analysis: Atomic Absorption Spectrometry.

Occurrence/Origin: In ores, including those of zinc. Cadmium in water is due nearly exclusively to industrial discharges (e.g. from electroplating, paint-making, manufacture of plastics etc) and landfill leachates.

Health/Sanitary Significance: Very highly toxic, hence severe restrictions on its concentrations in waters.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.01		①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.003		
	EU Drinking Water Directive [98/83/EC]		0.005		
	Vietnam WQ Standard, Level 1		0.005		
	South African WQ Guidelines		0 - 0.005 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<2		
		Public Sewers	<1		
		Marine Coastal Areas	<2		
	EU Surface Water Directive (75/440 EEC)	A-1	0.005		②
		A-2	0.005		
		A-3	0.005		
	Vietnam WQ Standard, Level 2		0.005		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.01		
	South African WQ Guidelines		≤0.01 (TWQR)		Table:2
	Canadian Environmental Quality Guidelines		0.0051		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.005		
	South African WQ Guidelines				Table:3
	Canadian Environmental Quality Guidelines			Equation	③
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this, the water becomes toxic.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Cadmium on Human Health

Cadmium Range (µg/L)	Effects
Target Water Quality Range 0 - 5	***No observable health effects***
As a precautionary measure, it is recommended that the TWQR not be exceeded because of the potentially acute and/or irreversible effects of cadmium on human health	
5 - 10	No observable health effects, unless zinc nutritional status is suboptimal, or in smokers, where there is a slight risk of subclinical effects on long-term exposure
10 - 20	Threshold for health damage with continuous exposure. Single incidence of exposure will not have observable effects
20 - 1 000	Danger of kidney damage with long-term exposure. Brief exposure, for less than one week should not cause any noticeable damage. Exposure should not exceed one week
> 1 000	Danger of acute cadmium poisoning, with the possibility of fatalities

Note:
In the environment, cadmium occurs in association with zinc, in a zinc to cadmium ratio of approximately 300:1. This association is attributed to the chemical similarity between the two metals and provides a guide for calculating the tolerable cadmium intake. The daily requirement for zinc is approximately 15 mg/day, and hence the tolerable concentration of cadmium is calculated to be approximately 50 µg/day. Similar values are reported by the WHO, 1993, which are based on the "safe" level of cadmium in the renal cortex. This should not exceed 50 mg/kg, to give a tolerable daily cadmium intake of not more than 1 µg/kg (BW)/day. This gives a tolerable cadmium intake of not more than 70 µg/day for a 70 kg human. The criteria are based on the assumption that not more than 20 % of the total dietary intake of cadmium is from water. Intake via smoking was not taken into account for the calculation of the above criteria.

Table 2: Effects of Cadmium on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Quality
Target Water Quality Range ≤ 0.01	***Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/L in nutrient solutions. Conservative limits are needed because of cadmium's potential for accumulation in plants and soils to concentrations that may be toxic to humans and animals***
0.01 - 0.05	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 0.05	Acceptable for irrigation only over the short term on a site specific basis

Table 3: The TWQR and criteria for total Cadmium at different water hardness (mg $CaCO_3$ /L) in aquatic ecosystems are:

TWQR and Criteria	Cadmium concentration (µg/L)			
	< 60 (Soft)	60-119 (Medium)	120-180 (Hard)	> 180 (Very hard)
Target Water Quality Range (TWQR)	***≤ 0.15***	***≤ 0.25***	***≤ 0.35***	***≤ 0.40***
Chronic Effect Value (CEV)	0.3	0.5	0.7	0.8
Acute Effect Value	3	6	10	13

③ *Cadmium concentration =* $10^{0.86[\log10(hardness)]-3.2}$ *µg/L*

CHROMIUM

Units Used for Analytical Results: mg/l Cr

Normal Method(s) of Analysis: Atomic Absorption Spectrometry.

Occurrence/Origin: Natural occurrence is in ore, but chromium arises in surface waters from discharges from electroplating, tanning, textile, paint and dyeing plants.

Health/Sanitary Significance: Chromium is toxic, to a degree which varies with the form in which it occurs, whether as the trivalent CrIII or the hexavalent CrVI form. The latter is considered the more hazardous but because it is difficult to distinguish by analysis the figures quoted below refer mainly to the total chromium concentrations.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.05	hexavalent	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.05	total	
	EU Drinking Water Directive [98/83/EC]		0.05	total	
	Vietnam WQ Standard, Level 1		0.01	hexavalent	
	South African WQ Guidelines		0 - 0.05 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<0.1	hexavalent	
		Public Sewers	<2.0	hexavalent	
		Marine Coastal Areas	<1.0	hexavalent	
	EU Surface Water Directive (75/440 EEC)	A-1	0.05	total	②
		A-2	0.05		
		A-3	0.05		
	Vietnam WQ Standard, Level 2		0.02	hexavalent	
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.04	hexavalent	
	South African WQ Guidelines		≤ 0.1 (TWQR)		Table:2
	Canadian Environmental Quality Guidelines		0.008	hexavalent	
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.02	hexavalent	
	South African WQ Guidelines		< 0.007 (TWQR)		Table:3
	Canadian Environmental Quality Guidelines		0.001	hexavalent	
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① May be carcinogenic above this limit.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Chromium(VI) on Human Health

Chromium(VI) Range (mg/L)	Effects
Target Water Quality Range ***0 - 0.050***	***Risk of cancer induction insignificant*** ***No toxic or aesthetic effects***
As a precautionary measure it is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of chromium(VI) on human health	
0.05 - 1.0	Possible risk of induction of gastrointestinal cancer following long-term exposure
1.0 - 5.0	Undesirable taste, slight nausea, and increasing risk of cancer induction
> 5.0	Risk of acute toxicity

Table 2: Effects of Chromium(VI) on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Soil Sustainability
Target Water Quality Range ***≤ 0.10***	***Depending on plant species, nutrient solutions containing 0.1 mg/L can induce chromium toxicity***
0.10 - 1.0	Maximum acceptable concentration for fine-textured neutral to alkaline soils
> 1.0	Acceptable for irrigation only over the short term on a site specific basis

Table 3: The TWQR and criteria for dissolved Chromium(VI) in aquatic ecosystems are:

TWQR and Criteria	Chromium(VI) concentration (μg/L)
Target Water Quality Range (TWQR)	*≤ 7*
Chronic Effect Value (CEV)	14
Acute Effect Value (AEV)	200

COPPER

Units Used for Analytical Results:	mg/l Cu
Normal Method(s) of Analysis:	Atomic Absorption Spectrometry.
Occurrence/Origin:	Ores; industrial wastes.
Health/Sanitary Significance:	Copper is not particularly toxic to humans (indeed, it is an essential dietary requirement) and medicinal doses up to 20 mg/l are not unknown. However, astringent tastes in water can be caused by levels above 1 mg/l Cu.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.05	Permissible limit 1.5	①
	CPCB, Class A		<1.5		
	CPCB, Class C		<1.5		
	WHO, 2008		2		
	EU Drinking Water Directive [98/83/EC]		2		
	Vietnam WQ Standard, Level 1		0.1		
	South African WQ Guidelines		**0 - 1 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<3		
		Public Sewers	<3		
		Marine Coastal Areas	<3		
	EU Surface Water Directive (75/440 EEC)	A-1	0.05		②
		A-2	0.1		
		A-3	1		
	Vietnam WQ Standard, Level 2		0.2		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.5		
	South African WQ Guidelines		**≤ 0.2 (TWQR)**		Table:2
	Canadian Environmental Quality Guidelines		0.2	for cereals	
			1	for tolerant crops	
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	<0.04		③
		(Cyprinid)	<0.04		
	Vietnam WQ Standard, Level 2		0.2		
	South African WQ Guidelines				Table:3
	Canadian Environmental Quality Guidelines			Equation	④
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Astringent taste, discoloration and corrosion of pipes, fittings and utensils will be caused beyond this limit.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Copper on Aesthetics and Human Health

Copper Range (mg/L)	Effects
Target Water Quality Range 0 - 1	***No health or aesthetic effects***
1 - 3	No health effects. Astringent taste and staining of laundry and plumbing fixtures start appearing
3 - 30	No health effects. Severe taste and staining problems
30 - 200	Gastrointestinal irritation, nausea and vomiting. Severe taste and staining problems
> 200	Severe poisoning with possible fatalities. Severe taste and staining problems
Note: It is recommended that the concentration of copper in potable water should not exceed 30 mg/l, as this is the threshold for acute poisoning with nausea and vomiting.	

Table 2: Effects of Copper on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield	Crop Quality
Target Water Quality Range ≤ 0.2	***Depending on plant species, nutrient solutions containing 0.1 - 1.0 mg/L can induce copper toxicity***	***Yield reduction and crop failure are the main effects of copper-contaminated soils*** ***Generally copper does not accumulate in edible parts of plants to levels that are dangerous to consumers (root crops such as potatoes and radishes have been shown to concentrate copper)***
0.2 - 5.0	Maximum acceptable as concentration for fine textured neutral to alkaline soils	
> 5.0	Acceptable for irrigation only over the short term on a site specific basis	

③ Parameter is "Dissolved copper." The G values given are with reference to a hardness value of 100 mg/$CaCO_3$. Relevant values for other hardness levels are as follows:

Hardness	10	50	100	500	mg/ CaCO3
Copper (S)	0.005	0.022	0.04	0.112	mg/l Cu
(C)	0.005	0.022	0.04	0.112	mg/l Cu

Table 3: The TWQR and criteria for dissolved Copper at different water hardness (mg $CaCO_3$ /L) in 3 aquatic ecosystems are:

TWQR and Criteria	Copper concentration (µg/L)			
	< 60(Soft)	60-119 (Medium)	120-180 (Hard)	> 180 (Very hard)
Target Water Quality Range	***≤ 0.3***	***≤ 0.8***	***≤ 1.2***	***≤ 1.4***
Chronic Effect Value (CEV)	0.53	1.5	2.4	2.8
Acute Effect Value (AEV)	1.6	4.6	7.5	12

④ The CWQG is a minimum of 2 µg/L regardless of water hardness

$$\text{Copper concetration} = e^{0.8545[\ln(\text{hardness})]-1.465} * 0.2\ \mu g/L$$

MERCURY

Units Used for Analytical Results: mg/l Hg
Normal Method(s) of Analysis: Atomic Absorption Spectrometry; or ICP [inductively-coupled plasma] Spectroscopy.
Occurrence/Origin: Normally from industrial waste discharges.
Health/Sanitary Significance: Very toxic, especially in organo-mercury compounds (e.g. methyl-mercury).

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.001		①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.006		
	EU Drinking Water Directive [98/83/EC]		0.001		
	Vietnam WQ Standard, Level 1		0.001		
	South African WQ Guidelines		0 - 0.001 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<0.01		
		Public Sewers	<0.01		
		Marine Coastal Areas	<0.01		
	EU Surface Water Directive (75/440 EEC)	A-1	0.001		②
		A-2	0.001		
		A-3	0.001		
	Vietnam WQ Standard, Level 2		0.001		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.001		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.001		
	South African WQ Guidelines				Table:2
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this, the water becomes toxic.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Mercury on Human Health

Mercury Range (µg/L)	Effects
Target Water Quality Range (0 - 1)	***No health effects expected***
It is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of mercury on human health	
1 - 5	At two µg/L water provides up to 13 % of the safe daily intake, and at five µg/L water provides 33 % of the safe daily intake. Risk to the general population is unlikely A very slight risk of neurotoxicity due to organic mercury may exist for sensitive individuals at the upper limit of this range
5 - 20	Brief, episodic exposure unlikely to have adverse effects Some risk of chronic neurotoxic effects due to organically complexed mercury
20 - 50	Risk of neurotoxicity with consequent serious disabilities with continuous exposure
50 - 1 000	Risk of neurotoxicity with continuous exposure, particularly to organic mercury compounds. Acute effects may occur, particularly with organic mercury compounds
1 000 - 10 000	Chronic effects; acute poisoning with damage to the nervous system and brain may occur with single exposure, and definitely with continuous exposure
> 100 000	Acute poisoning; permanent brain damage and/or death is possible

Table 2: The TWQR and criteria for total Mercury in aquatic ecosystems:

TWQR and Criteria	Mercury concentration (µg/L)
Target Water Quality Range (TWQR)	$\leq$ ***0.04***
Chronic Effect Value (CEV)	0.08
Acute Effect Value (AEV)	1.7

Note:

- The South African criteria for mercury have been derived on the assumption that a maximum of 10 % of the total mercury in a water sample is present as methyl mercury.
- This assumption is justified for all well-aerated waters where reducing conditions, which favour the occurrence of methyl mercury, are absent. However, in poorly-aerated waters, a greater proportion of the total mercury will be present as methyl mercury;
- The data available **did not** satisfy the minimum chronic database requirement. A safety factor of 6 was used for the derivation of the CEV; and
- The effects of both inorganic and organic compounds were treated as being linearly related to their respective concentrations as well as being additive.

IRON

Units Used for Analytical Results: mg/l Fe

Normal Method(s) of Analysis: Colorimetric (o-Phenanthroline); Atomic Absorption Spectrometry.

Occurrence/Origin: Geological formations (especially under reducing conditions); acid drainage; effluent discharges.

Health/Sanitary Significance: The objections to iron are primarily organoleptic, but there has been recent medical concern about high levels in drinking water.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.3	Permissible limit 1	①
	CPCB, Class A		<0.3		
	CPCB, Class C		<50		
	WHO, 2008		N.A.		
	EU Drinking Water Directive [98/83/EC]		0.2		
	Vietnam WQ Standard, Level 1		0.5	Total iron	
	South African WQ Guidelines		**0 - 0.1 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<3		
		Public Sewers	<3		
		Marine Coastal Areas	<3		
	EU Surface Water Directive (75/440 EEC)	A-1	0.2		②
		A-2	2		
		A-3	2		
	Vietnam WQ Standard, Level 2		1	Total iron	
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		1.5	Total iron	
	South African WQ Guidelines		**≤5 (TWQR)**		Table:2
			≤0.2 (TWQR)		Table:3
	Canadian Environmental Quality Guidelines		5		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		1	Total iron	
	South African WQ Guidelines				Table:4
	Canadian Environmental Quality Guidelines		0.3		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures and promotes iron bacteria.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Iron on Aesthetics, Human Health and Household Distribution Systems

Iron Range (mg/L)	Effects
Water Quality Target Range 0 - 0.1	***No taste, other aesthetic or health effects associated with consumption and use***
0.1 - 0.3	Very slight effects on taste and marginal other aesthetic effects Deposits in plumbing with associated problems may begin to occur. No health effects; the water is generally well tolerated
0.3 - 1.0	Adverse aesthetic effects (taste) gradually increase as do possible problems with plumbing. No health effects
1.0 - 10	Pronounced aesthetic effects (taste) along with problems with plumbing. Slight health effects expected in young children, and sensitive individuals
10 - 30	Severe aesthetic effects (taste) and effects on the plumbing (slimy coatings). Slight iron overload possible in some individuals. Chronic health effects in young children and sensitive individuals in the range 10 - 20 mg/L, and occasional acute effects toward the upper end of this range
30 - 100	As above
	Long-term health effects gradually increase
100 - 300	As above
	Chronic health effects. Acute toxicity may begin to appear
300 - 3 000	As above
	Chronic and acute health effects. Accidental iron poisoning from water is rare
3 000 - 30 000	As above
	Lethal toxicity occurs

Table 2: Effects of Iron on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Quality
Target Water Quality Range ≤ 5.0	***Not toxic to root uptake by plants in aerated soils. Plant foliage damaged or blemished by iron deposits when wetted during irrigation***
5.0 - 20.0	Maximum acceptable as concentration for fine textured neutral to alkaline soils
> 20.0	Exceeds the maximum acceptable concentration used by most international guidelines

Table 3: Effects of Iron on Water Uses involving Irrigation Equipment

Concentration Range (mg/L)	Clogging of Irrigation Equipment
< 0.2	Only minor problems encountered with clogging of drip irrigation systems
0.2 - 1.5	Moderate problems encountered with clogging of drip irrigation systems
> 1.5	Severe problems encountered with clogging of drip irrigation systems

Table 4: The TWQR for Iron in aquatic ecosystems

Target Water Quality Range (TWQR)
The iron concentration should not be allowed to vary by more than 10 % of the background dissolved iron concentration for a particular site or case, at a specific time.

MANGANESE

Units Used for Analytical Results: mg/l Mn
Normal Method(s) of Analysis: Colorimetric (Persulphate); Atomic Absorption Spectrometry.
Occurrence/Origin: Widely distributed constituent of ores and rocks.
Health/Sanitary Significance: No particular toxicological connotations; the objections to manganese - like iron - are aesthetic.

WATER USE	STANDARDS		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.1	Permissible limit 0.3	①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.4		
	EU Drinking Water Directive [98/83/EC]		0.05		
	Vietnam WQ Standard, Level 1		0.1		
	South African WQ Guidelines		**0 - 0.05 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<2		
		Public Sewers	<2		
		Marine Coastal Areas	<2		
	EU Surface Water Directive (75/440 EEC)	A-1	0.05		②
		A-2	0.3		
		A-3	1		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.8		
	South African WQ Guidelines		**≤0.02 (TWQR)**		Table:2
					Table:3
	Canadian Environmental Quality Guidelines		0.2		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines				Table:4
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures.

② A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Manganese on Aesthetics and Human Health

Manganese Range (mg/L)	Effects
Target Water Quality Range 0 - 0.05	***No health or aesthetic effects; marginal aesthetic problems occasionally found in the 0.02-0.05 mg/L range***
0.05 - 0.10	Tolerable range, although slight staining may occur. No health effects
0.10 - 0.15	Threshold for significant staining and taste problems. No health effects
0.15 - 1.0	Increasingly severe staining and taste problems. No health effects
1.0 - 2.0	Very severe staining and taste effects. No health effects
2.0 - 5.0	Extreme staining, likely to be aesthetically unacceptable to a large proportion of users. No health effects
5.0 - 14	Unacceptable levels of aesthetic effects. Health effects rare
14 - 20	Very severe, aesthetically unacceptable staining. Domestic use unlikely due to adverse aesthetic effects. Some chance of manganese toxicity under unusual conditions
> 20	Domestic use unlikely due to extreme aesthetic effects. Chronic toxicity; at high concentrations, possible acute effects

Table 2: Effects of Manganese on Crop Yield and Soil Sustainability

Concentration Range (mg/L)	Crop Yield and Soil Sustainability
Target Water Quality Range ≤0.02	***Depending on plant species, nutrient solutions containing a few tenths of a mg/L can induce manganese toxicity***
0.02 - 10.0	Maximum acceptable concentration for fine-textured neutral to alkaline soils
> 10.0	Acceptable for irrigation only over the short term on a site specific basis

Table 3: Effects of Manganese on Water Uses involving Irrigation Equipment

Concentration Range (mg/L)	Clogging of Irrigation Equipment
< 0.1	Only minor problems encountered with clogging of drip irrigation systems
0.1 - 1.5	Moderate problems encountered with clogging of drip irrigation systems
> 1.5	Severe problems encountered with clogging of drip irrigation systems

Table 4: The TWQR and criteria for dissolved Manganese in aquatic ecosystems are:

TWQR and Criteria	Manganese concentration (µg/L)
Target Water Quality Range (TWQR)	***≤180***
Chronic Effect Value (CEV)	370
Acute Effect Value (AEV)	1 300

NICKEL

Units Used for Analytical Results: mg/l Ni
Normal Method(s) of Analysis: Atomic Absorption Spectrometry.
Occurrence/Origin: Principal sources are minerals and industrial wastes.
Health/Sanitary Significance: Very limited.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		N.A.		
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.07		
	EU Drinking Water Directive [98/83/EC]		0.02		
	Vietnam WQ Standard, Level 1		0.1		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<3		
		Public Sewers	<3		
		Marine Coastal Areas	<5		
	EU Surface Water Directive (75/440 EEC)	A-1	N.A.		①
		A-2	N.A.		
		A-3	N.A.		
	Vietnam WQ Standard, Level 2		0.1		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.1		
	South African WQ Guidelines		**≤0.2 (TWQR)**		Table:1
	Canadian Environmental Quality Guidelines		0.2		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.1		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines			Equation	②
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Nickel on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Quality
Target Water Quality Range ***≤ 0.20***	***Depending on plant species, nutrient solutions containing 0.5 - 1.0 mg/L can induce nickel toxicity***
0.20 - 2.0	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 2.0	Acceptable for irrigation only over the short term on a site-specific basis

② The CWQG is a minimum of 25 ug/L regardless of water hardness.

Nickel concentration = $e^{0.76[\ln(\text{hardness})]+1.06}$ $\mu g/L$

LEAD

Units Used for Analytical Results: mg/l Pb
Normal Method(s) of Analysis: Atomic Absorption Spectrometry.
Occurrence/Origin: Leaching from ores; effluent discharges; attack on water pipes.
Health/Sanitary Significance: Toxic cumulative poison.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.05		
	CPCB, Class A		<0.1		
	CPCB, Class C		<0.1		
	WHO, 2008		0.01		
	EU Drinking Water Directive [98/83/EC]		0.01		
	Vietnam WQ Standard, Level 1		0.02		
	South African WQ Guidelines		0 - 0.01 (TWQR)		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<0.1		
		Public Sewers	<1.0		
		Marine Coastal Areas	<2.0		
	EU Surface Water Directive (75/440 EEC)	A-1	0.05		①
		A-2	0.05		
		A-3	0.05		
	Vietnam WQ Standard, Level 2		0.02		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		0.05		
	South African WQ Guidelines		≤0.2 (TWQR)		Table:2
	Canadian Environmental Quality Guidelines		0.2		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		0.02		
	South African WQ Guidelines				Table:3
	Canadian Environmental Quality Guidelines			Equation	②
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Lead on Human Health

Lead Range (µg/L)	Effects
Target Water Quality Range 0 - 10	***No danger of any adverse effects by exposure from water***
It is recommended that the TWQR not be exceeded due to the potentially acute and/or irreversible effects of lead on human health	
10 - 50	No danger of any adverse health effects except for a slight risk of behavioural changes and possibility of neurological impairment, where the exposure to lead from other sources, such as food, is not minimised
50 - 100	Possible neurological damage where the nerve and brain tissues are developing, that is, in foetuses and young children. Young children and pregnant women should avoid exposure
100 - 300	Definite danger of neurological impairment in children Alternative water supply should be used by sensitive groups (children and pregnant women)
> 300	Symptoms of chronic lead poisoning are possible with continuous exposure

Table 2: Effects of Lead on Crop Yield and Quality

Concentration Range (mg/L)	Crop Yield and Quality
Target Water Quality Range ≤0.2	***Application at the rate of 1 000 mm/annum for 100 years would result in lead accumulation to 89 mg/kg in the top 150 mm of soil. Few plants appear to be affected at this level***
	Yield reduction and crop failure are the main effects of lead contaminated soils. Generally lead does not accumulate in edible parts of plants to levels that are dangerous to consumers (potatoes, lettuce and hay have, however, been shown to concentrate lead)
0.2 - 2.0	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 2.0	Acceptable for irrigation only over the short term on a site-specific basis

Table 3: The TWQR and criteria for dissolved lead at different water hardness (mg $CaCO_3$ /L) in 3 aquatic ecosystems are:

TWQR and Criteria	Lead concentration (µg/L)			
	< 60 (Soft)	60-119 (Medium)	120-180 (Hard)	> 180 (Very hard)
Target Water Quality Range	***≤ 0.2***	***≤ 0.5***	***≤ 1.0***	***≤ 1.2***
Chronic Effect Value (CEV)	0.5	1	2	2.4
Acute Effect Value (AEV)	4	7	13	16

② The CWQG is a minimum of 1 µg/L regardless of water hardness.

Lead concetration = $e^{1.273[\ln(\underline{hardness})]-4.705}$ *µg/L*

SELENIUM

Units Used for Analytical Results: mg/l Se

Normal Method(s) of Analysis: Atomic Absorption Spectrometry.

Occurrence/Origin: Weathering of rocks/soils, but major environmental sources are man-made.

Health/Sanitary Significance: Toxic element except in trace concentrations.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<0.01		①
	CPCB, Class A		N.A.		
	CPCB, Class C		N.A.		
	WHO, 2008		0.01		
	EU Drinking Water Directive [98/83/EC]		0.01		
	Vietnam WQ Standard, Level 1		N.A.		
	South African WQ Guidelines		N.A.		
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<0.05		
		Public Sewers	<0.05		
		Marine Coastal Areas	<0.05		
	EU Surface Water Directive (75/440 EEC)	A-1	0.01		②
		A-2	0.01		
		A-3	0.01		
	Vietnam WQ Standard, Level 2		N.A.		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	N.A.		
		(Cyprinid)	N.A.		
	Vietnam WQ Standard, Level 2		N.A.		
	South African WQ Guidelines		N.A.		
	Canadian Environmental Quality Guidelines		N.A.		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this, the water becomes toxic.
② A1, A2 or A3, depending on the (increasing) degree of treatment.

ZINC

Units Used for Analytical Results: mg/l Zn
Normal Method(s) of Analysis: Atomic Absorption Spectrometry.
Occurrence/Origin: Natural geological occurrence and from wastes.
Health/Sanitary Significance: Inhalation of zinc-containing fumes can cause a variety of physiological effects, but principal significance of excessive amounts in water is that emetic effects occur.

WATER USE	STANDARD		Desirable Limit	Remarks	Explanation
Drinking, Domestic Use	BIS (IS 10500 : 1991)		<5	Permissible limit 15	①
	CPCB, Class A		<15		
	CPCB, Class C		<15		□
	WHO, 2008				②
	EU Drinking Water Directive [98/83/EC]		N.A.		
	Vietnam WQ Standard, Level 1		0.5		
	South African WQ Guidelines		**0 - 3 (TWQR)**		Table:1
Surface Water	CPCB (Schedule-VI)	Inland Surface Water	<5		
		Public Sewers	<15		
		Marine Coastal Areas	<15		
	EU Surface Water Directive (75/440 EEC)	A-1	3		③
		A-2	5		
		A-3	5		
	Vietnam WQ Standard, Level 2		1		
Irrigation	CPCB, Class E		N.A.		
	CPCB (Schedule-VI)	Land for Irrigation	N.A.		
	Vietnam WQ Standard, Level 3		1.5		
	South African WQ Guidelines		**≤1.0 (TWQR)**		Table:2
	Canadian Environmental Quality Guidelines		1	when soil pH < 6.5	
			5	when soil pH > 6.5	
Aquatic Ecosystem, Fisheries	CPCB, Class D		N.A.		
	EU Freshwater Fish Directive (78/659/EEC)	(Salmonid)	<0.3		④
		(Cyprinid)	<1		
	Vietnam WQ Standard, Level 2		1		
	South African WQ Guidelines		**≤2 (TWQR)**		Table:3
	Canadian Environmental Quality Guidelines		0.03		
Outdoor Bathing, Recreational Use	CPCB, Class B		N.A.		
	EU Bathing Water Directive (76/160/EEC)		N.A.		
	South African WQ Guidelines		N.A.		

N.A. = Not Available

① Beyond this limit it can cause astringent taste and an opalescence in water.

② No health-based guideline value is proposed, However, drinking-water containing zinc at levels above 3 mg/litre may not be acceptable to consumers.

③ A1, A2 or A3, depending on the (increasing) degree of treatment.

Table 1: Effects of Zinc on Aesthetics and Human Health

Zinc Range (mg/L)	Effects
Target Water Quality Range 0 - 3	***No aesthetic or human health effects***
3 – 5	Slight opalescence or bitter taste. No health effects
5 - 10	Clearly discernable bitter taste and opalescence. No health effects
10 - 50	Bitter taste; strong opalescence. Some instances of chronic toxicity expected
50 - 700	Bitter taste; milky appearance. Acute toxicity with gastrointestinal irritation, nausea and vomiting
> 700	Bitter taste; milky appearance. Severe, acute toxicity with electrolyte disturbances and possible renal damage

Table 2: Effects of Zinc on Crop Yield and Soil Sustainability

Concentration Range (mg/L)	Crop Yield and Soil Sustainability
Target Water Quality Range ≤1.0	***Toxic to many plants at concentration of 1 mg/l and less in nutrient solutions. The TWQR should protect most plants from absorbing toxic concentrations of zinc, even when grown on acid sandy soils***
1.0 - 5.0	Maximum acceptable as concentration for fine-textured neutral to alkaline soils
> 5.0	Acceptable for irrigation only over the short term on a site-specific basis

④ Parameter is "Total zinc." The I values given are with reference to a hardness value of 100 mg/l $CaCO_3$. Relevant values for other hardness levels are as follows;

Hardness	10	50	100	500	mg/ $CaCO_3$
Zinc (S)	0.03	0.2	0.3	0.5	mg/l Zn
(C)	0.3	0.7	1	2	mg/l Zn

Table 3: The TWQR and criteria for dissolved Zinc in aquatic ecosystems are:

TWQR and Criteria	Zinc concentration (μg/L)
Target Water Quality Range (TWQR)	***≤ 2***
Chronic Effect Value (CEV)	3.6
Acute Effect Value (AEV)	36

Appendix-C

Contribution of Pollution loads by different Municipal Committees of the Punjab State to the River Satluj

Sr.No.	Name of Municiple Committee	Mode of Disposal	Discharge (KL/day)
1.	Nangal	Directly into river	250
2.	B.B.M.B Nangal	-do-	2760
3.	Anandpur Sahib	-do-	392
4.	Ropar	-do-	1000
5.	Phillaur	-do-	600
6.	Ludhiana	Through Budha Nala	100240
7.	Jalandhar	Through East Bein	55160
8.	Nawanshashar	-do-	N.A.
9.	Hoshiarpur	-do-	8000
10.	Phagwara	-do-	12700

Source: PPCB

Appendix-D

Large and medium industrial units discharging directly or indirectly into river Satluj

Sr.No.	Name of Industry	Nature of the Industry	Effluent Discharge (MLD)
1.	M/s N.F.L Naya Nangal	Fertilizer	3.25
2.	M/s P.N.F.L Naya Nangal	Soda-ash Amm, Chloride	0.48
3.	M/s P.A.C.L Naya Nangal	Indl. chloride sodium hydroxide Sodium hydroxide hydrochloride Acid	0.25
4.	M/s R.T.P.	Electricity generation	-
5.	M/s Swaraj Mazda asron, Hoshiarpur	Auto mobile manufacturing	0.12
6.	M/s United Pulp and paper mills Asron, Hoshiarpur	Pulp paper mill	15.2
7.	M/s Zenith Paper Mills Bannel, Hoshiarpur	Pulp & Paper	8.0
8.	M/s Punjab Brewerries Ltd.	Brewery	0.655
9.	M/s Rockman Cycle Industry	Electroplating	0.435
10.	M/s Majectic Auto Ltd.	Electroplating	0.080
11.	M/s R.N.Gupta & Co.	Electroplating	0.012
12.	M/s Ashok Dyeing & Finishing Mills Pvt. Ltd.	Dyeing	0.260
13.	M/s Greatway Ltd.	Dyeing	0.320
14.	M/s Pb. Wool combers	Woolen	0.21
15.	M/s Nahar Spinning Mills	Spinning	0.820
16.	M/s New Bharat Vanaspati	Vanaspati	0.120
17.	M/s B.K.Duplex Board (P) Ltd.	Duplex Board Paper	0.233
18.	M/s Sukhjit Starch chemical Ltd.	Starch	1.52
19.	M/s Oswal Agro Mill	Sugar	1.005
20	M/s Jagjit Cotton Textile mills Ltd.	Fabrics	6.20
21.	M/s Doaba Co. Op. Sugar Mills Ltd.	Sugar	0.540
22.	M/s Soccer Tannery	Tannery	0.181
23.	M/s markfed Canneries State	Food	0.681

24.	M/s Agro Leather (P) Ltd.	Tannery	0.655
25.	M/s Pb. Tannery Ltd.	Tannery	0.60
26.	M/s Indo-Asian Ltd.	Electroplating	0.673
27.	M/s Bawa Skin Co.	Tannery	0.055
28.	M/s B.D.A Steels (P) Ltd.	Steel	0.05
29.	M/s Doaba Co. Op. Milk Producers Union	Milk Plant	0.507
30.	M/s Leather Engg. Works	Engineering	0.08
31.	M/s Zenith Paper Mill	Paper Mill	5.08
32.	M/s Mahavir Spinning Mills	Spinning	1.10
33.	M/s United Pulp & Paper Mills	Paper	4.5
34	M/s ABC paper Mill	Paper	1.60
35.	M/s Punjab Bone Mills	Bone Mills	0.20

Source: PPCB

Appendix-E

Volume of Runoff for Sirsa sub-watershed

Date	Rainfall (mm)	Runoff Volume (1000 m^3)
19-Feb	15.5	1
18-Jun	28.5	7
28-Jun	28.9	7
05-Jul	59.2	28
10	18.5	2
13	18.1	2
17	15.3	1
21	41.1	15
24	26.3	6
01-Aug	32.5	9
3	23.1	4
5	18.5	2
13	20.5	3
20	20.4	3
27	17.3	2
04-Sep	17.3	2
23	28.4	7
Cumulative flow (2003)		**100**
23-Jan	32.6	9
31	14	1
01-May	19.6	3
07-Jun	16.3	1
09-Jul	16.2	1
14	16.1	1
30	25.9	5
04-Aug	35.5	11
12	43	16
18	33.6	10
24	20.8	3
16-Sep	37.2	12
21	18.7	2
03-Oct	16.4	1
12	44	17
Cumulative flow (2004)		**94**
23-Jan	19.9	3
28	14.4	1
08-Feb	15.4	1
16	33.3	10
22	20.7	3
26-Jun	39.5	14
07-Jul	16.6	1
07-Aug	23.2	4
17	17.3	2
21	19.2	2
29	15.1	1
13-Sep	18	2
18	14.5	1
23	18.2	2
Cumulative flow (2005)		**46**

Appendix-F

Volume of Runoff for Siswan sub-watershed

7	Rainfall (mm)	Runoff Volume (1000 m^3)
29-Jan	9.8	0
19-Feb	15.5	1
01-Mar	14.2	1
03-Jun	12.6	0
18	28.5	6
23	11.9	0
25	12.6	0
28	28.9	6
02-Jul	9.6	0
5	59.2	27
10	18.5	2
14	13.9	1
17	15.3	1
21	41.1	14
24	26.3	5
01-Aug	32.5	8
3	23.1	4
5	18.5	2
13	20.5	2
20	20.4	2
27	17.3	1
30	10	0
01-Sep	11.5	0
4	17.3	1
Cumulative Flow (2003)		**85**
16-Jan	10.3	0
23	28.4	6
24	11.4	0
31	14	1
01-May	19.6	2
07-Jun	16.3	1
06-Jul	9.9	0
9	16.2	1
15	10.4	0
30	25.9	5
04-Aug	35.5	10
18	33.6	9
25	10.7	0
16-Sep	37.2	11
21	18.7	2
03-Oct	16.4	1
12	44	16
23	19.9	2
Cumulative Flow (2004)		**68**
28-Jan	14.4	1
08-Feb	15.4	1
16	33.3	9
20	13.6	0
22-Mar	20.7	3
26-Jun	39.5	13
07-Jul	16.6	1
15	12.8	0
18	10.7	0
31	10.5	0
02-Aug	11.4	0
7	23.2	4
17	17.3	1
21	19.2	2
29	15.1	1
13-Sep	18	2
18	14.5	1
23	18.2	2
Cumulative Flow (2005)		**40**

Appendix-G

Volume of Runoff for Swan sub-watershed

Date	Rainfall (mm)	Runoff Volume (1000 m^3)
23-Jan	19.4	3
07-Feb	14.8	1
16	33.6	11
20	15.8	1
11-Mar	16.6	2
22	16.6	2
26-Jun	27.9	7
01-Jul	12.1	0
7	39.4	15
12	33.7	11
19	13.2	1
07-Aug	31	9
17	27.1	7
21	26.7	6
10-Sep	18.9	3
14	15.1	1
18	18.2	2
23	21.1	4
Cumulative Flow (2005)		**85**
Annual average actual river flow (1000 m^3)		**236520**

Appendix-H

Volume of Runoff for Budha Nala sub-watershed

Date	Rainfall (mm)	Runoff Volume (1000 m^3)
28-Jan	20.2	9
01-Feb	13.1	4
19	78.4	62
02-Mar	10.4	2
20	4.8	0
18-Apr	13.1	4
23	8.7	1
26	41.7	27
28	23.1	11
30	7.2	1
07-Jul	11.8	3
10	28.2	15
13	58.5	43
18	41.4	27
21	88.3	72
06-Aug	24.9	12
10	6.5	1
12	17.4	7
19	5.5	0
28	22.7	11
31	14.3	5
03-Sep	151.5	134
13	26.8	14
23	9.2	2
Cumulative Flow (2003)		**465**
Annual average actual river flow (1000 m^3)		**155167**
23-Jan	19.8	8
31	14.2	4
01-May	13.9	4
24	13.4	4
07-Jun	12.4	3
18	19.1	8
21	7.9	1
09-Jul	7.1	1
15	15.3	5
17	29	16
30	4.9	0
04-Aug	12.2	3
9	63.8	48
18	23	11
20	30	17
26	10.8	2
16	5.8	0
03-Sep	31.7	18
12	45	30
23	19.8	8
28	23.6	11
Cumulative Flow (2004)		**205**
Annual average actual river flow (1000 m^3)		**147158**
08-Jan	6.8	1
13	6.8	1
16	20.1	9
22-Feb	25.6	13
09-Mar	7	1
26	18.9	8
29	6.5	1
08-Jul	12.6	3
12	34.3	20
30	47.9	33
01-Aug	14.1	4
7	20.1	9
18	7.2	1
23	16.8	6
10-Sep	67.2	51
13	22.1	10
15	5.9	0
28	10.8	2
Cumulative Flow (2005)		**173**
Annual average actual river flow (1000 m^3)		**158272**

Appendix-I

Volume of Runoff for East Bein river sub-watershed

Date	Rainfall (mm)	Runoff Volume (1000 m^3)
28-Jan	15	4
01-Feb	10.6	2
19	77.8	59
02-Mar	6.6	0
18-Jun	9.1	1
23	10.3	2
28	18.2	6
30	11.3	2
07-Jul	9.6	1
10	22.8	10
13	48.9	32
18	33.6	18
21	75.4	57
27	6.5	0
30	5.7	0
06-Aug	21.1	8
10	8.5	1
12	18.7	7
29	6.1	0
31	9.9	2
03-Sep	121.9	102
13	22.5	9
23	6.7	0
Cumulative Flow (2003)		**326**
Annual average actual river flow (1000 m^3)		**98041**
23-Jan	17.6	6
31	12.7	3
02-May	13.6	3
25	12.9	3
08-Jun	11.5	2
19	14.9	4
22	9	1
25	6.4	0
16-Jul	13.1	3
18	23.9	10
02-Aug	9.5	1

5	27.3	13
10	53	36
21	30.1	15
27	17.3	6
04-Oct	22.6	10
13	34	19
Cumulative Flow (2004)		**137**
Annual average actual river flow (1000 m^3)		**80546**
23-Jan	22.5	9
28	23.9	10
08-Feb	8	1
10	6.1	0
13	5.3	0
16	17.5	6
23-Apr	21.1	8
27	5.2	0
10-Jun	5.5	0
27	10.6	2
01-Jul	8.1	1
5	5.5	0
9	34.5	19
13	41	25
31	39.9	24
02-Aug	12.2	3
8	29.7	15
19	5.1	0
22	12.7	3
24	12.9	3
11-Sep	59.2	42
16	5.4	0
29	8.2	1
Cumulative Flow (2005)		**173**
Annual average actual river flow (1000 m^3)		**168508**

Appendix-J

Volume of Runoff for Satluj river sub-watershed

Date	Rainfall (mm)	Runoff Volume (1000 m^3)
28-Jan	15	4
01-Feb	10.6	2
19	77.8	60
02-Mar	6.6	0
18-May	9.1	1
23	10.3	2
28	18.2	6
30	11.3	2
07-Jul	9.6	1
10	22.8	10
13	48.9	32
18	33.6	19
21	75.4	57
27	6.5	0
30	5.7	0
06-Aug	21.1	9
10	8.5	1
12	18.7	7
29	6.1	0
31	9.9	2
03-Sep	121.9	102
13	22.5	10
23	6.7	0
Cumulative Flow (2003)		**329**
Annual average actual river flow (1000 m^3)		**6285370**
23-Jan	17.6	6
31	12.7	3
01-May	13.6	4
24	12.9	3
07-Jun	11.5	2
18	14.9	4
21	9	1
24	6.4	0
15-Jul	13.1	3
17	23.9	11
01-Aug	9.5	1

4	27.3	13
9	53	36
20	30.1	16
26	17.3	6
03-Oct	22.6	10
12	34	19
Cumulative Flow (2004)		**139**
Annual average actual river flow (1000 m^3)		**2224424**
23-Jan	22.5	10
28	23.9	11
08-Feb	8	1
10	6.1	0
13	5.3	0
16	17.5	6
23-Mar	21.1	9
27-Apr	5.2	0
10-May	5.5	0
27	10.6	2
01-Jul	8.1	1
5	5.5	0
9	34.5	19
13	41	25
31	39.9	24
02-Aug	12.2	3
8	29.7	15
19	5.1	0
22	12.7	3
24	12.9	3
11	59.2	42
16	5.4	0
29	8.2	1
Cumulative Flow (2005)		**175**
Annual average actual river flow (1000 m^3)		**4045458**