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GIS Based Groundwater Quality Evaluation with Particular Reference to India

Edited by
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Chapter: GIS Based Ground Water Quality Evaluation with Particular Reference to India

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Preface

Groundwater is used for domestic, industrial water supply and irrigation all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and accelerated pace of industrialization. Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions. Rapid urbanization has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal, especially in urban areas. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it.

Water quality index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of groundwater. This book deals with the present situation of groundwater quality in India, highlights the water quality standards to be met for domestic and irrigation purposes, explains the preparation of Drinking Water Quality Index (DWQI) map and Irrigation Water Quality Index (IWQI) Map using Geographical Information System (GIS) and also presents a review on the different procedures adopted for groundwater quality evaluation for drinking and irrigation purposes.

Thank You

About Author

Dr. Jasmin I., has graduated in Civil Engineering from TKM College of Engineering, Kollam, Kerala (2003) with distinction, persuaded post graduation in Water Resources Engineering (2005) from College of Engineering Guindy, Anna University, Chennai and Ph.D. (2013) from College of Engineering, Sri Venkateswara University, Tirupati. My areas of interest include Ground water modeling, Application of RS and GIS in Water Resources Engineering. Various distinctions received during my studies include 'MES Merit Award' (1996), 'Janab Najmul Hussain Memmorial Gold Medal' (2002) for the course Habitat Engineering, First Rankand Gold Medal (2005) in Post-graduation (M.E.) from College of Engineering, Guindy, Anna University. My research outcomes of post-graduation and Ph.D. were published in various referred international journals and presented in various national/international conferences. I am the reviewer for many national and international journals and also life member of professional bodies like Indian Remote Sensing Society, Indian Water Resources Society, Indian Association of Hydrologist and Associated Member of Institute of Engineers.

Acknowledgement

I express my deep sense of gratitude and indebtedness to my guide and mentor Prof. P. Mallikarjuna, Department of Civil Engineering, S.V.U. College of Engineering, Tirupati for his constant guidance and encouragement. My sincere and deep sense of gratitude to my friends for their kind cooperation and moral support. I find myself groping for appropriate words to thank my family members for their constant support and blessings. I owe my heartfelt gratitude to my husband who showered love and extended moral support and

wish to keep on record the love and affection of my sweet little son towards me.

Finally, I bow the almighty for making everything worthwhile.

Abstract

Groundwater is used for domestic, industrial water supply and irrigation all over the world. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and accelerated pace of industrialization. Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions. Rapid urbanization has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal, especially in urban areas. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it.

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Chapter 1

Groundwater Quality

Water is the most important renewable and finite natural resource, basic human need and a valuable national asset. Water is available as vapour in the atmosphere, water or ice on land and groundwater beneath the earth's crust. Evaporation of water from water bodies, formation and movement of clouds, rain and snowfall, stream flow and groundwater movement are some of the dynamic aspects of water. Efficient development and optimum utilization of water resources is of great significance to its overall development.

The earth's water resources are not uniformly distributed. Oceans are the largest reservoirs of saline water, which is not readily usable for various needs. The percentage distributions of global water and fresh water are shown in Figure 1.

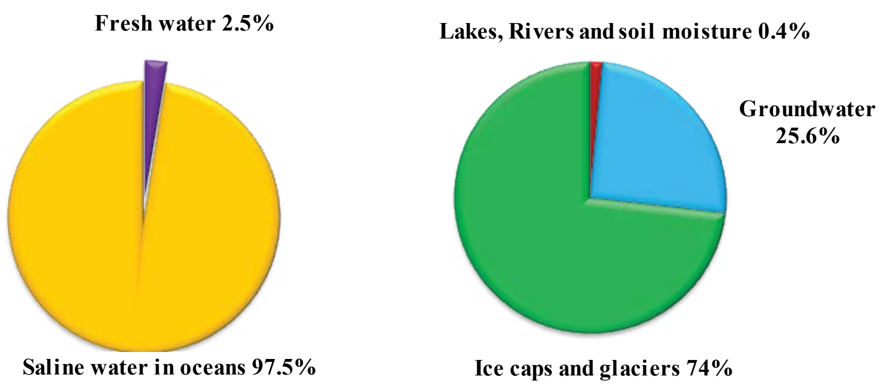

Figure 1: (a) Global water distribution and (b) Global fresh water distribution.

Groundwater occurs beneath the earth's surface in significant quantities in porous and pervious geologic formations (aquifers). In many parts of the world, groundwater sources are the most important supply of drinking water, particularly in areas where the surface water sources are limited or polluted. Because of several inherent qualities of groundwater such as excellent natural quality, limited vulnerability, low development cost and drought reliability, it has become an immensely important and dependable source of water supplies in all climatic regions in both developed and developing countries [1].

In recent times, several studies across the globe indicated that the climate change made a significant impact upon freshwater resources availability. In developing countries, the demand for water has increased manifold over the years due to population growth, urbanization, rapid industrialization, agricultural expansion and economic development. Indiscriminate use of agrochemicals, improper water planning and sewage management, lack of awareness and, non-implementation of desired measures have created an alarming scenario of freshwater scarcity.

The spatio-temporal variations in rainfall and regional variations in geology and geomorphology have led to uneven distribution of groundwater in different regions. Unplanned and haphazard development of groundwater has led to a sharp decline in groundwater levels [2]. Along the coastal zones also, the delicate balance between sea water and groundwater has been disturbed leading to sea water intrusion into the fresh water aquifers causing irreparable damage and environmental degradation. Myriad consequences of unsustainable groundwater use are becoming increasingly evident and, the key concern is to maintain a long-term sustainable yield from aquifers [1].

The importance of groundwater lies not only in its wide spread occurrence and availability but also in its consistent good quality. Groundwater quality is indicated by the amount of dissolved or suspended inorganic or organic matter through which it acquires physical and chemical characteristics. Under natural conditions, the spatial and temporal variations in the composition of groundwater depend on rain water, soil strata and aquifer materials [3]. The variations in the groundwater quality are due to rock - water interaction and oxidation - reduction reactions during the percolation of water through formations [4-7].Leaching of salts, ion-exchange processes and residential time of groundwater in aquifers causes hydro geochemical variations in groundwater [8]. Water quality is affected by changes in nutrients, sedimentation, temperature, pH, heavy metals, non-metallic toxins, persistent organics and pesticides, and biological factors as well.

The quality of groundwater varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids present in it. Unsafe or inadequate water, sanitation, and hygiene cause approximately 3.1 percent of all deaths, over 1.7 million deaths annually, and 3.7 percent of DALYs (disability adjusted life years) worldwide (WHO 2002). The quality of ground water is of great importance in determining the suitability of particular groundwater for public water supply, irrigation and industrial uses.

Chapter 2

Causes of Groundwater Quality Degradation

Causes

Water quality plays an important role in promoting agricultural production and standards of human health. Urbanization, increased agricultural activities and over-exploitation adversely affect the groundwater quality. The parameters of concern in groundwater quality in various parts of India are due to higher level of fluoride, arsenic contamination, nitrate problems in intensively irrigated and agricultural fields, improper sewage collection in urban areas and salinity problems in intensive irrigated (command areas) and coastal areas of the country.

Figure 2: shows the causes of groundwater pollution from point and non-point sources, Schematic representation of groundwater quality degradation from various sources.

The groundwater quality degradation may be mainly due to

- Over withdrawal of water
- Increased application of fertilizers
- Pollution from agro-chemicals
- Industrial and domestic pollution
- Insanitary conditions in rural and urban areas
- Groundwater depletion
- Water logging
- Siltation
- Soil salinisation
- Degradation of wetlands

High fluoride concentration in groundwater, beyond the permissible limit of 1.5 ppm, is a major issue affecting a large segment of rural population to the tune of 25 million spread in over more than 200 districts in 17 states in India. Nearly 6 million children below the age of 14 suffer from dental, skeletal and non-skeletal fluorosis. The presence of arsenic in water is geogenic. In West Bengal, nearly 13.8 million people in 75 blocks are reported at risk. It is also reported that around 0.2 million people have arsenic related skin manifestations. The entire Gangetic delta plain, which consists of alluvial soil, contains arsenic in the deeper aquifers. It causes skin lesions and can lead to arsenicosis at a later stage. In recent years high arsenic contamination has also been reported from different parts of eastern UP, Bihar and Jharkhand.

Other water quality problems include varying levels of iron in groundwater especially in northeastern India, which restricts its utility owing to colour, turbidity and taste. The presence of iron in groundwater is found in parts of Madhya Pradesh, Uttar Pradesh, coastal Orissa, Andhra Pradesh and Tamil Nadu. Heavy metals such as chromium, lead, nickel, zinc, copper, manganese and nitrates around industrial towns are reported, however extensive surveys have yet to be carried out. Many coastal districts in India suffer from excess salinity in groundwater. Over the last decade industrial waste and the municipal solid waste have emerged as the leading causes of the pollution of surface and groundwater.

Different types of pollutants produce different kind of negative impacts downstream, based on their mobility, ability to accumulate, and persistence in the environment. Persistent organic pollutants are of particular concern because of their long life time and potential adverse human and environmental impacts. The Ganges-Brahmaputra River system in India receives petrochemical, pesticide, and other factory wastewaters, in addition to sewage and agricultural runoff, before flowing into Bangladesh.

Groundwater itself does not inherently contain faecal coliform. The presence of faecal coliforms in groundwater indicates a potential public health problem, because faecal matter is a source of pathogenic bacteria and viruses. The groundwater contamination from faecal coliform bacteria is generally caused by percolation from contamination sources (domestic sewage and septic tank) into the aquifers and because of poor sanitation. This results in outbreak of various water-borne diseases like diarrhoea, gastroenteritis, jaundice, hepatitis, cholera and typhoid. The density of coliform group is the criteria for the degree of contamination and has been the basis for bacteriological water quality standard. In ideal situation all the samples considered should be free from coliform organisms but in practice, it is not attainable always and therefore, BIS has recommended the following standard.

- 95% of water samples should not contain any coliform organisms in 100 ml throughout the year.
- No water sample should contain *E.Coli* in 100 ml water.
- No water sample should contain more than 10 coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

Effect of Agricultural Impact on Groundwater Quality

The Food and Agriculture Organization [9] has compiled a summary of common agricultural impacts on surface water and groundwater resources (Table 1).

Agricultural activity	Impacts	
	Surface water	**Groundwater**
Tillage/ Ploughing	Sediments carry phosphorous and pesticides adsorbed to sediment particles; siltation of river beds and loss of habitat, spawning ground etc.	Soil compaction can reduce infiltration to the groundwater system.
Fertilizing	Runoff of nutrients, especially phosphorus, leading to eutrophication causing taste and odour in public water supply; excess algal growth leading to deoxygenation of water and kills fish.	Leaching of nitrate to groundwater; excessive levels are a threat to public health.
Manure spreading	Carried out as a fertilizer activity; spreading on frozen ground results in high levels of contamination of receiving waters by pathogens, metals, phosphorus, and nitrogen leading to eutrophication and potential contamination. Manure application spreads antibiotics and other pharmaceutical products that are given to livestock.	Contamination of groundwater, especially by nitrogen

Pesticides	Runoff of pesticides leads to contamination of surface water and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish. Pesticides are carried as dust by wind over very long distances and contaminate aquatic systems.	Some pesticides may leach into groundwater causing human health problems from contaminated wells.
Feedlots/animal Corrals	Contamination of surface water with many pathogens (bacteria, viruses, etc.) leading to chronic public health problems. Also contamination by metals, antibiotics, and other pharmaceuticals contained in urine and faeces.	Potential leaching of nitrogen, metals, etc. to groundwater.
Irrigation	Runoff of salts leading to salinization of surface waters; runoff of fertilizers and pesticides to surface waters with ecological damage, bioaccumulation in edible fish species, etc. High levels of trace elements such as selenium can occur with serious ecological damage and potential human health impacts.	Enrichment of groundwater with salts, nutrients (especially nitrate).
Clear cutting	Erosion of land, leading to high levels of turbidity in rivers, siltation of bottom habitat, etc. Disruption and change of hydrologic regime, often with loss of perennial streams; causes public health problems due to loss of potable water.	Disruption of hydrologic regime, often with increased surface runoff and decreased groundwater recharge; affects surface water by decreasing flow in dry periods and concentrating nutrients and contaminants in surface water.
Silviculture	Broad range of effects: pesticide runoff and contamination of surface water and fish; erosion and sedimentation problems.	Soil compaction limits infiltration
Aquaculture	Release of pesticides and high levels of nutrients to surface water and groundwater through feed and faeces, leading to serious eutrophication.	

Table 1: Agricultural impacts on water quality.

(Modified from FAO 1996, published in UNEP 2010)

Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. Assessment of water quality is very important for knowing its suitability for various purposes.

Bodies Governing Water Quality in India

The key agencies operating national level water quality programs are Central Pollution Control Board (CPCB), Central Water Commission (CWC) and Central Ground Water Board (CGWB). CPCB is under the Ministry of Environment and Forests and has a direct mandate to maintain/restore the water quality of the natural water bodies to the level required for their designated best-uses. The water resources utilization and management is mostly the subject of CWC and CGWB, both under the Ministry of Water Resources. Though there is a real wealth of information with these agencies on water discharge, sediment load and water potential/balance characteristics, progress on sharing data between agencies is yet to be made.

Chapter 3

Water Quality Standards

Drinking Water Specifications

The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institution (ISI) has laid down the standard specifications for drinking water [10,11]. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess the suitability of water for drinking purpose. The drinking water quality standards as per BIS [10,11] and World Health Organization [12-14] is furnished in Table 2.

Characteristics	Bureau of Indian Standards (BIS)		WHO guidelines
	Desirable Limit	Permissible Limit	Max. Allowable concentration
Colour (Hazen Units)	5	25	15
Turbidity (NTU)	5	10	5
pH	6.5-8.5	No relaxation	6.5-8.5
Odour	Unobjectionable	-	-
Taste	Agreeable	-	-
Total Hardness (mg/l)	300	600	500
Chlorides (mg/l)	250	1000	250
Residual free Chlorine (mg/l)	0.2	-	-
Dissolved Solids (mg/l)	500	2000	1000
Calcium (mg/l)	75	200	-
Sulphate (mg/l)	200	400	400
Nitrate (mg/l)	45	100	10
Fluoride (mg/l)	1	1.5	1.5
Phenolic compounds (as C_6H_5OH) (mg/l)	0.001	0.002	-
Anionic detergent (as MBAS) (mg/l)	0.2	1	-
Alkalinity (mg/l)	200	600	-
Boron (mg/l)	1	5	-
Zinc (mg/l)	5	15	5
Iron (mg/l)	0.3	1.0	0.3
Manganese (mg/l)	0.1	0.3	0.1
Copper (mg/l)	0.05	1.5	1
Arsenic (mg/l)	0.05	No relaxation	0.05
Cyanide (mg/l)	0.05	No relaxation	0.1
Lead (mg/l)	0.05	No relaxation	0.05
Chromium (mg/l)	0.05	No relaxation	0.05
Aluminum (mg/l)	0.03	0.2	0.2
Cadmium (mg/l)	0.01	No relaxation	0.005
Selenium (mg/l)	0.01	No relaxation	0.01
Mercury (mg/l)	0.001	No relaxation	0.001
Total Pesticide (mg/l)	Absent	0.001	-

Table 2: Drinking Water Quality Standards as per BIS and WHO guidelines.

The details of some of the important physico-chemical parameters in groundwater quality for drinking purpose such as pH, Total Dissolved Solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), sulphate (SO_4^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), nitrate (NO_3^{-}), fluoride (F^{-}), total hardness (TH), arsenic, alkalinity, iron, heavy metals and pesticides are explained.

pH: pH represents the concentration of hydrogen ion in groundwater and is an important index of acidity or alkalinity. The lower value produces sour taste and higher value an alkaline taste.

Total Dissolved Solids (TDS): The total dissolved solids denote the various types of minerals present in water in the dissolved form. Generally, groundwater contains calcium, magnesium, iron, sodium, fluoride, nitrate, sulphate, and chloride. TDS is the sum of cations and anions concentration. The presence or absence of these constituents determines the usefulness of groundwater for various purposes. If any of these constituents exceeds its tolerance limit, it adversely affects the body system and causes health deterioration. If TDS is high, palatability decreases and causes gastro-intestinal irritation. A high content of dissolved solids increases the density of water and reduces solubility of gases like oxygen. Water with low concentration of TDS may be unacceptable for drinking due to its flat, insipid taste.

Calcium (Ca^{2+}): Most of the geological materials of aquifer are composed of calcium. It presents in groundwater as a material of suspension. Calcium bicarbonate solution causes hardness in water. It is highly essential for nervous and muscular system, cardiac functions and for coagulation of blood. The insufficiency of calcium in drinking water is responsible for rickets and defective teeth, while presence of excess concentration of calcium causes kidney or bladder stones. The concentration of calcium above the desirable limit causes encrustations in water supply system.

Magnesium (Mg^{2+}): Geologically, magnesium rich minerals are associated with basic and ultra basic rocks of igneous and metamorphic origin. Magnesium is essential as an activator of many enzyme systems. The salts of magnesium are cathartic and diuretic. The high concentration of magnesium causes laxative effect. Magnesium deficiency is associated with functional changes of skeletal muscles and cardiovascular systems.

Sodium (Na^{+}): Sodium is highly soluble and often found in groundwater. Most rocks and soils contain sodium compounds. The increased sodium levels in groundwater are due to erosion of salt deposits and sodium bearing rock minerals, occurrence of brackish water in aquifers, saltwater intrusion into wells in coastal areas, leaching of irrigation water through soils high in sodium, groundwater pollution by sewage effluents and, infiltration of leachate from landfills or industrial sites. The high concentration of sodium may be harmful to persons suffering from renal and cardiac diseases.

Potassium (K^{+}): Potassium in groundwater is due to weathering and erosion of potassium-bearing mineral (feldspar), leaching of fertilizers and sea water intrusion. Potassium, an essential nutritional element, is laxative when it exceeds permissible limits.

Sulphate (SO_4^{2-}): Sulphate generally occurs in groundwater as soluble salt of calcium, magnesium and sodium. The sulphate content of water changes significantly with time due to infiltration of rainwater and groundwater recharge. High sulphate content in drinking water imparts bitter taste. It also causes gastro-intestinal irritation with magnesium or sodium and may have cathartic effect. High concentration of sulphate along with magnesium may produce laxative effect.

Bicarbonate (HCO_3^-): The primary source of carbonate and bicarbonate ions in groundwater is dissolved CO_2 in rain water. It enters the soil and dissolves in groundwater. An increase in temperature or decrease in pressure causes reduction in solubility of CO_2 in water.

Chloride (Cl^-): Chloride is the most common anion in groundwater. Chloride concentration varies widely in water and is directly related to mineral content in water. The chloride concentration is high in groundwater, where the temperature is high and rainfall is less. Also, the coastal aquifers which suffer from sea water intrusion may show abnormal concentration of chloride. Soil porosity and permeability have a key role in building up the cloride concentration. Excessive chloride concentration is injurious to people suffering from heart and kidney diseases. It also affects taste, palatability and, increases the rate of corrosion of metals in the distribution system.

Nitrate (NO_3^-): Nitrate occurrence is mainly due to aerobic decomposition of nitrogen from organic matter. Nitrate values in groundwater may be high due to over-application of fertilizers, improper manure management practices and maintenance of septic systems. The higher concentration of nitrates in infants causes methaemoglobinaemia (Blue baby disease) where the skin of infants becomes blue due to decreased efficiency of haemoglobin to combine with oxygen. It increases the risk of gastric cancer, adversely affects central nervous system and cardiovascular system.

Fluoride (F^-): Fluoride is one of the main trace elements in groundwater, which generally occurs as a natural constituent. Bedrock containing fluoride minerals is generally responsible for its high concentration in groundwater [15,16] . It is present in soil strata due to geological formations in the form of fluorapatite, amphiboles such as hornblende, trimolite and Mica. Weathering of sedimentary rocks contributes a major portion of fluoride in groundwater. A small amount of fluoride is beneficial to human health for preventing dental caries. But higher concentration causes digestive disorders, skin diseases, and increases risk of dental fluorosis. Fluoride in larger quantities (20-80 mg/day) taken over a period of 10-20 years results in crippling and skeletal fluorosis which is severe bone damage.

Total Hardness (TH): Water hardness is caused primarily by the presence of cations such as calcium and magnesium and, anions such as carbonate, bicarbonate, chloride and sulphate. The concentration of total hardness above the desirable limit affects water supply system (scaling), causes excessive soap consumption, calcification of arteries, urinary problems and stomach disorder.

Arsenic: Immediate symptoms of acute poisoning typically include vomiting, oesophageal and abdominal pain, and diarrhoea. Long-term exposure to arsenic causes cancer of the skin, lungs, urinary bladder, and kidney. There can also be skin changes such as lesions, pigmentation changes and thickening

Iron: A dose of 1500 mg/l has a poisoning effect on a child as it can damage blood tissues. The higher concentration may cause digestive disorders, skin diseases and dental problems.

Alkalinity: Increased alkalinity causes objectionable taste to water. The higher concentration may affect osmotic flow and movement of fluids.

Heavy Metals: The concentration of heavy metals such as cadmium, zinc and mercury above permissible limit damages nervous system, kidney and other metabolic disruptions.

Pesticides: Higher concentration of pesticides weakened immunity, abnormal multiplication of cells leads to tumour formation. They contain chlorides that cause reproductive and endocrinal damage. The persistent organic pollutants in pesticides cause high blood pressure, hormonal dysfunction and growth retardation.

Hydrogeochemical Evaluation of Groundwater

Groundwater is represented as a solution of cationic constituents [calcium (Ca^{2+}), Magnesium (Mg^{2+}) and alkaline metals], anionic constituents [Sulphate (SO_4^{2-}), Chloride (Cl^-)] and those contributing to alkalinity [Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-)]. Ionic concentrations are plotted in a Piper trilinear diagram [17] as shown in Figure 3 to infer the hydrochemical facies.

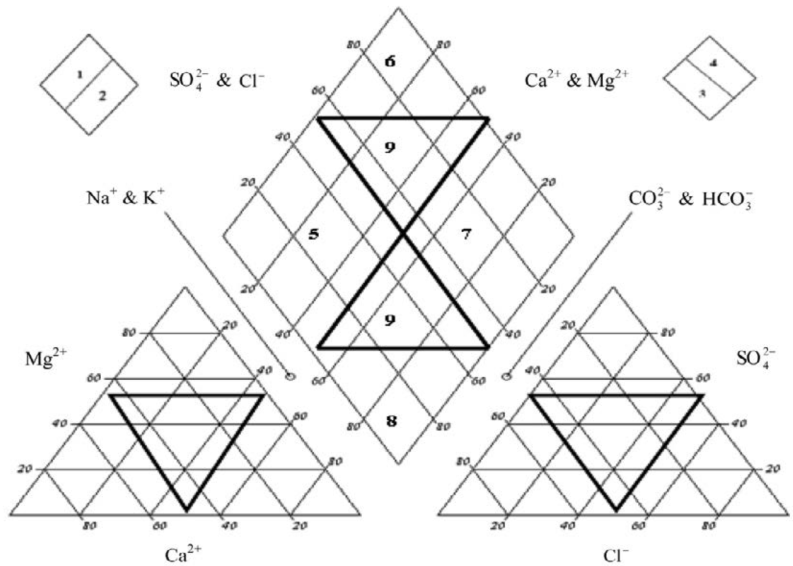

Figure 3: Hydrochemical facies of groundwater.

Sub-division	Characteristics of sub-division
1	Alkaline earth exceeding alkalies
2	Alkalies exceeding alkaline earths
3	Weak acids exceeding strong acids
4	Strong acids exceeding weak acids
5	Magnesium bicarbonate type
6	Calcium chloride type
7	Sodium chloride type
8	Sodium bicarbonate type
9	Mixed type (no cation-anion pair exceeding 50 %)

The linear plots are most suitable for the representation of groundwater composition. These plots include two triangles: one for plotting anions and the other for cations. The cation and anion fields are combined to show a single point in a diamond shaped field and categorized based on the sub-division presented in Figure 3. These trilinear diagrams are useful in bringing out the chemical relationships among the groundwater samples.

Irrigation Water Quality Parameters

The composition and concentration of dissolved constituents in groundwater determine its quality for irrigation. The irrigation water quality affects considerably the crop yield. Good irrigation water quality has the potential to produce maximum crop yield under good soil and water management practices. The factors generally considered for evaluation of groundwater quality for irrigation purpose are Salinity, Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Sodium Percent (Na %) and Boron

Salinity

Salinity hazard occurs when salts start to accumulate in the crop root zone reducing the amount of water available to the crops. These salts often originate from dissolved minerals in the applied irrigation water or from a high saline water table. The reduction in crop yield occurs when the salt content of the root zone reaches to the extent that the crop is no longer able to extract sufficient water from the salty soil. When this water stress is prolonged, plant growth slows down and drought-like symptoms may develop [18]. Unless the soil is leached with low salt content water, the soil salinization makes agricultural lands unsuitable for irrigation [19].

The extent of salinity hazard is measured by the ability of water to conduct an electric current. Electrical Conductivity (EC) is a function of total dissolved solids, and is used to express the salinity of water. In general, the amount of water available to the crops gets lower when the electrical conductivity is higher. Also, as plants transpire pure water, the readily available water for plant growth decreases as the conductivity increases. Under such circumstances, the soil appears to be wet but the crop experiences physiological drought. The irrigation water quality is classified based on EC values of less than 250, 250 – 750, 750 – 2000, 2000 – 3000 and greater than 3000 μS/cm as excellent, good, permissible, doubtful and very poor respectively [19].

Sodium Absorption Ratio (SAR)

SAR is a measure of sodium hazard to crops. While high EC in water leads to formation of a saline soil, high sodium content (SAR) leads to development of an alkali soil. SAR value of irrigation water quantifies the relative proportions of sodium (Na^+) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water [20] and is computed as

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad (1)$$

SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium sensitive plants suffer from sodium accumulation in the plant tissue at low exchangeable sodium condition causing deterioration of the physical condition of the soil. If the proportion of sodium is high, the alkali hazard is high and if calcium and magnesium predominate, the hazard is less. If water used for irrigation is high in sodium and low in calcium content, then exchangeable calcium in soil may replace sodium by base exchange reaction in water. This destroys the soil structure owing to dispersion of clay particles. The irrigation water quality is classified based on SAR values of less than 10, 10 – 18, 18 – 26 and greater than 26 as excellent, good, doubtful and unsuitable respectively [20].

Residual Sodium Carbonate (RSC)

Groundwater, containing high concentration of carbonate and bicarbonate ions, tends to precipitate calcium and magnesium as carbonates. As a result, an increase in the relative proportion of sodium decreases the soil permeability. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. RSC indicates the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium (Richards, 1954) [19].

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

The irrigation water quality is classified based on RSC values of less than 1.25, 1.25 – 2.5 and greater than 2.5 as good, doubtful and unsuitable respectively (Richards, 1954) [19].

Sodium percent (Na %)

Sodium reacts with soil and reduces its permeability. While sodium combining with carbonate leads to the formation of alkaline soils, sodium combining with chloride forms saline soils. Both these soils affect the plant growth (Wilcox, 1955) [18].

The sodium percent is expressed as

$$Na\ (\%) = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} x100 \quad (3)$$

The irrigation water quality is classified based on Na (%) values of less than 20, 20 – 40, 40-60, 60-80 and greater than 80 as excellent, good, permissible, doubtful and unsuitable respectively (Wilcox, 1955) [18].

Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant.

Chapter 4

Groundwater Quality Evaluation Using GIS

The quantity, quality and availability of drinking water are of the most important environmental, social and political issues at global level. The lack of potable water adversely affects the general health and life expectancy of the people in developing countries [21]. The concentration of several inorganic and organic substances beyond acceptable range causes an adverse impact on human health. Groundwater quality evaluation, therefore, becomes one of the most important aspects in groundwater studies to understand its use for different purposes such as domestic, irrigation and industry [22-25].

Water Quality Index

The Water Quality Index (WQI), which was developed in 1970s, is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. That, thus, becomes an important parameter for the assessment and management of groundwater. WQI is defined as a rating, reflecting the composite influence of different water quality parameters. WQI is calculated from the point of view of the suitability of groundwater for human consumption. It aims at giving a single value to the water quality of a source. This is achieved by translating the various constituents present in a sample and their concentrations into a single value. This can be used to compare different samples for quality on the basis of the index value of each sample.

Importance of WQI

- WQI is the convenient tools to examine trends i.e., to understand the improvement or degradation of water quality at a location over period of time that can be changes from season to season in a year or from year to year.
- WQI helps the policy makers to prioritize the water quality problems at a location and allocate resources/funds based on it.
- WQI helps in ranking of allocations at various locations
- WQI provides a guideline for the authorities for enforcement of standards by comparing with the existing water quality standards at a location.
- WQI highlights the specific environmental conditions
- WQI helps governmental decision-makers in evaluating the effectiveness of regulatory programme
- WQI acts as public information and paves way for scientific research.

Steps Involved in the formulation of WQI

The important steps in the formulation of WQI are as follows. More detailed explanation may be obtained from [26] in 'Water Quality Indices- State of the art review'.

1. Parameter selection

The parameter selection is highly subjective. The water sample may contain different constituent elements in neutral or ionic form (metals, non-metals, metalloids), organics (pesticides, detergents, other organics of industrial or natural origin), cations, anions, suspended solids, radioactive elements, pathogenic bacteria, fungi etc. No assessment can test for all contaminants, nor is there epidemiological health information about the importance, or the risk levels, for most contaminants. As a result, any water quality programme must necessarily choose those important parameters, which together reflect the overall water quality for the purpose.

The problem of subjectivity can be reduced by statistical analysis of past data, which involves large number of experts in collecting opinion. Therefore enormous care, attention, experience, and consensus-gathering skills are required to ensure the most representative parameters for inclusion in a WQI.

2. Transformation of the parameters of different units and dimensions to a common scale using sub indices

3. Assignment of weightages to all the parameters

Similar to parameter selection, assigning weightages is also subjective in nature. Some indices adopt equal weight for all parameters, while some other adopts different weights for different parameters.

4. Aggregation of sub-indices to produce a final index score

GIS Based Groundwater Quality Index

Handling of large volumes of data requires a powerful set of tools for collecting, storing, retrieving, transforming and displaying the spatial data depending on the purpose. The Geographical Information System (GIS) is an organized collection of computer hardware, software, geographical data and personnel, designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information [27]. The data manipulation represents it in proper understandable form and analysis converts it into desired output before displaying the final output [28]. The idea involved in groundwater quality map preparation is shown in Figure 4.

The water quality mapping involves data collection from various spheres. Groundwater data are especially limited in scope and availability compared to surface-water data. Without adequate data, serious water quality challenges are unlikely to be identified and managed adequately to protect human and ecosystem health. Conversely, by monitoring water quality and collecting and sharing water quality data, it is possible to determine if water quality in groundwater is improving or deteriorating and to identify growing problems and potential solutions that require prompt action.

The area of interest can be prepared from topographic map and digital image processing of satellite imagery. The next step involves identification of groundwater sampling points. The number, location and frequency (monthly, seasonly, yearly) of sampling depends on the problem. After sampling, the chemical analysis has to be carried out and, the constituents to be analyzed were determined depending on the intensity of problem. Expert advice is highly required. The thematic maps for each of the constituents can be prepared in GIS environment, and spatial integration can be done to obtain a water quality map. This can further be compared with respective national standards for drinking and irrigation.

The detailed procedure for preparation of Drinking Water Quality Index (DWQI) map and Irrigation Water Quality Index (IWQI) map using GIS is explained below. A study carried out in a river basin in South India is considered as an example [29]. The flow chart showing the methodology adopted for the study is shown in Figure 5.

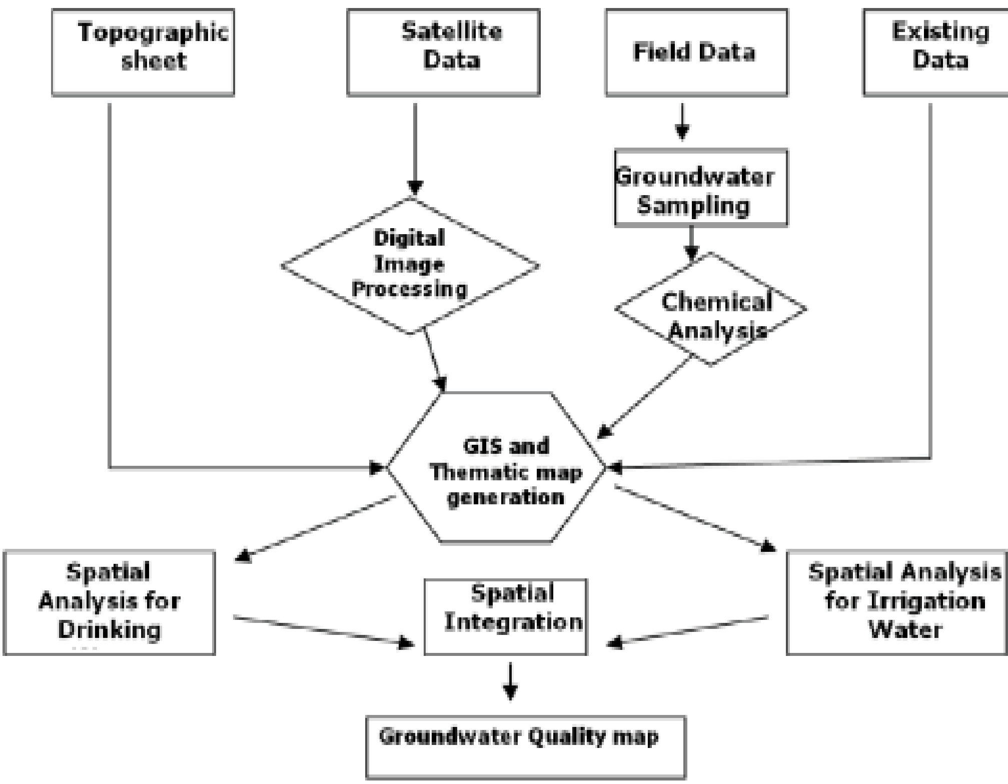

Figure 4: Steps in groundwater quality map preparation.

The physic-chemical parameters of groundwater chosen for the study include pH: Total

Dissolved Solids (TDS); cations such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}),

Potassium (K^{+}); anions such as Chloride (Cl^{-}), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^{-}), Fluoride (F^{-}), Nitrate (NO_3^{-}) and Total Hardness (TH) for drinking purpose and, Salinity, Sodium absorption ratio (SAR), Residual Sodium Carbonate (RSC) and Sodium Percent (Na %) for irrigation purpose during post-monsoon (January) and pre-monsoon (June) seasons.

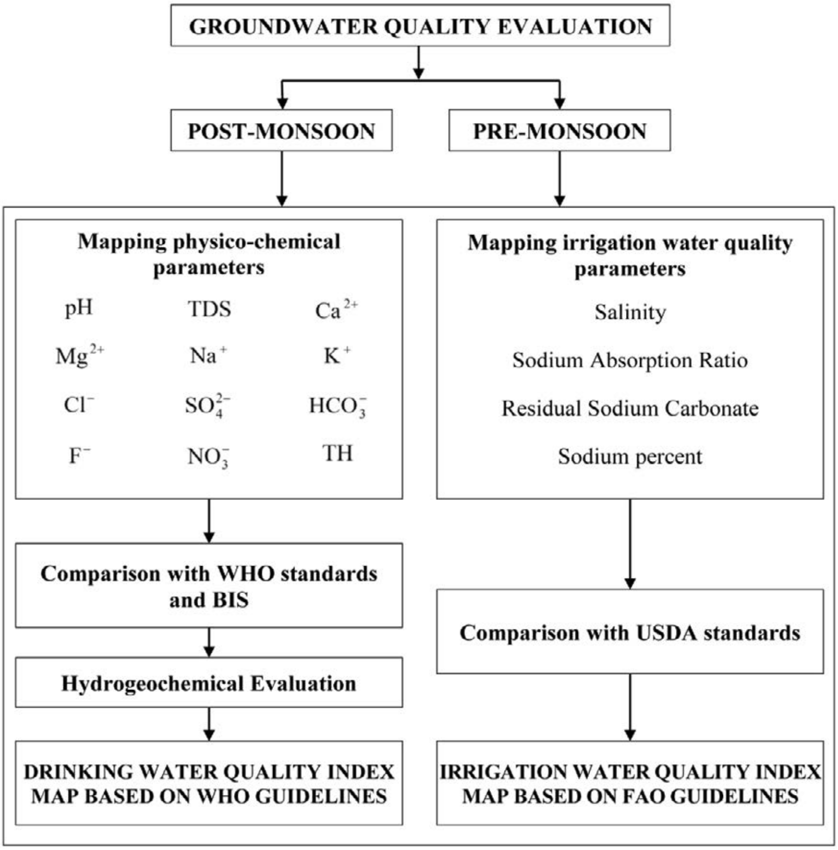

Figure 5: Methodology for groundwater quality evaluation.

Drinking Water Quality Index

The base map of the area was prepared from Survey of India toposheets and updated with the satellite imagery of the area. The available groundwater quality data for the monitoring stations in the study area was collected from the Government of India departments. In addition to that, some more groundwater sampling stations were identified, samples were collected for both post- and pre monsoon seasons and chemical analysis were carried out. The data collected from Government departments and the field sampling was entered in GIS database.

The spatial and temporal variations of physico-chemical constituents of groundwater were studied by comparing the physico-chemical parameters such as pH, TDS, $Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, F^{-}, NO_3^{-}$ and TH with drinking water quality standards prescribed by WHO and BIS. The spatial distribution maps were prepared for each of the physico-chemical parameters using Inverse Distance Weighted (IDW) interpolation technique in ArcGIS for both seasons. These maps were classified as 'desirable', 'maximum permissible' and areas 'exceeding maximum permissible' limit based on WHO guidelines as presented in Table 3. The thematic maps showed the spatial variation of each of the constituents in the study area along with its areal extend. It also helps to understand the temporal variation (post- and pre monsoon) of constituents.

Parameter	Category		
	Desirable	Maximum Permissible	Exceeding Maximum Permissible
pH	7 – 8.50	8.50 – 9.2	< 7 and >9.2
TDS	0 – 500.0	500.1 – 1500.0	500.1 - 1500.0
Ca^{2+}	0 – 75.0	75.1 – 200.0	75.1 – 200.0
Mg^{2+}	0 – 50.0	50.1 – 150.0	50.1 – 150.0
Na^{+}	-	< 200	< 200
K^{+}	-	< 12	< 12
SO_4^{2-}	0 – 200.0	200.1 – 400.0	200.1 – 400.0
HCO_3^{-}	-	< 500	< 500
Cl^{-}	0 – 200.0	200.1 – 600.0	200.1 – 600.0
NO_3^{-}	-	< 45	< 45
F^{-}	-	< 1.5	< 1.5
TH	0 – 100.0	100.1 – 500.0	100.1 – 500.0

Table 3: Classification of groundwater quality map into various categories as per WHO guidelines.

The groundwater chemistry and influence of monsoon on water quality of the basin was determined by plotting the Piper trilinear diagram as per Figure 4.

The Drinking Water Quality Index (DWQI) proposed by Ramakrishnaiah et al., 2009 [30] is adopted for the preparation of DWQI map of the river basin for post- and pre-monsoon seasons. The index was computed by assigning weights (w) to the water quality parameters (a) based on their perceived threat to water quality. The standards for drinking purpose as recommended by WHO (Table 2) were considered for DWQI computation.

The relative weight (W_a) is computed using

$$W_a = \frac{w_a}{\sum_{a=1}^{n} w_a} \quad (4)$$

where,

w_a = weight of water quality parameter 'a'

n = number of parameters

The quality parameters (pH, TDS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, F^{-}, NO_3^{-} and TH) were assigned weights ranging from 1-5 according to their importance in the quality of water for drinking purpose. The maximum weight of 5 was assigned to pH and total dissolved solids due to their major importance in water quality assessment. Bicarbonate was given a weight of 1 as it is not very significant in the water quality assessment and Fluoride was also assigned a weight of 1, as it is not causing any contamination in the study area. The cations, anions and total hardness were assigned weights between 1 and 4 based on their importance in the water quality evaluation.

A Quality Rating Scale (q_a) for each parameter was calculated by dividing its concentration by its respective WHO standard and expressed as

$$q_a = \frac{C_a}{S_a} \times 100 \tag{5}$$

where,

C_a = concentration of water quality parameter (a) in mg/l

S_a = WHO standard for water quality parameter (a) in mg/l

The sub-index (SI) was determined for each parameter, which is used to determine the DWQI as

$$SI_a = W_a \times q_a \tag{6}$$

$$DWQI = \sum SI_a \tag{7}$$

The Drinking Water Quality Indices (DWQI) obtained for each station were entered as attribute in GIS, and interpolated using IDW method to obtain the DWQI map. This process was repeated for both post- and pre-monsoon periods. The drinking water quality is classified based on DWQI values of less than 50, 50 – 100, 100 – 200, 200 – 300 and greater than 300 as excellent, good, poor, very poor and unsuitable category respectively.

Irrigation Water Quality Index

The irrigation water quality and the associated hazards to soil characteristics and crop yield is a complex phenomenon involving the combined effect of influencing parameters. The hazards affecting irrigation water quality include (a) salinity hazard, (b) infiltration and permeability hazard, (c) specific ion toxicity hazard, (d) trace element toxicity hazard and (e) hazard due to miscellaneous impacts on sensitive crops [17]. A linear combination of these hazards forming a single index, known as Irrigation Water Quality Index (IWQI), is used to assess the suitability of irrigation water.

In the irrigation water quality evaluation, post and pre-monsoon maps of irrigation water quality parameters were evaluated based on United States Department of Agriculture (USDA) standards. The spatial maps of electrical conductivity representing salinity hazard, a combined electrical conductivity and sodium absorption ratio criterion representing infiltration and permeability hazard, Cl^- and Na^+ representing specific ion toxicity hazard, F^- representing trace element toxicity hazard, and $G_1 = w_1 r_1$ and pH representing miscellaneous effects hazard were prepared. These maps were reclassified into irrigation suitable classes as high, medium and low as per FAO guidelines, and overlaid by assigning weights to obtain Irrigation Water Quality Index (IWQI) maps for post- and pre- monsoon seasons.

The salinity hazard index (G_1) is formulated as

$$G_1 = w_1 r_1 \tag{8}$$

The infiltration and permeability hazard index (G_2) is expressed as

$$G_2 = w_2 r_2 \tag{9}$$

The specific ion toxicity hazard index (G_3) is obtained as the weighted average of influencing toxic specific ions as

$$G_3 = \frac{w_3}{n} \sum_{j=1}^{n} r_j \tag{10}$$

where,

n = number of influencing parameters

The trace element toxicity hazard index (G_4) is determined by

$$G_4 = w_4 r_4 \tag{11}$$

The hazard index due to miscellaneous effects index (G_5) is calculated as the weighted average of influencing parameters (pH, HCO_3^- etc.) as

$$G_5 = \frac{w_5}{n} \sum_{k=1}^{n} r_k \tag{12}$$

where,

w_1, w_2, w_3, w_4 and w_5 = weights assigned to the hazard groups

r_1, r_2, r_j, r_4 and r_k = rating values

The Irrigation Water Quality Index (IWQI) is expressed as

$$\text{IWQI} = \sum_{l=1}^{5} G_l \tag{13}$$

where,

G_l = irrigation water hazard index

The hazard groups are assigned weights of 1 to 5 depending on their influence in the irrigation water quality assessment and, assigned suitability ratings of 3, 2, 1 for high, medium and low suitability of irrigation water respectively as shown in Table 4. The IWQI is classified into irrigation water suitability class as low (< 22), medium (22-37) and high (> 37) [31].

Irrigation water hazard	**Weight**	**Parameter**	**Suitability rating (r)**		
			High	**Medium**	**Low**
			3	**2**	**1**
Salinity hazard	5	EC (μS/cm)	< 700	700 - 3000	> 3000
Infiltration and permeability hazard	4	SAR 0 – 3	EC > 700	EC 700 – 200	EC < 200
		3 – 6	> 1200	1200 - 300	< 300
		6 – 12	> 1900	1900 - 500	< 500
		12 – 20	> 2900	2900 – 1300	< 1300
		20 – 40	> 5000	5000 – 2900	< 2900
Specific ion toxicity	3	SAR(Na^+)	< 3	3 – 9	> 9
		Cl^-	< 140	140 – 350	> 350
Trace element toxicity	2	F^-	< 1	1 – 15	> 15
Miscellaneous effects	1	HCO_3^-	< 90	90 – 500	> 500
		pH	7 - 8	6.5 – 7 and 8 - 8.5	< 6.5 and > 8.5

Table 4: Irrigation water quality classification.

Chapter 5

Case Studies

Knowledge on hydrochemistry is important to assess the quality of groundwater for understanding its suitability for drinking and irrigation purposes. Narayana and Suresh (1989)[32] prepared correlation matrices for the relationship between physical and chemical parameters of groundwater. The geochemical characterization of groundwater at Visakhapatnam, Andhra Pradesh [33-36] indicated deterioration of water quality due to over-exploitation [37]. compared the analytical results of groundwater in Rajshahi city of Bangladesh with WHO limits. [38] Used GIS to represent and understand the spatial variation of geochemical elements in Panvel Basin, Maharashtra.

Asadi et al. (2007) [39] prepared thematic maps for water quality analysis of the municipal corporation of Hyderabad by visual interpretation of visual interpretation of SOI toposheets and linearly enhanced fused data of IRS-ID PAN and LISS-III imagery on 1:50,000 scale using AutoCAD and ARC/INFO software. Spatial distribution maps of major physico-chemical water quality parameters were prepared using curve fitting method in Arc View GIS software and Drinking Water Quality Index (DWQI) was determined. The study helped to clearly identify areas which exhibited poor, very poor and unfit water quality and appropriate methods for improving the water quality in affected areas were suggested.

Babiker et al. (2007) [40] proposed a GIS based groundwater quality index method to synthesize available water quality data (Ca^{2+} , Cl^- and Na^+) by indexing them numerically relative to WHO standards.

Sadashivaiah et al. (2008) [41] evaluated the groundwater quality in Tumkur Taluk, Karnataka. The parameters considered for determining Water Quality Index (WQI) include pH, total hardness, calcium, magnesium, bicarbonate, chloride, nitrate, sulphate, total dissolved solids, iron, manganese and fluorides. Regression analysis was carried out with TDS as dependent variable and Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , NO_3^- , Na^+ and (HCO_3^- + CO_3^{2-}) as independent variables. The high value of WQI was found due to higher values of iron, nitrate, total dissolved solids, hardness, fluorides, bicarbonate and manganese in groundwater.

Shah et al., (2008) [42] considered the physico-chemical parameters such as pH, EC, TDS, total alkalinity, Calcium Hardness (CaH), Magnesium Hardness (MgH), Total Hardness (TH), Cl^- , F^-, Na^+, K^+, DO, BOD, COD and sulphate of groundwater samples of Gandhinagar taluka of Gujarat state, India to arrive at WQI. The experimental values of water samples were compared with WHO standards and United State Salinity Laboratory for drinking and irrigation purposes respectively. The statistical analysis like mean, Standard Deviation (SD), Coefficient of Variance (% CV), analysis of variance (ANOVA), *t*-test, Coefficient Of Correlation (r) and regression analysis of obtained data were carried out. The results showed that the quality of water is poor for drinking and reasonably good for irrigation purpose.

Rajankar et al. (2009) [43] calculated WQI for different groundwater sources viz., dug wells, bore wells and tube wells at Khaperkheda region, Maharashtra. Twenty two different sites were selected in post monsoon, winter and summer season; and water quality index was calculated using water quality index calculator given by National Sanitation Foundation (NSF) information system. The samples were analyzed for different physical, chemical and bacteriological parameters including nine parameters of water quality index (BOD, DO, faecal coliforms, nitrate, pH, temperature change, TDS, total phosphate and turbidity) using standard methods. WQI showed fair water quality rating during post-monsoon season which then changed to medium in summer and winter seasons for dug wells, but showed medium water quality rating for bore wells and hand pumps in all seasons.

In India, several studies have reported groundwater contamination by nitrate due to agricultural activities [44-46] and soil contamination due to irrigation water quality [47,48]. Subramani et al. (2005) [49] studied the groundwater quality and its suitability for drinking and agricultural uses in Chittar basin, Tamil Nadu. The results of the study were compared with the recommended limits suggested by WHO. The hydrochemical studies carried out in Ranga Reddy district, Andhra Pradesh [50,51], Harran plain, Turkey [52], Ishwardi Municipal Area, Pabna District, Bangladesh [53] and Markandeya river basin, Karnataka [54] revealed the quality of water suitable for drinking, irrigation and industrial uses.

The studies carried out by [55-57] used GIS as a database system to prepare maps of water quality according to concentration values of different chemical constituents, to locate groundwater quality zones suitable for domestic and irrigation purposes.

Dhembare (2012) [58] assessed the irrigation water quality of Dynaneshwar Dam water, Ahmednagar, Maharashtra through sodium, calcium, magnesium and chlorine concentration. The quality indices were evaluated with sodium absorption ratio (0.17 to 3.87), soluble sodium percentage (12.87 to 40.09), residual sodium carbonate (-0.3 to -8.0), Schoeller Index (0.20 to 0.70) and Kelly's Index (0.26 to 0.75). The indices were well in agreement with United States Environmental Protection Agency standards, indicating the water quality as highly suitable for irrigation.

Simsek and Gunduz (2007) [59] proposed a GIS integrated tool to evaluate the quality of irrigation water based on the potential soil and crop problems of the Simav Plain located in western Anatolia, Turkey. The results showed that groundwater quality in the aquifer is found to be fairly good and is mostly suitable for irrigation purpose.

It can be inferred from the above literature that good data, innovative technology and regular monitoring are the cornerstones of effective efforts to improve groundwater quality. Addressing water quality challenges will mean building capacity and expertise in developing countries and deploying real-time, low-cost, rapid, and reliable field sampling tools, technologies, and data-sharing and management institutions.

Chapter 6

Concluding Remarks

Groundwater resources degradation is an issue of significant societal and environmental concern in India, where which plays a crucial role as a decentralized source of drinking. Systematic estimation and budgeting of groundwater resources based on spatio-temporal distribution, its allocation for meeting the competing demands for irrigation, industrial and domestic usage and, conjunctive use of surface and groundwater resources are therefore essential for optimal utilization of available groundwater on a sustained basis.

Some of the management measures that may be adopted to reduce the intensity of water quality degradation are:

- For reducing microbial contamination, authorities should strictly ensure disinfection at the point of use.
- For chemical pollution/contaminants, the interim solution like defluoridation and arsenic removal plants need to be promoted.
- A combination of salts, zeolite and chlorine bleach can be adopted for treating turbidity, suspended solids and low level fluoride and arsenic contamination.
- Long-term solutions like rainwater harvesting, artificial recharge and restoration, and protection of tanks, lakes and other water bodies should be adopted.
- Promotion of traditional structures like open wells and sanitized dug wells is effective in tackling the problems due to iron, arsenic and fluoride.
- Household ceramic filters are effective in prevention of diarrhoea in many developing countries. More effort is needed to promote these filters through village entrepreneurship.
- Ground water quality assessment in industrial areas and in urban areas with specific reference to toxic pollution to evolve mitigative plans.
- Set up water quality monitoring stations at major water intake points to check water quality. Also, undertake inter-state water quality monitoring programme.

- Environmental awareness of the health impacts due to poor quality water should be emphasized though education of the public and community participation.

With information on the importance of clean water for life and health, and research on the current state of the waterways in hand, communities will strive for water quality improvements. New approaches and techniques need to be developed and applied to address emerging issues and to provide decision-makers with relevant and accurate assessment of data and information. Water Quality Index, thus forms a very useful tool for communicating the information on overall quality of water. GIS based water quality mapping forms an effective tool essential for monitoring, modeling and environmental change detection. The book brings an insight into the capabilities of GIS in exploring the full value of environmental data through spatial analysis and visual display of geographic information.

Education and capacity building at larger scales can promote effective watershed, national, and international interventions that develop better standards, regulation, and enforcement to improve collective behavior. Including water education in the formal educational curricula is a key intervention to step up to higher scales of awareness. The future of water quality at local, regional, and global scales depends on investments of individuals, communities, and governments at all levels to ensure that water resources are protected and managed in a sustainable manner.

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