WATER RESOURCES, POLLUTION, WATER QUALITY MANAGEMENT AND MONITORING

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Abstract *Out of all the available water resources, 97% of water is present in oceans, 2% is in polar ice caps and fresh water lakes constitute 1% of the water. In India, out of total rainfall in an area of 3290 lakh hectares, a rainfall of 4000 billion cubic meters annually, 41% (10,02,400 lakh) is lost as evaporation and transpiration, 40% (9,77,600 lakh) is lost as run off, 10% (2,44,400 lakh) is retained as soil moisture and 9% (2,19,960 lakh) seeps in for recharging ground water. India will be requiring about 1,20,10,000 lakh cubic meters (cum) of water in the year 2050 to cater to the needs of about 150 crores population for its food, drinking water, domestic, irrigation, navigational, environmental and ecological requirements. The demand for water for irrigation, industrial, and domestic uses is increasing with development. Many developmental projects, industrial/ urbanization programs or policies are likely to have both qualitative and quantitative effects on surface and ground water environment (river, lakes, esturies, oceans), which may result in considerable impacts on aquatic faunal or floral species and aquatic ecosystems. The release of complex and diverse industrial wastes impair the quality of environment and poses a threat to human health directly or indirectly. Surface waters are classified according to intended uses that dictate the specific physical, chemical, and biological quality standards, thus insuring that the most beneficial uses will not be deterred by pollution. Different human activities like agriculture, industrial and land use changes contribute significantly to the deterioration of water quality which if managed properly can help in its conservation. An important aspect of groundwater pollution is the fact that it may persist underground for years, decades, or even centuries. This is in marked contrast to surface water pollution. For control of groundwater pollution the point sources and diffuse sources, have to be monitored and regulated properly.*

WATER RESOURCES MANAGEMENT

Water is a vital natural resource which forms the basis of all life. Further, water is a key resource for all economic activities ranging from agriculture to industry. With ever increasing pressure of human population, there is severe stress on water resources.

EARTH'S WATER BUDGET

Out of all the available water resources, 97% of water is present in Oceans, 2% is in polar ice caps and fresh water lakes constitute 1% of the water. In India, out of total rainfall in an area of 3290 lakh hectares, a rainfall of 4000 billion cubic meters annually, 41% (10,02,040 lakh) is lost as evaporation and transpiration, 40%

(97,77,600 lakh) is lost as run off, 10% (2,44,4000 lakh) is retained as soil moisture and 9% (2,19,960 lakh) seeps in for recharging groundwater. Of the 40% stream flow water, 8% is used for irrigation, 2% for domestic use, industries use 4%, and electric generation needs 12%. Total water use in the world has increased from 1000 km^3 y^{-1} in 1940, to 4130 km^3 y^{-1} in 1990 and 5000 km^3 y^{-1} in 2000. At least one fifth of the world's people lack access to safe drinking water. Eighty countries account for 40% of the world's population. Forecasts are that by 2025 as much as 2/3 of the world's population will be affected by moderate to severe water scarcity unless appropriate mitigation measures are taken.

The population in India is increasing at an annual rate of 1.7 crores and by the year 2025 may cross 150 crores. India will be requiring about, 1,2010,000 lakh cubic meters (cum) of water in the year 2025 to cater to the needs of about 150 crores population for its food, drinking water, domestic, industrial, navigational, environmental and ecological requirements due to which there is a great need to conserve water. Experts' opinion is that there would be no underground water by 2025 in Rajasthan if the present rate of indiscriminate utilization continues. Annually, 1/3rd of the area in the country is drought hit while some areas struggle/suffer with natural calamities like floods. Even 30% of the available water is not efficiently used, whereas most of the waters are wasted in to the sea.

EFFORTS FOR WATER CONSERVATION

A massive ten-year watershed programme for development of all the degraded and waste lands was launched during 1997 in Andhra Pradesh so as to treat 100 lakh hectares of waste and degraded lands which is highly commendable with reference to sustainable development. As a result of this effort, 27 lakh hectares of degraded and waste land is under treatment up to December 2000 with participation of stake holders through 5472 watershed committees. Similarly, under Joint Forest Management (JFM), 16.6 lakh hectares of degraded forest land was treated with community participation through 6647 Vana Samrakshana samithis.

Water pollution

The demand for water for irrigation industrial, and domestic uses is increasing with development. Many developmental projects, industrial/urbanization programs or policies are likely to have both qualitative and quantitative effects on surface and ground water environment (rivers, lakes, esturies, oceans), which may result in considerable impacts on aquatic faunal or floral species and aquatic ecosystems.

The release of complex and diverse industrial wastes impair the quality of environment and poses a threat to human health directly or indirectly. The liquid wastes may permeate into the ground or find their way into the surface waters causing severe problems of water pollution due to which the access of safe drinking water in the entire world has been tremendously effected. Domestic sewage leads the spread of water borne disease like typhoid, cholera, gastroenteritis, dysentery, hepatitis etc. The toxic substances present in the industrial wastes can affect the aquatic life, thus distrupting the whole ecosystem. Mercury and organochlorine pesticides are important examples of bioaccumulating substances. A large number of birds like hawks and eagles have also been found to be adversely affected by consuming DDT containing organisms.

Source of water pollution can be classified as (a) Non-point sources, and (b) Point sources which are given in Table 1. Major types of pollutants are given in Table 2.

Table 1 Non-point and point sources

Non-point Pollutants	Point Pollutants
Pollutants from: Urban area, Industrial area, Rural runoff	Specific discharges from: Municipalities or industrial complexes
Examples: Sediment, Pesticides, or Nitrates entering surface water runoff from agricultural farms	Examples: Organics or metals entering surface water as a result of wastewater discharge from a manufacturing plant.

SURFACE WATER POLLUTION

The effects of pollution sources on water quality are manifold and depend upon the type and concentration of pollutants. Soluble organics, as represented by high BOD wastes, cause depletion of oxygen in the surface water. This can result in fish getting killed, and undesirable aquatic life and odors. Even trace quantities of certain organics may cause undesirable taste and odors, and certain organics may be biomagnified in the aquatic food chain. Suspended solids decrease water clarity and hinder photosynthetic process; if solids settle and form sludge deposits, changes in benthic ecosystems result. Color, turbidity, oils, and floating materials are of concern because of their aesthetic undesirability and possible influence on water clarity and photosynthetic processes. Excessive nitrogen and phosphorous can lead to algal overgrowth, with concomitant water treatment problems resulting from algae decay. Acids, alkalies and toxic substances have the potential for causing fish kills and creating other imbalances in stream ecosystems.

WATER QUALITY MANAGEMENT

Many uses of water are restricted within narrow ranges of water quality, such as public and industrial water supply. Therefore, control of quality is required to ensure that the best usage of water is not prevented by indiscriminate use of watercourses for disposition of wastes.

Surface waters are classified according to intended uses that dictate the specific physical, chemical, and biological quality standards, thus insuring that the most beneficial uses will not be deterred by pollution. Criteria defining quality are dissolved oxygen, solids, coliform bacteria, toxins, pH, temperature, and other parameters as necessary.

Table 2 Major types of pollutants

Pollutant	Major sources	Effects
Oxygen-demanding wastes	Sewage effluent; agricultural run-off including animal wastes; some industrial effluents (from paper mills, food-processing, etc.)	Decomposition by aerobic bacteria depletes level of dissolved oxygen in water; flora and fauna perish; further decomposition by anaerobic bacteria produces foul-smelling toxic substances such as hydrogen sulfide.
Plant nutrients	Sewage effluent including phosphates from detergents; agricultural run-off, especially nitrates from fertilizers.	Algal blooms; death of submerged vegetation; production of large amounts of dead organic matter with subsequent problems of oxygen depletion (see above)
Acids	Acid rain; mine drainage; planting of extensive areas of coniferous forests, which acidify the soil.	Acidification of natural waters; sharp decline in species richness; concomitant increase in level of toxic metals in solution.
Toxic metals Hg, Pb, Cd, Zn, Sn	Ore mining; associated industrials; lead from vehicle exhaust emissions	Biomagnification of toxic metals with each successive stage of food chain; threat to consumers including humans
Oil	Drilling operation; oil tanker spills; natural seepage; waste disposal	Contamination of the aquatic environment, death of birds and mammals
DDT (an organochlorine)	Direct application; agricultural run-off and via aerial crop-spraying	Biomagnification; top carnivores (especially birds) at risk; very persistent in the environment
PCBs(a series of) Organochlorines	Sewage effluent; waste incineration in toxic dumps; landfill sites	Biomagnification; top carnivores at risk; effects on human health include joint pain, Chloracne and fatigue
Radiation	0% from natural sources; 20% from nuclear weapons testing, medical X-rays, nuclear energy industry, etc.	Degree of tissue damage and risk of death depend on exposure; radionuclides can be biomagnified, and some are very persistent in the environment
Heat	Coolant waters from industry, principally the electricity generating industry	Change in species composition usually accompanied by a decrease in species richness; fish may migrate or be killed by suffocation; reproductive cycle of fish and other aquatic organism disrupted

As water travels through the hydrologic cycle, it changes from pure salt-free moisture suspended in the troposphere as clouds to the brine of the sea. Through the cycle, it progressively picks up salts by trickling through the atmosphere, flowing on the earth's surface, percolating through the soil medium and the unsaturated zone, and moving in the saturated zone.

Different human activities like agriculture, industrial and land use changes contribute significantly towards the deterioration of water quality, which if managed properly can help in its conservation.

Agricultural Uses

Irrigation, in particular, degrades the quality of water due to

1. Concentration of salts in irrigation water as a result of evapotranspiration, and
2. Pick-up of fertilizers and other soluble additives applied to the soils.

Industrial Uses

The major applications of water in industrial plants are: (1) cooling, (2) boiler feed, (3) processing and (4) sanitation. The quality and chemical composition of the waste water varies with respect to the type of industry and water use. Pollution effects of industrial waste water are well recognized.

Land Use Changes

Changes in land use due to industrialization and urbanization also contribute significantly to deterioration of water quality.

CONTROL MEASURES FOR SURFACE WATER POLLUTION

The characteristic of municipal effluents are, being controlled by governmental regulations (Table 3), by adopting proper treatment facilities. According to criteria established for secondary treatment, the average allowable BOD and suspended solids can each be to a maximum of 30 mg/l. In selected locations, tertiary standards for phosphate content can be made to a maximum of 1.0 mg/l of phosphorous and/or require oxidation of ammonia nitrogen to nitrate.

Reducing pollution in agricultural and drainage is usually not practical beyond the benefits resulting from good land management. Significant phosphorous reduction in major rivers is not realistic expectation because of both uncontrolled land drainage and reluctance to pay for phosphate precipitation in waste water treatment. Consequently, many reservoirs on rivers have significant deterioration of water quality from nutrient enrichment, with anaerobiosis of the bottom waters being the common result.

Establishing a lower limit for dissolved oxygen protects propagation of fish and other aquatic life, as well as enhancing recreation and reducing the possibility of odors resulting from decomposition of waste organic material.

Table 3 ISI tolerance limits for the industrial effluents

Characteristics	Tolerance limits for industrial effluents discharge into		
	Inland surface water	Public sewers IS: 2490-1982	On land for irrigation
BOD (5 day 20°C mg/l)	30	350	100
COD mg/l	250	-	-
PH	5.5-9.0	5.5-9.0	5.5-9.0
Total suspended solids mg/l	100	600	200
Oil and grease mg/l	10	20	10
Phenolic compounds mg/l	1	5	-
Cyanides (as CN mg/l)	0.2	0.2	0.2
Sulphides (as S mg/l)	2.0	-	-
Fluorides (as F mg/l)	2.0	15	-
Total residual chlorine mg/l	1.0	-	-
Insecticides mg/l	0	-	-
Arsenic as As mg/l	0.2	0.2	0.2
Cadmium as Cd mg/l	2.0	1	-
Chromium hexavalent mg/l	0.1	2.0	-
Copper mg/l	3.0	3.0	-
Lead mg/l	0.1	1.0	-
Mercury mg/l	0.01	0.01	-
Nickel mg/l	3.0	3.0	-
Selenium mg/l	0.05	0.05	-
Zinc mg/l	5.0	15.0	-
Chlorides (as Cl mg/l)	1000	1000	600
Sulphates mg/l	1000	1000	1000
% Sodium	-	60	60
Ammonical nitrogen mg/l	50	50	-
Nitrates as NO_3 mg/l	-	-	-
Radioactive materials			
α- Emitters	10^{-7}	10^{-7}	10^{-8}
β- Emitters	10^{-6}	10^{-6}	10^{-7}

Cold water fish require stringent limitations, 6 mg/l with a minimum of 7 mg/l at spawning times: while warm-water species being more tolerant need 4 to 5 mg/l. Dissolved solids are restricted because high concentrations interfere with agricultural, domestic, and industrial water uses. The strictest coliform standard applies to shelfish harvesting, since the meat may be eaten without being cooked. The next most stringent coliform standard is for contact recreation where persons are likely to ingest water while bathing or water skiing.

GROUNDWATER POLLUTION

The principal source and causes of ground water pollution are listed in Table 4, under four categories – municipal, industrial, agricultural, and miscellaneous. Most of the pollution stems from disposal of wastes on or into the ground. Methods of disposal include placing wastes in percolation ponds, on the ground surface (spreading or irrigation), in seepage pits or trenches, in dry streambeds, in land fills, into disposal wells, and into injection wells. Since groundwater in any regions is a high-quality economical source, future demand is expected to increase for domestic use.

Table 4 Possible sources of ground water contamination

Category I Sources designed to discharge substances
Subsurface percolation (e.g., septic tanks and cesspools).
Injection wells: Hazardous waste, Nonhazardous waste (e.g., brine disposal and drainage), Nonwaste (e.g. enhanced recovery, artificial recharge, solution mining, and in-situ mining).
Land application: Wastewater (e.g., spray irrigation), Wastewater by-products (e.g., sludge), Hazardous waste.

Category II Sources designed to store, treat, and/or dispose of substances; discharge through unplanned release
Landfills: Industrial hazardous waste, Industrial nonhazardous waste, Municipal sanitary waste, Open dumps, including illegal dumping (waste), Residential (or local) disposal (waste), Surface impoundments, Hazardous waste, Nonhazardous waste.
Materials stockpiles (nonwaste), Graveyards, Animal burial.
Aboveground storage tanks: Hazardous waste, Nonhazardous waste, Nonwaste
Underground storage tanks: Hazardous waste, Nonhazardous waste, Nonwaste, Containers, Hazardous waste, Nonhazardous waste, Nonwaste.
Open burning and detonation sites: Radioactive disposal sites.

Category III Sources designed to retain substances during transport or transmission
Pipelines: Hazardous waste, Nonhazardous waste, Nonwaste,
Materials transport and transfer operations: Hazardous waste, Nonhazardous waste, Nonwaste.

Category IV Sources discharging substances as consequence of other planned activities
Irrigation practices (e.g., return flow): Pesticide applications, Fertilizers applications, Animal feeding operations, Deicing salt applications, Urban runoff, Percolation of atmospheric pollutants, Mining and mine drainage, Surface mine-related, Underground mine-related.

Category V Sources providing conduit or inducing discharge through altered flow patterns
Production wells: Oil (and gas) wells, Geothermal and heat recovery wells, Water supply wells, Other wells (nonwaste), Monitoring wells, Exploration wells.

Category VI Naturally occurring sources whose discharge is created and/or exacerbated by human activity
Groundwater- Surface water interactions, Natural leaching, Salt-water intrusion/brackish water upconing (or intrusion of other poor-quality natural water).

Change in water quality resulting from withdrawal of groundwater or channelization of river, although induced by human activities, are often viewed as natural contamination. Strict controls over diversion of groundwater in coastal plains can be affective in eliminating saltwater intrusion. In cases where seawater can enter only through limited narrow geologic gaps, freshwater injection wells have been installed parallel to the seashore across the gap. The resulting water mound acts as a barrier, reversing the hydraulic gradient in the aquifer so that the groundwater flow is toward the sea again.

An important aspect of groundwater pollution is the fact that it may persist underground for years, decades, or even centuries. This is in marked contrast to surface water pollution. Reclaiming polluted groundwater is usually much more difficult, time consuming, and expensive than reclaiming polluted surface water. Underground pollution control is achieved primarily by regulating the pollution source, and secondarily by physically entrapping and, when feasible, removing the polluted water form the underground.

EVALUATION OF POLLUTION POTENTIAL

To measure the pollution potential from a given source, Le Grand (1964) developed an empirical control system which is given by the sum of the numerical ratings of the five factors. Total point values may be interpreted in terms of possibility of pollution. Although this procedure is imperfect, it has the advantages of providing quantitative evaluations and of permitting relative comparisons, of potential pollution from alternative waste disposal sites.

Effective prevention from point sources, such as wastewater ponds, landfills, refuse piles, buried storage tanks and deep injection wells, is based on site selection, controlled design, proper construction and careful operation. Strategically located monitoring wells around the site for testing of groundwater are recommended for early warning.

NATURAL CONTAMINATION

The principal natural chemicals found in groundwater are dissolved salts, iron and manganese, fluoride, arsenic, radionuclides and trace metals. Both geologic and climatic conditions influence mineral composition. In arid regions with limited water recharge, slow percolation results in mineralized poor quality water with high content of sodium chloride.

In humid climates, weathering of sedimentary rock releases calcium and magnesium, creating excessive hardness. Fluoride is a constituent of mineral fluoride found in sedimentary, igneous and metamorphic rocks. In some regions, high concentrations of fluoride in groundwater result in fluorosis (mottling of teeth) and in extreme cases, bone damage.

Arsenic can be a significant problem in aquifers of volcanic deposits where concentrations are higher than the maximum contaminant level. Small amounts of metals, such as selenium, cadmium, lead, copper and zinc are found in rocks and unconsolidated deposits. Despite this groundwater generally contains only traces of these metallic elements and their presence is rarely a water-quality problem.

For control of groundwater pollution, the point and diffuse sources have to be monitored and regulated properly.

Calculation of Water Quality Index

For calculation of Water Quality Index (WQI), selection of parameters has great importance. Since selection of too many parameters might widen the WQI and importance of various parameters depends on the intended use of water, eight physico-chemical parameters namely pH, TDS, total alkalinity, total hardness, chloride, sulphate DO and BOD are normally used to calculate WQI. The calculation of WQI can be made using weighted arithmetic index method given in the following steps.

Calculation of Subindex or Quality Rating Let there be η water quality parameters. Quality rating or subindex, q_η, corresponding to η^{th} parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value. The q_η is calculated using the following expression (Tiwari and Mishra, 1985):

$$q_\eta = 100\{(V_\eta - V_{10})/(S - V)\} \qquad (1)$$

where q_η is quality rating for the η^{th} water quality parameter; V_η is estimated value of the η^{th} parameter at a given sampling station; S_η is standard permissible value of η^{th} parameter; V_{10} is ideal value of η^{th} parameter in pure water.

All the ideal values (V) are to be taken as zero for the drinking water except for pH = 7.0 and dissolved oxygen = 14.6 mg/l.

Calculation of Unit Weight The unit weights (W_n) for various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

$$W_n = K/S_n \qquad (2)$$

where W_n is unit weight for parameters; S_n is standard value for parameters; and K is constant for proportionality.

Calculation of WQI

WQI is calculated from the following equation:

$$WQI = \sum_{\eta=1}^{\eta} q_\eta W_\eta \Big/ \sum_{\eta=1}^{\eta} W_\eta \qquad (3)$$

SUMMARY

Different human activities like agriculture, industrial and land use changes contribute significantly to the deterioration of water quality, which if managed properly can help in water conservation. An important aspect of groundwater pollution is the fact that it may persist underground for years, decades, or even centuries. This is in marked contrast to surface water pollution. For control of groundwater pollution the point sources and diffuse sources, have to be monitored and regulated properly.

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INDIAN NATIONAL COMMITTEE ON HYDROLOGY (INCOH)

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Constituted by the Ministry of Water Resources in 1982

INCOH Publications

Publication of Jalvigyan Sameeksha Journal

To disseminate information and promote hydrological research in the country, INCOH brings out the bi-annual Journal '*Jalvigyan Sameeksha*' (Hydrology Review Journal). The papers published in the Journal are by invitation only. The Journal is widely circulated to all organisations and agencies dealing with water sector.

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IHP-VI activities

India is actively participating in the IHP-VI activities and has chalked out a detailed program in accordance with IHP-VI themes towards preparation of reports, taking up research studies, organisation of seminars/symposia at national and regional level, promotion of hydrological education in the country, establishing nodal point for implementation of G-WADI program of IHP, UNESCO, for arid and semi-arid regions of South and Central Asia, and HELP basin program for India. It is envisaged to participate in all the relevant and feasible programs identified under the various focal areas of IHP-VI as given below.

India's participation in IHP-VI programs

Focal Area	Integrated assessment of water resources in the context of global land based activities and climate change
Focal Area	Extreme events in land and water resources
Focal Area	Dry lands
Focal Area	Public awareness raising on water interactions
Focal Area	Continuing education and training for selected target groups

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