WATER THE VERSATILE RESOURCE

Water, one of the fundamental resources, is also **one of the most unusual substance.** Although its chemical formula is simple yet the effect of water on environment is more consequential than ever imagined. As the universal solvent', it possesses extra ordinary ability to dissolve a broad range of substances. The salinity of the world's oceans is a direct result of water's ability to dissolve rock materials as it flows overland to sea. It has the highest heat of vaporization. Because of water's high heat capacity, the presence of oceans, lakes and large rivers, prevents extreme fluctuation in local temperatures. Even within the human body(75% water by volume) water is critical in maintaining uniform body temperature.

The Earth's atmosphere contains 0.02 to 4 percent water by volume, depending on the location. In addition to providing sources for precipitation, atmospheric water vapor intercepts some of the ultraviolet radiation and intercepts heat loss from the earth and redirects part of it to the Earth. Thus water plays a major role in virtually every aspect of human life. Regrettably, too few of us understand the physical and chemical properties of water well enough to effectively solve urgent and nearly universal problems relating to its cost, availability, distribution and contamination. Water problems of any type stem largely from lack of knowledge and therefore, from mis-management of this versatile resource.

THE EARTH HYDROSPHERE

Any one studying water must first understand how the Earth evolved and the changes that have taken place in and near Earth's crust. Recent discoveries now demonstrate that the Earth is a dynamic planet. Subtle changes are occurring constantly in the arrangement of continents, the building and destruction of mountain chains, the creation and movement of the sea floor and even the climatic conditions affecting the planet. Geologists now know much about how the Earths' hydrosphere has evolved. It is believed that the Earth formed about 4.5 billion years ago did not have atmosphere, hydrosphere or the familiar, crustal components seen today.

Ideas concerning a plausible theory for evolution of water on the Earth's surface developed within the framework of a theory called "**Plate tectonics**", proposed in 1912 by Alfred Wegener – a German meteorologist. The theory proposes that the Earth's crust is broken up into a global mosaic of individual plates which vary greatly in size. Some of these plates underlie only the oceanic basins, whereas other make up large, continental land masses as well as nearby ocean floors.

Table 1 : Estimate of the Water Balance of the World

Parameters	Surface area $(km^2)x10^6$	Volume $(km^3)x10^6$	Volume (%)	Equivalent Depth (m)*	Residence time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1-10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks-1 year
Groundwater	130	60	4	120	2 weeks-10,000 years
Icecaps and glaciers	17.8	30	2	60	10-1000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

SOURCE : Nace 1971 *Computed as though storage were uniformly distributed over the entire surface of the earth

These plates are in constant motion with respect to one another and depending upon their configuration they may often collide or keep pulling apart or mere slipping along one another. When plates collide one of the plates may buckle down the other and is subjected to partial melting on approaching the high heat zone at a depth of 80 to 170 km. Because of the melting process of the Crustal plates, gases such as carbon di-oxide (CO_2), Nitrogen (N_2) , Hydrogen (H_2), Hydrogen Sulphide (H_2S), Sulphur-di-oxide (SO_2) and Carbon Monoxide (CO) were released in the accompanying volcanic eruptions. The principal gas released was water vapor because hydrogen and oxygen exist in the chemical structure of many rock-forming minerals. When these rocks are melted, hydrogen and oxygen are released during volcanic eruptions and unite quickly in the atmosphere to form water vapor.

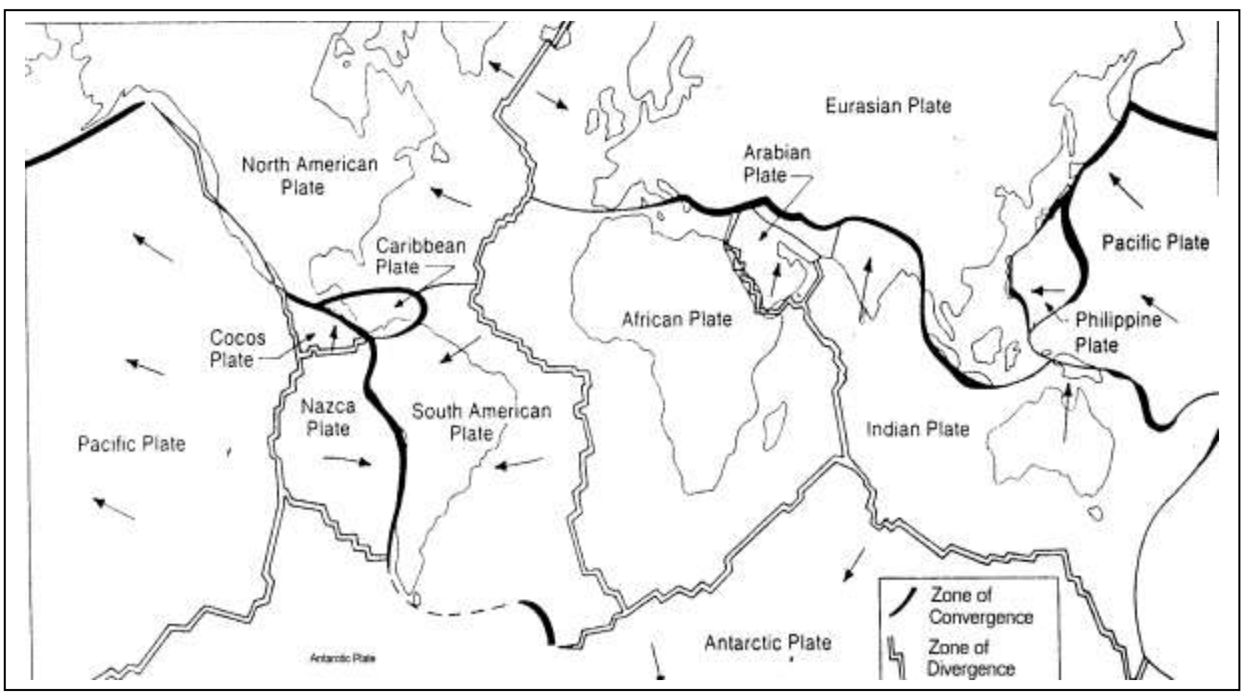


Fig. 2: Configuration of Mosaic of Crustal Plates

THE HYDROLOGIC CYCLE

The endless circulation of water between oceans, atmosphere and land is called the hydrologic cycle. The circulation is primarily governed by solar energy. The gravity inflow to the hydrologic cycle arrives as precipitation in the form of rainfall or snowmelt. Outflow takes place as stream flow, evaporation from open bodies of water/soil surface and transpiration from the soil by plants.

As the rain fall on the earth, some flows down hill as run off into a stream, lake or ocean. Some evaporates, some is taken up by plants. The rest trickles down through subsurface soil and rock. This water eventually reaches the water-table. Water from the water table is discharged in wetlands, lakes and streams at places where the water-table meets the land surface. The sun causes evaporation from these surface water and water vapor accumulates in the atmosphere and clouds begin to form , the hydrologic cycle thus begins - a new.

Pic .1: Water (Hydrologic) Cycle

Groundwater – the buried treasure

The word groundwater should be considered as a complex medium composed of ground and water. While both the components are complimentary and interactive they influence in the resulting characteristics of groundwater. groundwater is an increasingly important resource all over the world. The term groundwater is usually reserved for the subsurface water that occurs beneath the water-table in soils and geologic formation that are fully saturated. Geo-chemically, groundwater is aqueous solution of bicarbonates, chlorides and sulphates of alkaline earth and alkali metals. It supports drinking water supply, livestock needs irrigation, industrial and many commercial activities. While the degree of reliance on groundwater varies significantly, the need of groundwater as a dependable resource of fresh water has been unquestionable.

In the overall geo-strategic scenario groundwater has also offered a medium for many environmental solutions. It is key to under standing a wide variety of geologic processes for eg.- the generation of earthquakes, the migration and accumulation of petroleum and the genesis of certain type of ore deposits, soil type and land forms.

ORIGIN AND CLASSIFICATION OF GROUNDWATER

Groundwater, irrespective of its occurrence is an integral part of hydrologic cycle. For the origin of groundwater there are two theories. **Condensation theory** – support the origin of groundwater resulting from condensation of water vapor present in the host rock at the time of their formation. According to **Infiltration theory-** Groundwater results from infiltration of atmospheric water into the ground.

Depending upon the source and mechanism of its genesis groundwater can be '**connate water'-** filled in interstices of sedimentary rock,' **juvenile groundwater'- which is** of cosmic origin resulting from volcanic / magmatic eruption, '**meteoric water'**- – which is contributed by rainfall and ' **rejuvenated water'-** which results from compaction of loosely packed sediments

OCCURRENCE AND MOVEMENT OF GROUNDWATER

Once water is introduced to the earth as rainfall or snow-melt it exists in the ground in several different environments. Broadly these environmental zones can be classified into two groups viz. a zone of '**Vadose Water'** (or 'unsaturated zone', where all the soil / rock interstices are partly filled with water) and a zone of '**Phreatic Water'** (or 'zone of saturation', where all the soil / rock interstices are fully filled and saturated with water). These two zones are separated by the groundwater table. See fig. 3.

Fig. 3 : Spatial Location of Groundwater

In Vadose Zone, three types of water exist. In vertical downward sequence , they are Soil water, Intermediate Vadose and Capillary water. Soil water is the component available to plants and hence subjected most to transpiration and evaporation losses. The depth of Soil water component varies from 0.9 m to 9.1 m.. The Intermediate Vadose component lies in between Soil Water and Capillary water. At the bottom of Intermediate Vadose component, Capillary water exists which is formed due to capillary rise in the medium of Vadose zone coming in contact with water table. The thickness of the Vadose zone and its component mostly depend upon the soil type and geography of the area. Water, below the water table is generally called groundwater. The bottom of groundwater zone is nearly impossible to delineate because it grades almost imperceptibly into a region where openings in the rock, are more and more isolated. Groundwater in unsaturated zone moves downward under the influence of gravity, whereas, in the saturated zone it moves in a direction determined by the surrounding hydraulic gradient.. The groundwater zone may be imagined as a huge natural reservoir or system of reservoirs in soil or rocks whose capacity is the total volume of pores or openings that are filled with water.

In terms of the holding (porosity) and transmitting (permeability) capacity of groundwater the host medium or geologic unit can be uniquely identified as,

- **AQUIFER** -which can hold and also transmit significant quantities of water under ordinary hydraulic conditions;
- A**QUITARD** -which can hold and also transmit water but their permeability is not sufficient to allow the completion of production well
- **AQUICLUDE** -which can hold but can not transmit
- A**QUIFUGE** - which can neither hold nor transmit water.

MOVEMENT OF GROUNDWATER

Groundwater in its natural state is invariably moving . This movement is governed by established hydraulic principle and can be expressed by **Darcy's Law**, which states "Flow rate through porous media is proportional to the head loss and inversely proportional to the length of the flow path"

$$Q = \frac{K (h_1 - h_2)}{L}$$

Q : Specific discharge ;
K : Hydraulic conductivity ;
h_1-h_2 : Head loss
L : Distance of travel by groundwater

It is generally believed that movement of Groundwater follows ground elevation or the general topography of the area.

Fig. 4 : Types of aquifers and their relative setting

Aquifer System

In terms of potential for storage and permeability the aquifers are the most sought-after geologic medium in hydro-geological studies. 'Water Bearing Formation' and 'Groundwater Reservoirs' both are synonyms for the word 'Aquifer'. Water as such can exist in aquifers under two completely different physical conditions. The most common conditions is when the water table is exposed to the atmosphere through openings in the overlying medium This type of aquifer is referred to as an '**unconfined aquifer'**.

Groundwater may also occur under **'confined conditions'.** Confined groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations. The confined aquifer is generally subjected to pressure higher than atmospheric than atmospheric pressure.

In some geologic settings, a local zone of saturation may also exist at some level above the regional water. The upper surface in such localized zone is called perched water tables and such local water bearing zones are called '**perched aquifers'**.

FORMATION OF AQUIFER SYSTEM

All igneous and metamorphic rocks exposed near the earth's surface are in an unstable chemical and physical condition and over geologic time these rocks breakdown into finer and finer components. Destruction of rocks and the redistribution of the rock particles play a significant role in producing all the major types of aquifer systems. These particles are entrained and re-distributed by the three agents of erosion- wind, running water and glacier ice.

The factors responsible for the formation of aquifer system are:

- Weathering
- Erosion
- Meandering in river
- Glaciation and glacial deposits
- Structural changes (fracture/joints) in igneous / metamorphic rocks
- Formation of extrusive(void – containing) rocks at great depths

Groundwater flow pattern

Usually, the general direction of groundwater flow can be established on the basis of the local topography (use of topographical maps or aerial photos) and the presence of streams or rivers which act as groundwater discharge boundaries. The near-surface groundwater flow generally follow surface drainage pattern. If the flow direction can not be established, three small diameter (piezometric) wells are temporarily installed in the aquifer. Relative **water level in these wells reveal the direction of flow. Other methods of delineating groundwater flow pattern include electromagnetic induction, earth resistivity survey, radioactivity and temperature logging.**

Geology also offers control on the rate of groundwater movement. The size of the pores and their relative connectivity (permeability) determine the rate at which water moves into , through and out of aquifer. Groundwater moves more quickly in coarse sand sometimes as much as several meters per day while in case of clay which are generally impermeable the movement may seldom move not more than an inch per year.

Pollutants, once trapped in the saturated groundwater flow, tend to form plumes of polluted water extending down stream from the pollution source. Where groundwater has a rapid flow, plume tends to be long and thin, whereas at less flow rate the groundwater, especially in unsaturated zone, move vertically and may take several months and years to reach the saturated zone and get mixed with water table. Once in saturated zone, the pollutants spread out laterally and move in the direction of groundwater flow.

Pic. 3: Groundwater Exploration

The pollutants in the saturated zone either float on top of aquifer, if pollutants are of low density and immiscible, or move into the aquifer if contaminated water is buoyant . The movement of pollutants in saturated zone can take place by 'Convection'- transfer of pollutants, or by ' Dispersion' – in the form of molecular diffusion, resulting in mixing of two adjacent miscible liquids even if there is no flow.

Groundwater Chemistry

Apart from the use of groundwater, which require specific characteristics, the role of groundwater chemistry is important in determining suitability of well. The chemistry of groundwater has an unusual characteristics in terms of its ability to dissolve a greater range of substances than any other liquid by virtue of its occurrence in different environmental conditions controlled by specific pressure and temperature different from on-land conditions. Chemical process in groundwater zone can influence the strength of geologic materials and in situations where they are not recognized, can cause failure of artificial slopes, dams, mining excavations etc.

In certain cases, the dissolution characteristics of Groundwater is influenced by the decaying humus in soil and concomitant release of carbon dioxide which forms a complex medium with Groundwater and increases its reactivity.

Most of the calcium, magnesium and bi-carbonate ions found in groundwater come from dissolution of carbonate rocks. Near surface groundwater has a nearly constant temperature however, with increasing depth mostly influenced with the geo-thermal heat the water temperature rises in the order of 1^{o}F per 1000 ft. depth. Therefore most groundwater found at greater depth is more mineralized due to increased solubility on account of elevated temperature.

The most abundant dissolved gases present in groundwater are nitrogen, oxygen, carbon-dioxide, methane, hydrogen sulphide and nitrous oxide. While the last three gases mostly result from bio-geo-chemical process the rest are mostly contributed by atmospheric influence in their relative order of abundance.

Table-2: Classification of dissolved inorganic constituents in groundwater

Major constituents (greater than 5 mg/l)		Copper	Rubidium
Bicarbonate	Silicon	Gallium	Ruthenium
Calcium	Sodium	Germanium	Scandium
Chloride	Sulfate	Gold	Selenium
Magnesium		Indium	Silver
Minor constituents (0.01-10.0 mg/l)		Iodide	Thallium
Boron	Nitrate	Lanthanum	Thorium
Carbonate	Potassium	Lead	Tin
Fluoride	Strontium	Lithium	Titanium
Iron		Manganese	Tungsten
Trace constituents (less than 0.1 mg/l)		Molybdenum	Uranium
Aluminium	Bromide	Nickel	Vanadium
Antimony	Cadmium	Niobium	Ytterbium
Arsenic	Cerium	Phosphate	Yttrium

Barium	Cesium	Platinum	Zinc
Beryllium	Chromium	Radium	Zirconium
Bismuth	Cobalt		

(Davis and De Wiest,1966)

SOURCE OF GROUNDWATER POLLUTION

The sources of groundwater pollution are many and varied. Pollution by disease causing micro organisms occur when human and animal waste containing virus , bacteria and parasites come into contact with groundwater. Chemical pollutants can leach into groundwater from a variety of sources including hazardous waste dumps, sewage, land-treatment sites, injection wells, indiscriminate solid waste disposal, percolation of pesticides and fertilizer from agricultural field and accumulation of industrial waste water on land.

Pic. 4 : Overuse of fertilizer and pesticides - lead to groundwater pollution

TOP : **Pic. 5 : Abandoned Chemical Storage Tanks – a potential source of Groundwater pollution**

BOTTOM: **Pic. 6 : Leaking Underground Storage Tank – Potential source of Groundwater pollution**

TOP : **Pic . 7 : Discharge of dyes & chemicals directly on land can totally alter the soil profile as well as groundwater quality**

BOTTOM : **Fig. 5 : Groundwater Pollution - Inter-relation of different major sources**

IMPACT OF GROUNDWATER POLLUTION

The severity of groundwater pollution is of particular significance on account of the following:

- Its vulnerability to pollution ;
- The associated complexity in pollution source identification ;
- Limited feasible options for treatment of groundwater, all of which are cost prohibitive ;
- Complicated process in fixing geophysical boundaries ;
- Difficulty in prediction of movement ;
- Insufficient dilution ;
- Slow movement ;
- Lack of any natural cleansing capability ;

Moreover, in most of cases where Groundwater is observed polluted, the area is densely populated and as commonly seen, there is no immediate fresh water substitute available at such locations.

A variety of adverse impacts due to Groundwater contamination is possible – including effects on public health, the environment, agricultural productivity (e.g. due to increased salinity in irrigation water) and on the out put of industries requiring high quality water.

Until recently one of the major reasons for the critical status of Groundwater pollution is a common myth that groundwater is pristine i.e. potential contaminant percolating through the subsurface would adhere to the soil or be degraded by natural process and therefore would not enter or greatly affect Groundwater quality. Thus the Groundwater had been regarded as a safe and convenient depository for the waste and non-waste by-products, generated by the society. However, with the passage of time and increasing number of serious incidences, there is a growing concern of Groundwater pollution. Its impact can be appreciated by categorizing the type of contaminants usually observed in Groundwater.

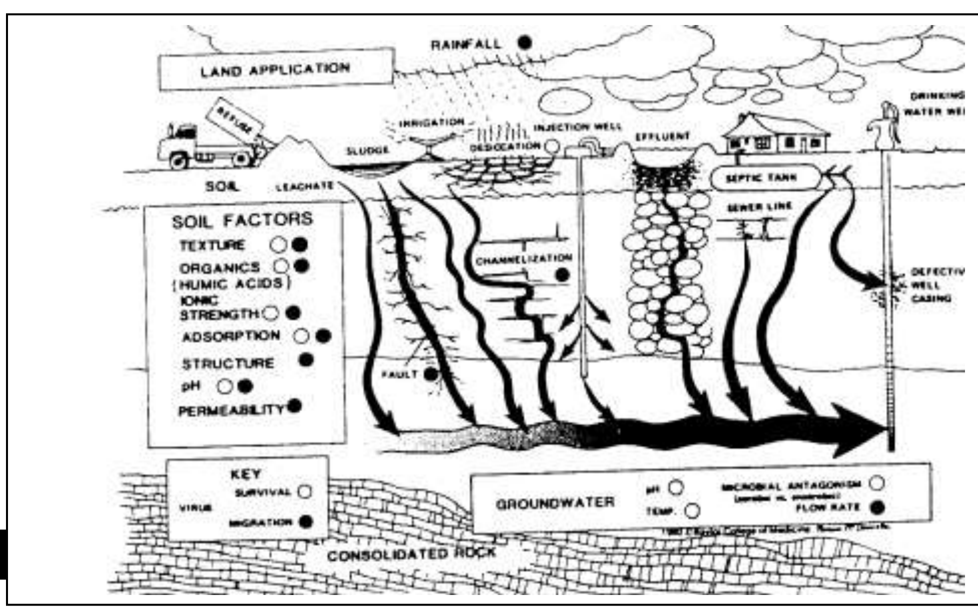


Fig. 6 : Sources of Groundwater Pollution

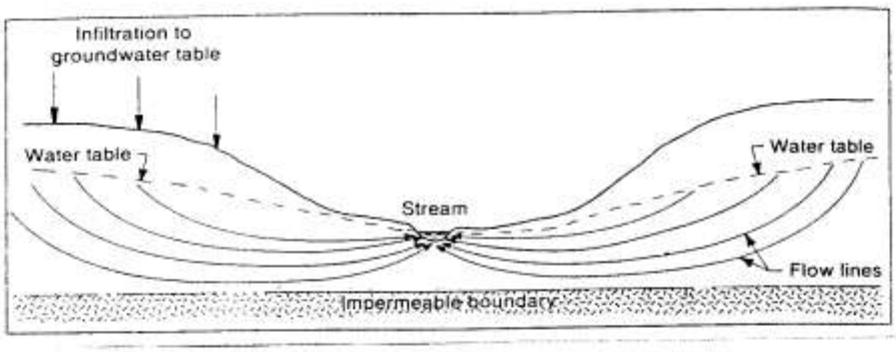


Fig. 7 : Groundwater Infiltration

a. Biological contaminants

Pathogenic biological organisms that have been found in groundwater include

- Bacteria
- Viruses (e.g. Entero-viruses and hepatitis)
- Parasites (e.g. Protozoa, worms and fungi)

The potential for bacterial contamination of groundwater depends on both the survival rate of the species and characteristics of the sub-surface eg. moisture content, pH and temperature. Bacterial contamination most commonly result from the introduction of human (or animal) fecal material usually when septic tanks or cess pools leak or over flow. The common disease associated with biological contaminants present in groundwater can be one or more of the following :

1. Amoebiasis
2. Balantidiasis
3. Cholera
4. Dracontiasis
5. Gastro enteritis
6. Giardiasis
7. Hepatitis-A
8. Paratyphoid
9. Salmonellosis
10. Typhoid
11. Tularemia
12. Shigellosis

b. Inorganic Contaminants

The concentration of most bulk and trace inorganic contaminants found in groundwater varies by area and in many instances, over time . Some of the common inorganic constituents of groundwater and their impact are described in table-3.

c. Organic Contaminants

The organic substances that pose the greatest threat to the quality of groundwater are those that are relatively soluble, non-volatile and refractory. The main mechanism that influences most of these compounds from readily migrating water from land surface into aquifer system is ‘adsorption in soil water zone’.

Apart from naturally occurring humic and fulvic acids, there are many complex organic compounds which result from anthropogenic activities and with-stand bacterial decomposition.

The most common pathway for organic compounds to reach groundwater is through excessive use of pesticides and herbicides and indiscriminate burial of their containers.
Some of the commonly observed organic compounds in groundwater are aldrine, lindane, methoxychlor, toxaphene , DDT, trichloroethylene, carbon tetrachloride, tetrachloro ethylene etc. Almost all the above compounds are known to promote/cause carcinogenicity and their severity depends upon the extent and scale of exposure.

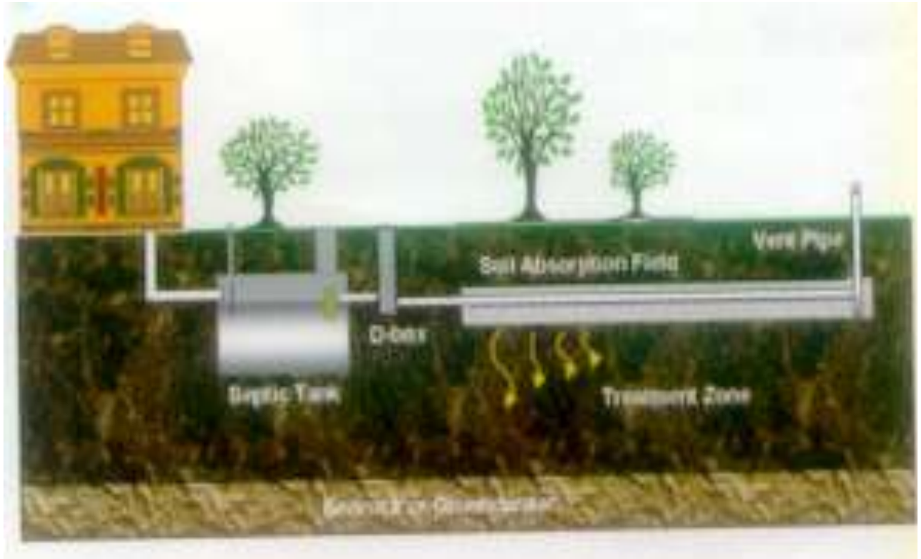
d. Radionuclides

These result as waste from nuclear plants, nuclear weapon testing or use of radioisotopes in scientific laboratories medicine and industry.

The most commonly found radionuclides in groundwater is Radium-226. It results from specific geological conditions and hence classed as naturally occurring. The abundance of radioactive gas Radium-222 formed by the decay of Radium-226 can also be present in groundwater but has no appreciably adverse impact. However, it has been reported that continuous consumption of water containing Radium-226 at 5 pci/liter may cause between 1 to 3 cancer cases per year per million exposed persons.

GROUNDWATER MONITORING TECHNIQUES

Unlike surface water, wherein information on direction of movement, velocity, sources of contamination are available; monitoring of groundwater involves various investigation prior to the actual assessment of groundwater quality. The topography , soil profile, geology, aquifer characteristics, land-use pattern, source of pollution and above-all, the extent of groundwater development are some of the important pre-requisites to decide the scheme of groundwater monitoring. For a representative information on groundwater quality the first information to look for is the movement of groundwater.



Pic. : 8 : Improper Proper Septic Tank / Flush Waste — a source of bacterial contamination of groundwater

Table -3 : Common inorganic constituents of Ground water and their impact

Constituents	Impact
Nitrate	• Carcenogenicity in adults in acute exposure • Infantile metheloglobоanemia (blue baby syndrome) in acute exposure. It can also be reported in adults
Fluoride	• Mottling of tooth enamel • Crippling of bones
Hardness (Chloride Sulphates bi-carbonates)	• Scaling of (consumer) appliance • Less foaming
Sodium	• Hypertension • Congestive cardiac failure • Renal disease
Arsenic	• Hemorrhage in gastro intestinal tract • Sloughing of mucosal epithelium • Cardio-vascular disease (Reynold's sydrome)

	• Hyper pigmentation • Gangarine
Selenium	• Acute respiratory distress • Irritation and dermatitis • Central nervous system disorder • Liver necrosis • Gastroenteritis
Chromium	• Respiratory Carcenogenicity • Alergic dermatitis
Lead	• Retarded mental growth • Kidney disorder • Gonadal dysfunction • High Blood Pressure

Pic 9 : Waste burial sites contribute significantly in groundwater pollution

Monitoring of Groundwater Quality

In general, monitoring of groundwater quality involves collection of representative sample and simultaneous collection of hydro-geological information about the sampling location. The sample and hence the groundwater quality data may adversely affect if one or more of the following factors are not appropriately looked into.

a) Sample was taken from stagnant water in the open well or suddenly in case of bore well without removing the casing storage effect. The error can be largely overcome if 3 to 10 well-bore volumes are removed and in case of hand pumps- sufficient water is pumped out before taking the sample.

b) Samples are not taken at appropriate time intervals-seasonally and at improper locations.

c) Contamination due to entrained sediment.

d) Hydraulic characteristics of the (soil) formation near the screen , resulting in possible dilution of the contaminant.

e) Release of carbon-di-oxide during pumping and hence increase in pH which may cause many metallic ions to come out of solution.

f) The samples preservation is not properly done and analyzed without considering the parameter- specific prescribed period of retention.

Pic. 10 : Dark and light spots, small corns and physiological disorder due to inorganic arsenic

Tracer Studies

Groundwater monitoring in several cases involves placing a tracer such as, dye or salt in one well and noting the time of its arrival in a second well, down-gradient from the first. Tracers are used to determine groundwater flow patterns, the age of groundwater, geologic and geophysical origin of groundwater, volume of water, physico-chemical characteristics of the aquifer etc. The ability of tracer to indicate dispersion of pollutants is important because dilution rate of any pollutants is extremely important in assessing the severity of pollution problems

CONCEPT OF GROUNDWATER MODELING

In many instances of Groundwater monitoring, the ability to predict how the contaminant plume will behave in future can be done by using Mathematical Modeling Techniques to estimate the spread of a contaminant and its strength at any point in the plume. A model is a device that represents an approximation of a field situation and provide a frame work for synthesizing field information and for testing of ideas about how the system works. The steps to build the model are shown in the structure below.

The concept of Groundwater modeling is broadly based on following factors:

- Advection of the constituent with the water flowing through the aquifer
- Dispersion of the constituents
- Sources of pollution
- Characteristics of recipient medium

GROUNDWATER PROTECTION

Contamination of Groundwater is more complex than surface water pollution mainly because of difficulty in its timely detection and slow movement , which d requires special expertise to predict the path and rate of Groundwater movement. In addition the complex geo-chemical reactions taking place in the subsurface

1. Factors

Hydraulics/ hydrology	Soil properties		Waste / leachate properties
	Physical	Chemical	

⇓

2. Processes

Dilution/ dispersion	Adsorption	Precipitation	Biological activity	Other

⇓

3. Model

Convection & attenuation

⇓

4. Prediction

Contaminant concentrations in time and space

⇓

5. Assessments

Comparison of model results with field data

Fig. 8 : A typical groundwater modeling sequence

between myriad contaminants and earth materials are not always well-understood. Ideally speaking contamination should be prevented from occurring. After a contaminant or several contaminants are found in groundwater, a decision must be made on whether to rehabilitate the aquifer or find alternative groundwater resources.

Table 4 : Common types of tracers and their specific uses

Tracer	**Lowest Detectable Concentration**	**Advantages**	**Disadvantages**
Dyes: Uranine (Sodium fluorescein Rhodamine B Sulforhodamine G. Extra	0.01-0.04 ug/l	Easy to use, safe concentration can be measured in the field	Some dyes affected by pH, temperature, or are absorbed by clays and organic soils.
Strong Electrolytes Sodium chloride Potassium Chloride Lithium Chloride	1-0.01 mg/l	Can be measured in field or laboratory by electrical conductivity or electrical resistivity, Smaller concentrations measured by atomic absorption spectroscopy	Must use large amounts of salts if ordinary analytical methods are used.
Radioactive Isotopes	0.01 mg/l or	Can be used in such	May be radiation

Tritiated water Iodine ion Many others	lower	small quantities that don't effect on physical and chemical properties of water occurs, Concentrations easily measured by sophisticated equipment. Cost of tritiated water very low	danger (not in case of tritiated water). Requires expensive detection equipment
Detergents Alkylbensol-sulfonates	0.05 mg/l	Easy to use, safe	May be confused with sewage-related detergents. Material disperses in soil, thereby changing its permeability.

Table : 5 : Groundwater Pollution ….. responsible factors and their responses

Responsible Factor	Most Probable Response
Groundwater pollution originating on land surface	
Infiltration of contaminated surface water	Contamination of stream side aquifer due to polluted stream
Land disposal of waste	Contamination due to direct disposal of waste
Stock piles (ore) tailings (over burden dumps	Release of mineralized leachate
Disposal of Sewage/Sludge	Release of Biological mineralized leachate
Salt spreading on road	Pollution due to winter time road salting
Animals feed lots	Biological waste
Fertilizer and Pesticides	Run-off resulting from indiscriminate use of such items
Accidental spills	Spill of in-transit chemicals and contamination due to spray water used during such mishap.
Air borne source	Acid/alkali rain particulates as fall out from smoke/ flue dust automobile pollutants
Groundwater pollution originating above the groundwater table	
Septic tanks Cess pools	Biological contamination of groundwater
Surface impoundment	Leachate from lagoons for storage/treatment of sewage industrial wastewater oil field brines spent acids etc.
Underground storage tanks/pipelines	Corrosion and /or leakage
Artificial Recharge	In case of improper operation the recharge may lead to increased concentration of nitrates, metals, bacteria,

	viruses, detergents etc.
Groundwater pollution originating below the groundwater table	
Waste disposal in wet excavations	Contamination through abandoned mines
Agriculture drainage wells	Drainage of agricultural residues from marshes /ponds
Well disposal of waste	Contamination due to direct injection of waste
Secondary recovery of petroleum	Migration and ingress of hydrocarbons
Mines	Percolation of mine water
Exploratory wells and test holes	Inter-linking of aquifers leading to dissemination of pollutants
Abandoned wells	Direct migration of mineralized fluids
Water supply wells	Contamination by surface run-off
Excessive groundwater development	Salt water ingress

Aquifer Restoration

Once it is established that contamination of groundwater has occurred , some action must be taken to –

- Find and eliminate the sources ;
- Contain the contaminants in the area already affected ;
- Restore the water quality of the aquifer.

In majority of the areas, groundwater may be the only fresh water resource, hence restoration of aquifers may be of the highest priority regardless of the cost involved.

Wherever feasible identification and elimination of contaminants must be given the first priority. In case of difficulty, containment of the contaminant source is the other option in aquifer restoration. Recent research has shown that leakage is observed in virtually all land-fills, even if various types of plastic liners or clay liners have been used to retain the leachate. Capping abandoned land-fill sites with bentonite or other low permeability material prevents rain water from entering the site, thus eliminating the formation of leachate.

A combination of ‘containment’ and ‘abatement’ is one way to effect aquifer restoration. Containment- usually focuses on some hydraulic means of preventing the spread of the contaminant either through withdrawal of contaminated water or the injection of clean water to create a pressure ridge, Withdrawal of groundwater can reverse the local groundwater gradient, thereby preventing the advance of the contaminant front.

Slurry walls can also be used to isolate areas of contaminated groundwater. Slurry walls consists of bentonite, water and backfill material placed in deep trenches as deep as 100 ft. Ordinarily slurry walls last 20 to 40 years however its life is greatly affected by the groundwater chemistry.

Fig. 9 : Pollutant plume influenced by groundwater abstraction

Additional methods of aquifer restoration include

a) Re-oxygenation of groundwater by means of air compressors and wells to accelerate the growth of aerobic bacteria that metabolize contaminates.

b) Addition of nutrients to wells to stimulate the growth of bacteria

c) Recharge of aquifers to facilitate flushing out contaminants adsorbed onto soil particles.

d) Air stripping the contaminated water in an air-stripping tower to remove volatile organics.

<u>Fluctuation in Groundwater levels</u>

Water level fluctuation can result from a wide variety of hydrologic phenomena, some natural and source induced by man. In many cases, there may be more than one mechanism operating simultaneously. Summary of these mechanisms is discussed ahead wherein, they are classified according to whether they are natural or man-induced , whether they produce fluctuation in confined or unconfined aquifers and whether they are short lived, diurnal, seasonal or long term in time frame.

While monitoring the groundwater level it has been observed that in most of man-induced factors leading to over exploitation of groundwater the effective groundwater resource management stresses on two-pronged strategy, the one relates to ‘Static’ groundwater level and the other ‘Dynamic’ groundwater level. While the static water level pertains to the levels not affected by recharge and other seasonal influence, the dynamic water level – as the name implies has greater, influence of seasonal impacts. In an effective groundwater management strategy, the static water level and its restoration should be assigned priority to obviate the possible hazards of groundwater mining(over-exploitation) and associated geo-technical problems.

ARTIFICIAL RECHARGE OF GROUNDWATER

Long term water level declines as a results of injudicious exploitation of groundwater resource, may lead to several vexing problems. Some of these problems are, reduced well yields, land subsidence, intrusion of salty water especially in coastal areas, leakage into the aquifer of highly mineralized water. In order to over-come these serious environmental implications the recharge potential of groundwater resource has to be equally or in some cases more important aspect than the abstraction potential.

Groundwater is derived primarily from rain and snow melt that infiltrates the land surface and slowly percolates to the water table. This process of adding water to underground storage is called “**natural**” groundwater recharge. Where the materials in the earths’ surface are coarse and the slope of the land is gentle, there is generally more groundwater recharge than in areas where the strata consists of fine-grain material such as shale and clay, or where the slope is steep. The purpose of ‘artificial recharge’ is to increase the rate at which water infiltrates the land surface in order to supplement the quantify of groundwater in storage. Artificial recharge of groundwater has been practiced for scores of years throughout the world.

Pic. 11 : Sketch of Roof- Top Rain - Water Harvesting System

The type of artificial recharge system that can be developed at any specific site is controlled , to a large degree, by the geologic and hydrologic conditions that exist at that site . Site selection criteria, in addition to economic considerations should include at least the following

- Source of recharge water
- Chemical and physical characteristics of the recharge water
- Chemical characteristics of water in the aquifer
- Availability of an aquifer suitable for artificial recharge
- Thickness and permeability of the material overlying the aquifer, if any.
- Thickness and permeability of the aquifer.
- Proximity of the potential recharge site to an appropriate well field cone of depression.
- Water- level difference between the aquifer and the recharge site
- Topography.
- Availability of property (land)

Artificial Recharge techniques

Induced filtration

It is basically a method to artificially recharge the aquifers along river, lake or other such surface water bodies. The salient factors for this method are as follows :

- Depends to a large extent on the quantity of water that can be diverted from a stream or lake.
- Both horizontal and vertical wells are used.
- Permeability of streamside deposit and its linkage with aquifer to be recharged are the important controlling factor.
- During or after the floods resulting in deposition of low permeable material, dredging is recommended to restore the permeability of river bed medium.

- Chemical characteristics of the recharge source is of prime concern.

Water Spreading

It involves spreading the water mantle over an extensive area with flat/gentle topography. The controlling factors are

- Water contact time
- Soil permeability
- Area of inundation

In this technique recharge is facilitated through flooding the available area, by excavating ditches, modification in natural channel by building low-head check dams, irrigation during growing season. An attractive prospect of irrigation involves treated sewage which further undergoes natural treatment and augments recharge of groundwater simultaneously.

Recharge Pits and Shafts

From a regional point of view, conditions permitting recharge through water spreading technique are rare. In more general cases where aquifers and land surface are separated by low permeable or impermeable material artificial recharge system must penetrate the less permeable strata in order to access the aquifer system to be recharged. Some of the salient issues with Recharge pits and Shafts are –

- They are one of the useful recharge facilities especially in relatively small areas/areas where space or land availability is difficult.
- Construction and maintenance is simple relative inexpensive.
- Low turbidity and low microbial contamination of the source water are some important pre-requisite and are to be seriously looked into especially to avoid plugging of the pits and shafts..

Injection Wells

- In comparison to recharge pits and shafts , the injection wells tap deep aquifers
- Expensive to construct and maintain
- High tendency of plugging
- Introduction of well screen/casing is recommended to prevent caving of aquifer.

Artificial Recharge in Urban areas

Due to space constraints and excessive exploitation of groundwater the most acceptable and feasible mechanisms of artificial recharge in urban areas are **a-Roof- top water collection**, **b**-**Storm**

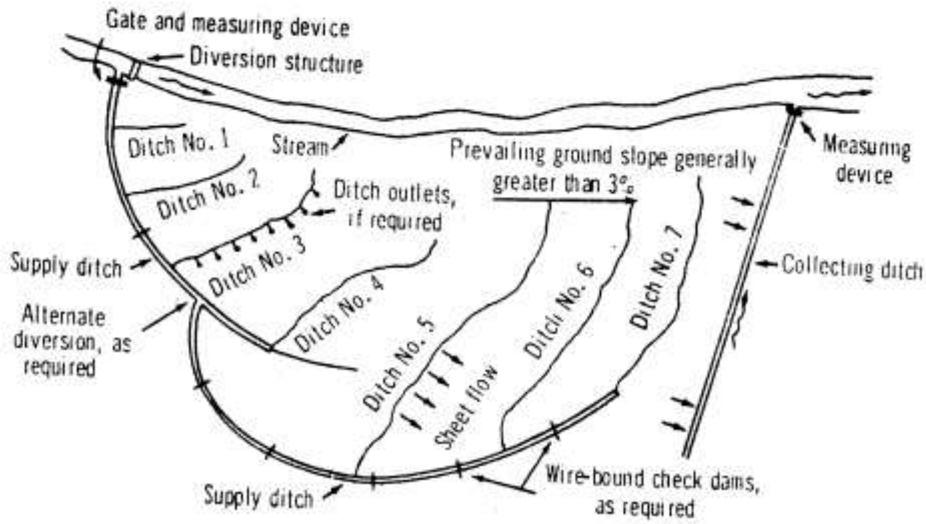
Advantage of Groundwater Recharge

- Groundwater (Well field) management
- Reduction of land subsidence
- Renovation of waste water
- Improvement of Ground water quality
- Storage of stream water during periods of high or excessive flow
- Reduction of flood flows
- Increase well yield
- Decrease the size of areas needed for water supply systems
- Reduction of salt water intrusion or leakage of mineralized water
- Increase stream flow

groundwater is saline, the less saline lens float on the saline water.

- Secondary recovery of petroleum (Oil).

run off collection and c-Street recharge pits/ trenches. These mechanisms, based on systematic hydrological studies to convey the collected water to aquifer zone, yield impressive results.



Bianchi & Muchal, 1970

Fig. 10 : Groundwater Recharge through river flow diversion

Pic. 12 : Pure Compound Recovery- A means of groundwater treatment

GROUNDWATER TREATMENT TECHNOLOGIES

The clean up of contaminated groundwater is very different from clean up of waste-water on the surface. The most obvious difference is that with groundwater clean-ups, the body of water is actually being cleaned. In waste-water(surface) cleanups, we control and treat the waste water that is entering a body of water. The water body, river or lake actually cleans itself once we stop putting pollutants into it. Groundwater is not able to clean itself hence we must clean-up the source of pollutants as well as the aquifer itself.

The mechanism of groundwater treatment starts with estimation of groundwater flow and concentration level of pollutants in the effected area.

Treatment for Organic Contaminants

Physico-Chemical methods- When a pure organic contaminant is released onto or into the ground the main force on the movement of the compound is gravity. If the ground is porous the spill will move downward. There will also be some lateral spread controlled by soil porosity. Eventually the contaminant may be absorbed on the soil particles, stopped by an impermeable layer of soil or encounters with an aquifer. On reaching the aquifer the contaminant may-

- Float on top of aquifer
- Dissolve into the aquifer
- Sink to the aquifer bottom .

For floating contaminants on top of aquifer the best treatment method recommended is **Pure compound Recovery, for other possibilities the specific treatment options are discussed below:**

a. Pure compound Recovery

This method is applicable for insoluble organic contaminants including most of the straight chain hydro-carbons. The treatment mechanism involves placing a well in the middle of the spill area .Water is removed and the water-level in the immediate vicinity decreases. The non-soluble compounds accumulating in the well, keep floating on top of water and are recovered through oil -water separators or through introduction of hydrophobic screens.

Other mechanism to recover pure compounds especially in areas of shallow water table is to dig a trench in the path of ground movement. When Groundwater enters the trench, the floating organic remains on top of water and is later removed by skimmers.

b. Air Stripping

It is a process employed to remove volatile compounds (usually organics) from groundwater. The basic concept of stripping is to bring the contaminated water into intimate contact with air so that the volatile compounds undergo a phase change (from liquid phase to vapor phase). The air will then carry-off the contamination, leaving water free from these compounds . Air striping is accomplished in following ways by employing :

- Aeration tanks
- Cascade aerators
- Spray basins
- Packed towers

Pic. 13 : Recovery of polluting chemical from groundwater – "Trenching method"

c. Carbon Adsorption

The method involves use of carbon for its adsorptive qualities. For removal of odors and taste , the use of activated charcoal is an established technology especially for organic compounds even though these contaminants do not exhibit traditional taste.

Carbon adsorption is particularly suited for low concentration of non-voltaic components eg. phenols, pesticides and high concentration of non-degradable compounds. For better removal efficiency of non- degradable compounds, this method should be combined with 'Bio-logical treatment' or 'Air striping'.

d. Ultra Filtration and Synthetic Resin

While ultra filtration method is used for separation of emulsion, the synthetic resin perform similar function as activated carbon, however they can be made more selective and with higher treatment capacity.

e. UV-Ozone Reactors

This technology is used in rapid oxidation of low concentration of chlorinated organics in groundwater and is rated as one of the best treatment technologies.

Biological methods

Once the contaminant has entered the aquifer , biological treatment is the most economical method of treatment. Biological method employing specific bacteria are recommended for 'in-situ' treatment as well as 'above- the- ground' treatment. In both the cases the treatment system is provided with bacteria, nutrient and other favorable condition of pH, availability of oxygen etc.. In 'in-situ' treatment applied for both organic and inorganic contaminants selected acids or alkalies are placed in the path of groundwater. In some cases an immobilized neutralizing agent is introduced underground. The contaminant plume on contact with the acid–base neutralizing agent and in presence of de-composing bio-chemical reaction under controlled environment with excess or oxygen deficient conditions based on aerobic or anaerobic bacteria employed.

'Above-ground' treatment of groundwater requires placement of well in the contaminated aquifer and withdrawal of groundwater which further undergoes biological treatment. The biological treatment above ground are analogous to conventional wastewater treatment technologies wherein, 'Suspended Growth Biological Reactors' or 'Fixed Film Reactors' are employed. The treatment configuration consists of 'Aerated lagoon', and 'Activated Sludge Process'.

Treatment for Inorganic Compounds

Unlike organic contaminants, the inorganic contaminants have, a greater chance of removal, transformation and adsorption in the unsaturated zone and hence possess lesser chance of reaching the aquifer zone. As a result of this it is observed that heavy metals moving through the soil are exchanged with cations in the soil and later removed. In certain cases of anaerobic zones in the soil, biological transformation of nitrates into nitrogen gas has been observed. The treatment methods usually recommended for inorganic constituents are discussed below. It may be noted here that the choice of method and their efficacy may involve bringing the portion of groundwater above ground or in certain cases provide ' in-situ' treatment

Chemical Addition

This is achieved by way of pH adjustment. It results in precipitation of heavy metals dissolved in groundwater. The pH adjustment (acid - to- neutral - and above) involves passing water through limestone bed, adding caustic soda or soda ash. For adjustment of alkaline groundwater bubbling carbon di-oxide or adding strong acid is recommended. In certain , specific cases introduction of chemical reducing agents like sulphur oxides, sodium bisulphate or ferrous sulphate are used to precipitate metals, which are soluble at high pH (e.g. hexavalent chromium, arsenic etc.)

Ion Exchange

It is basically the exchange of an ion with a high ion exchange selectivity for an ion with a lower selectivity. It is the basis of water softening in which divalent ion (e.g. calcium) usually having higher ion selectivity replaces mono-valent ion (e.g. sodium) at an exchange site on an ion exchange bed., This technique though being expensive is recommended for treating wide range of dissolved inorganic e.g. chloride, nitrates, sulphates and metals.

Reverse Osmosis

Employs semi- permeable membrane and high pressure resins. The membrane rejects inorganic material and allows passage of water through it. It can remove 50-90% of in-organics.

Electro-dialisis.

The method is a combination of reverse osmosis and Ion exchange technology. It is the recommended method for treatment of groundwater with moderate to high conductivity.

Distillation

Involves evaporation of contaminated water by heating followed by re-condensation. The in-organics do not evaporate and hence are left behind. The recommendation brings out clean water free from dissolved in-organics.

GROUNDWATER- Indian perspective

In India, groundwater has played the pivotal role in fulfilling the demands of domestic, industrial and agriculture sectors. At present the groundwater in India contributes more than 58% drinking water, 52% for agriculture production and 50% for urban and industrial sectors. Indiscriminate development and unscientific management of this resource has led to multiple problems of decline in groundwater level, sea water ingress , in-land salinity, groundwater pollution, land subsidence etc.

The measures that need to be adopted in the country to meet the increased water demand in the new millennium would include exploration of deeper aquifers, groundwater recharge, development of aquifers in flood plains, direct use of saline / brackish water, conjunctive use of surface and groundwater in canal command area, creation of groundwater sanctuaries and regulation of groundwater development.

Groundwater development in India
- Important Issues

During the past five decades, there has been phenomenal increase in growth of groundwater abstraction structures in India. Their number has increased from 4 million in 1951 to about 18 million in 1997-99, while in the same period irrigation potential created from Groundwater has increased from 6 to 30 million hectares.

Commensurate with this growth, groundwater development has been intensive in alluvial area of Indo-Ganga-Yamuna plains of Punjab, Haryana, Uttar Pradesh, Uttaranchal and in parts of hard rock terrain in southern States. Though over-exploitation of the resource in some parts of the country has created serious problems, a large portion of the available resources still remains untapped, particularly in north-eastern areas, where precipitation is high and the demand for irrigation is low and also in eastern States where fragmented nature of land holdings has been a major factor in low development of groundwater.

Adverse Impact of Groundwater Development

- **Over-Exploitation-**

In many arid and hard rock areas rapid pace of Groundwater development and associated overdraft has resulted in failure of wells and salinity ingress.

- **Water Logging-**

Large areas in command areas of major irrigation projects suffer from water logging, soil salinity or alkalinity. High intensity of irrigation without adequate drainage has resulted in rapid rise in water table and increased chances of water logging conditions.

- **Water Quality Deterioration-**

Landward movement of 'sea water – fresh water' interface has resulted into salinity ingress in several areas e.g. Minjur area Tamilnadu, Mangrol-Chorwad area-Porbander belt along Saurashtra coast, east of Neyveli lignite mines(Pondicheri). Over exploitation of groundwater has also resulted into severe arsenic anomaly reported from West Bengal.

Steps to resolve groundwater development constraints

- Development of comprehensive information system about the resource base.
- Setting groundwater quality standards reflecting national priorities.
- Establishment of groundwater protected areas by focusing on notification of protected areas for ' key aquifers', rather than attempting to protect at once, all groundwater resources .
- Groundwater pollution control by identifying sources and extent of pollution and by strict enforcement of remedial measure.
- Extraction control by setting legal limits on pumping or by motivation for efficient use of Groundwater.
- Restriction on subsurface disposal of solid as well as liquid waste
- Land use regulation by restricting use of chemical fertilizer and pesticides, housing density, set up of sewage treatment plants, under ground storage tanks pipelines etc.
- Conservation and augmentation of groundwater by enhancing the recharge capabilities of the aquifer using site-suitable techniques.

Fig 11 : Groundwater Resources in India

A : Replenishable Resource ; B : Available for irrigation ; C: Net Draft; D : GW for further use

Courtesy: CGWB

HYDROGEOLOGY OF GROUNDWATER PROVINCES IN INDIA

India is a vast country having diversified geological, climatological and topographical set-up giving rise to divergent groundwater situation.

The high relief areas of northern and north eastern regions occupied by Himalyan ranges, the hilly tracts of Rajasthan and Peninsular regions with steep topographic slope and characteristic geological set-up, offer high run-off and little scope for rain water infiltration. groundwater potential in these areas are limited to 'Intermountain Valleys'.

The large alluvial tract in Ganga-Brahmputra plains extending over 2000 km has extensively thick and hydraulically interconnected, moderate to high yielding aquifers. To the north of this tract all along the Himalyan foot hills and 'terai' belt down slope occur the linear belt with characteristics 'auto-flowing' conditions.

Entire peninsular India is occupied by hard rock formation with rugged topography and fissured nature of rocks. They give rise to discontinuous aquifers with limited to moderate yield potentials. In these areas the aquifer formations are limited to near-surface weathered mantle, abandoned river channels,

Coastal and deltaic tracts in the country form narrow linear strip around the peninsula. The eastern coastal, deltaic tracts and estuarial areas of Gujarat are receptacles of thick alluvial sediments. Though highly productive aquifers occur in these tracts, Salinity hazard impose quality constraints for groundwater development. In this terrain, groundwater abstraction requires to be regulated so as not to exceed annual recharge and also not to disturb hydro-chemical balance leading to sea water ingress.

Table 6: Ground Water Quality in problem Areas

S.No.	Area	Industrial Activities	Ground Water Quality Problem*
1.	Dhanbad (Bihar)	Fertilizers, Chemicals, Coke plants, Cement explosive factory and Ancillary units	Low pH, whereas NO_3, Al, Ca, TDS, TH ,Fe, Mn, Cr, Zn, Cu ,Hg & Cd, and also Pesticides exceeded standards
2.	Digboi (Assam)	Oil Refinery	Fe and Mn exceeded standards
3.	Durgapur (West Bengal)	Coal fields, Power and Chemical units	Heavy metals except Cu exceeded standards . Hg was

S.No.	Area	Industrial Activities	Ground Water Quality Problem*
			also reported as high as 9.5 mg/l. Phenolic compounds & CN were in traces. Total pesticides levels have exceeded standards
4	Howrah (West Bengal)	Foundries, Electroplating & other mechanical manufacturing units	Heavy metals viz. Pb, Cd, Cr, Fe & Mn were very high. EC, TH, Cl, TDS were some time very high Pesticides were also on high side CN & Phenolic compounds in traces.
5.	Bolaram-Patancheru (AP)	Pesticide, Pharmaceuticals	Phosphates, Hg, As, Cd, Fe, Mn & Pb TDS, TH, Ca exceeded standards, Pesticides were also found to be present.
6.	Greater Cochin (Kerala)	Fertilizer, Pesticides, Chemicals, Chlor – alkali	Predominantly acidic. The presence of coliform of faecal origin was high.
7.	North Arcot (TN)	Tanneries, dying units	Zn, Cu, Cr, Fe & Mn, total coliform exceeded standards at several locations.
8.	Bhadravathi (Karnataka)	Steel, Paper Mills	Zn, Fe & Mn , Pesticides like Aldrin, Dieldrin, Lindane & DDT Pathogenic organisms reported to be high.
9.	Ratlam-Nagda (MP)	Distillery , Dye (intermediates) Pharmaceutical (intermediates)	Colour, TDS, TH, Hg, Pb were on higher side , considerable amounts of Pesticides were also reported. Fecal Coliform were also present particularly at Nagda
10.	Vapi (Gujarat)	Dyes, Pesticides, Paper & Pulp mills, organic & inorganic chemicals	Phenolic compounds, Cyanide & heavy metals were present within limit as per drinking standards.
11.	Chembur (Maharashtra)	Petroleum, Refineries, Fertilizer & Petrochemical, Thermal Power Plant.	TDS, Alkativity, TH were higher, Heavy metals, Pesticides, phenolic compounds were present in concentrations, but not very significant. Coliform were on higher side.
12.	Korba (MP)	Thermal Power Plants, Ancillary Units, Alluminium	The presence of Cd, Fe, Cr & Cu has exceeded standards , Pesticides were also present.

S.No.	Area	Industrial Activities	Ground Water Quality Problem*
		industries, Mining	Coliform , F, TDS, CN, B & phenolic compounds also exceeded the standards.
13.	Singrauli (UP)	Thermal Power Plants, Alluminium Plant, Organic chemicals industries, Carbon Black plant, Caustic soda & pesticides.	Fe, Cr & Cu were present in predominance, Presence of high Aldrine, Dieldrin & Lindane levels were also observed. Beside this F, Ca, Mg, B, Coliform, Phenols exceeded standards .
14.	Mandi Gobindgarh (Punjab)	Wooden, Chemicals, Electroplating units and other Steel metals units.	Pb, Cu, Cd exceeded standards , Phenolic compounds & Cyanide was also present on higher side.
15.	Parwanoo (HP)	Ancillary , general industries, Fruit proceeding plant, pesticides.	Presence of Cd, Pb, Fe, Mn were observed on higher side. Traces of pesticides were also present. Phenolic exceeded standards .
16.	Kala-Amb (HP)	Paper Mills	Phenolic compounds exceeded standards; Heavy metals like Cd, Pb & Mn and also pesticides are above limits
17.	Pali (Rajasthan)	Textile, dyes	Colour, Lead, Zinc Fluoride TDS, Cl, Sn were in concentrates exceeding standards.
18.	Jodhpur(Rajasthan)	Textile, Steel, Engineering foundry, Chemicals, minerals dye plastic, oil, pulses and rubber.	Colour, Heavy metals such as Fe, Cr, Mn NO_3 Na, TDS exceeded standards
19.	Drain Basin Area, Najafgarh (Delhi)	Insecticides, Caustic Soda, Vanaspati, Electroplating etc.	EC, TDS Coliform, F, $NO_{3,}$ Fe & Cr both exceeded the drinking water standards.
20.	Angul- Talcher (Orissa)	Thermal Power station, Fertilizers, chemicals, Mining activities & aluminum	Cr, Fe, Cd, Pb , F and NO_3 were found in concentrates level exceeding standards
21.	Manali (TN)	Thermal Power Station, Fertilizer, Petroleum Refining	High microbial contamination have been reported, Nitrates, Fluoride have exceeded standards
22.	Vishakhapatnam (Andhra Pradesh)	Zinc Smelting, Fertilizer, Petroleum Refining	Heavy Metal, Fluoride and Nitrates exceeded standards

* with reference to BIS standards for drinking water ; Source: Central Pollution Control Board

GROUNDWATER RESOURCE ESTIMATE IN INDIA

The annually 'replenishable' groundwater resources of the country have been assessed as 432 billion cubic meter (BCM). After keeping a provision of 71 BCM per year for domestic and industrial use, 361 BCM/y is available for irrigation. The Ganga basin has the highest potential followed by Godavari basin and Brahmputra basin. The Indo-Gangatic alluvial plain with an area of around 25,000 km^2 is one of the largest groundwater reservoirs in the world.

In addition to replinishable resources, the country is blessed with enormous groundwater resources below the lowest level of groundwater fluctuation, termed as 'in-storage' groundwater resource. The in-storage groundwater resources upto the depth of 450 meters in alluvium and 100 meters in hard rock terrain have been estimated as 10812 BCM.

Groundwater Pollution in India

Apart from reported cases by different institutions, groundwater quality concerns in India was realized way-back in mid eighties with a systematic study of groundwater quality and identification of 'problematic zones' by Central Pollution Control Board with reference to pollution. These (problem) areas due to their complex industrial scenario and increasing dependence on natural resources have been witness to excessive exploitation of groundwater for domestic and industrial uses. With pollution control enforcement activities gaining momentum there were observed cases of indiscriminate waste disposal, subsurface discharge of effluent and inappropriate wastewater management by industries. This has led to severe stress on groundwater, in terms of ' quantitative imbalance' as well as 'quality deterioration'. In consideration of the potential of pollution in these problem areas, Central Pollution Control Board has initiated groundwater quality monitoring in these areas. As an integral part of such studies groundwater status shall be brought out with suggested measures for pollution control (see Table – 6).

Status of Groundwater in major Indian cities/towns

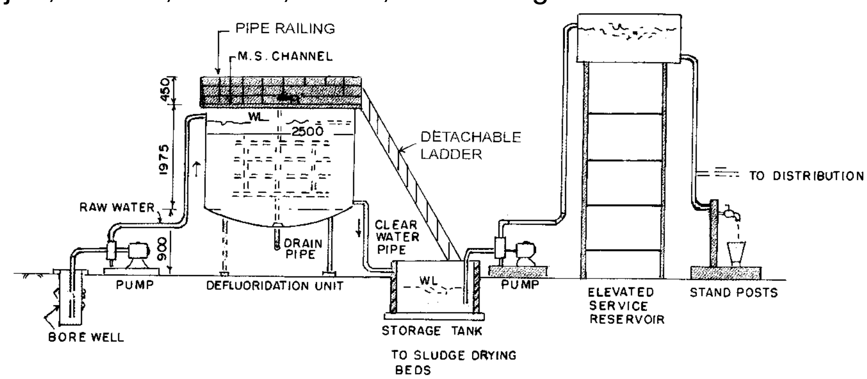
With only twenty five percent population living in urban areas, India has cities, amongst the biggest in the world. Indian urban centers are posed with problem of over-exploitation of groundwater due to increasing dependence on it as other fresh-water resources are dwindling fast. The poor urban infrastructure having no systematic provision of sewage or solid waste management, unplanned growth, un-organized land-use and poor drainage system further compound the groundwater quality concerns.

The very process of urbanization in Indian cities, has led to phenomenal decrease of natural (groundwater) recharge due to paving and soil compaction, thus promoting imbalance in over-all groundwater budget .

GROUNDWATER POLLUTION
- Areas of National Concern

Fluoride Pollution

Fluoride is often called a two edged sword. In small doses it has remarkable influence on the dental system by inhibiting dental caries, while in higher doses, it causes dental and skeletal fluoresis. In India 62 million people including 6 million children are affected with fluoride related health diseases. Excess fluoride in ground water is reported from 17 States, which include Andhra Pradesh, Rajasthan, Karnataka, Maharashtra, Tamil Nadu, Madhya Pradesh, Uttar Pradesh, Jammu and Kashmir, Punjab, Kerala, Orissa, Bihar, Gujarat. Of which Uttar Pradesh, Rajasthan, Gujarat, Andhra Pradesh and Tamilnadu are severely affected. As per water technology mission, 25 million people residing in 8700 villages in India are affected by fluoresis. Concentration level of fluoride in India reported from groundwater varies from 0.5 to 50 mg/l. Fluoride concentration has significant positive relationship with pH and negative relationship with hardness and magnesium.



FILL AND DRAW DEFLUORIDATION PLANT FOR RURAL WATER

TOP : Fig. 12 : Status of fluoride in seriously affected areas in India
BOTTOM : (Upper) 13 a & (Lower) 13 b : Fluoride treatment units suited for groundwater

The major factors of high fluoride anomaly in India include wide spread occurrence of fluoride rich soil, excessive use of phosphatic fertilizer, indiscriminate disposal of industrial effluent from phosphatic fertilizer, mining (Cu, Fe) and allied industries.

Fluoride levels in (ground) water can be reduced with addition of calcium hydroxide at pH about 10 . The NALGONDA technique is considered to be the most tried and cost effective technique of fluoride removal, however it also requires second stage treatment.

Fig 14 : Status of groundwater quality – Area Specific Scenario

<u>Arsenic Pollution</u>

In India, arsenic pollution in groundwater is mainly reported from West Bengal. Since its first reported case in early eighties, there are 1312 affected villages, 15 non-municipal and 9 municipalities in 8 districts in the State till date. On an approximation 34000 sq km area in the State is reported with high concentration of arsenic in drinking water abstracted from tubewells. Number of people at risk and other specific details are appended in table …. Some of the most affected districts in the State are South 24 Pargana (conc.0.06-3.20 ppm), North 24 Parganas (conc 0.06-1.28 ppm), Malda (conc 0.05-1.434 ppm), Nadia (conc 0.05-1.0 ppm), Murshidabad (conc 0.05-0.90 ppm) and Bardhaman (conc 0.10-0.50 ppm), Howrah(conc 0.09 ppm) and Hooghly (conc 0.6 ppm). The pollution is mostly reported from the intermediate water depth of 20-80 meter below ground level. The arsenic anomaly in the State is associated with high iron, calcium, magnesium and bicarbonates with low sulphate, fluoride and chloride. The problem of arsenic pollution has been reported to be due to the geological formations of the source material. Occurrence of ' arseno-pyrite' and the change of geo-chemical environment due to over-exploitation of groundwater or excessive fluctuation of groundwater table.

Nitrate Pollution

The problem of nitrate pollution in groundwater becomes severe in the country. The state of Maharashtra alone showed severe problem of nitrate pollution. The studies carried-out by Central Ground Water Board in the State revealed that, out of 688 samples, 75 % sample as have shown nitrate levels below desirable limits, while 14 % samples have nitrate levels above 100 mg/l. While the districts Bhandara, Nagpur and Pune have shown the nitrate concentration having above 45 mg/l., the Jalna district contributes highest percentage (55.56 %) of nitrate content above permissible limit. Other districts like Akola, Amravati, Chandrapur, Jalana, Sholapur, Wardha,Yavatmal have shown nitrate concentration exceeding 100 mg/l.

Indiscriminate Disposal of Sewage and Garbage

With increasing urbanization, the groundwater pollution due to indiscriminate disposal of untreated sewage and garbage has also acquired alarming proportion. With 70 –80 % of water supply getting converted into wastewater and limited facility (26 %) for its treatment, further compound the problem as encountered in all the major cities in India. This has resulted into outbreak of water borne diseases apart from microbial contamination of groundwater.

Table 9 : Arsenic affected areas in West Bengal (India) Population at risk

S. No.	District	Blocks affected by arsenic Pollution	No. of Blocks/ Municipality affected	Total villages	Total population	%of Population at risk	Depth range of arsenic Rich aquifer	Max. arsenic conc. (mg/l)
1.	Maldah	Englishbazar, Kaliachak (I,II,III)	5	1803	2637000	20.48	20.-95	1.43
2.	Murshidabad	Rejinagar, Domkal, Jalangi, Jiaganj,Bahrampur, Hariharpura, Beldanga, Nawada	15	226	4740000	24.64	20-100	1.85
3.	Nadia	Karimpur (I,II),Tehata, Kaliganj, Nakasiopara, Chapra, Shantipur, Kishanganj	13/1	1352	3852000	21.67	20-80	1.15

4.	North 24 Parganas	Habra,Barasat,Deganga,, Basirhat, Swaroopnagar, Sandeshkhali, Baduria, Gaighata, Bongaon, Hasnabad,,Barakpore	19/7	3812	7282000	12.18	20-80	1.40
5.	South 24 Parganas	Baruipur, Sonarpur, Bhangar, Baj Baj,Bishnupur, Joynagar, Basanti	10	Data not available	5715000	13..51	20-100	3.20
6.	Bardaman	Purbasthali (UT)	2	2579	6051000	0.31	20-4	0.28
7.	Howrah	Uluberia II, Sampur II, Ballyagar	3/1	763	3730000	5.12	20-50	09
8.	Hooghly	Balagarh	1	1928	4355000	0.68	20-80	0.6
		Total	**68**	**14563**	**38362000**	**11.58**		

Fig 15 : Status of inland salinity in different affected States

Salt Water Intrusion

Along about 7000 km long Indian coast line coastal aquifers form a vital source of fresh water. On the other hand, the aquifers being in hydraulic contact with sea are equally vulnerable to contamination due to intrusion of saltwater from the sea. The intrusion in these areas is caused by concentrated withdrawal of groundwater and reversal of natural hydraulic gradient. The problem has been reported in areas of Saurashtra, Tamilnadu, Andhra Pradesh and West Bengal.

It must be clearly understood that less than even 2% of sea water can diminish the water potability. The recommended remedial methods for salt water intrusion include modification of pumping pattern, artificial recharge, physical barrier and hydraulic barrier.

Groundwater Management Perspective

India's groundwater is not in a very good state. The annual recharge of water is far less than what is consumed. The situation is more alarming in urban areas due to population pressure and industrial growth. In spite of this, groundwater constitutes one vital component of water resource system and shall continue to play a key role in meeting the water needs. Hence it requires an integrated planning to optimally utilize, conserve and manage this precious resource. The concept of integrated approach for Groundwater management necessarily need to incorporate following aspects :

- Water conservation
- Watershed management
- Conjunctive use of surface and groundwater
- Augmentation of Groundwater by artificial recharge.

Apart from above, site- specific practices can also be highly purposeful and yield good results. Especially in coastal areas, increasing the direct use of brackish water combined with suitable crop pattern can reduce growing stress on fresh water. In Israel a similar exercise has yielded impressive results in case of cotton cultivation using brackish water for irrigation.

Source : CGWB

Fig. 16 : Stage of groundwater development* in different States

*Groundwater development refers to exploitation of groundwater

Note: Safe Area: < 65% Development; Gray Area 65-85% Development; Black Area > 85% Development

SUSTAINABLE GROUNDWATER DEVELOPMENT STRATEGY

Sustainable groundwater development depends upon the understanding of the processes in the aquifer system, quantitative and qualitative monitoring of the resource and inter-relation with land-use and surface water management . The key components of sustainable strategies are:

- Long term conservation of Groundwater resources
- Protection of Groundwater quality
- Consideration of environment impact of Groundwater development

The organizations overseeing the groundwater development should possess the expertise for cost effective data collection and evaluation of development schemes. Stress on proper land use planning and regulation on groundwater exploitation must be exercised.

Recognizing the need for regulation and development of groundwater resource in sustainable manner Govt. of India has constituted an authority titled Central Ground Water Authority.

Central Ground Water Authority

The authority was constituted on 14th Jan,1997 under the direction of Hon'ble Supreme Court. The term of the authority, which was initially for one year was extended for further five years vide Notification dated 13.01.1998.

As per notification, Central Ground Water Board was constituted as an Authority for the purposes of regulation and control of groundwater management and development. The following powers were given to the Authority to perform following functions –

- Exercise powers under Section 5 of the Environment Protection Act 1986 for issuing direction and taking such measures in respect of all the matters referred- to in subsection (2) of section 3 of the said Act.
- To resort to the penal provisions contained in section15 to 21 of the said Act.
- To regulate indiscriminate boring and withdrawal of groundwater in the country and to issue necessary regulatory directions with a view to preserve and protect the groundwater.

As per the notification, the Authority shall function under the administrative control of the Govt. of India in the Ministry of Water Resources with its Headquarter at Delhi. The jurisdiction of the Authority shall be whole of India..

After its constitution in 1977, the Authority has considered following issues which required immediate regulatory measures

- Conserve groundwater resources and ensure its proper use
- Control groundwater over-drawl in critical areas
- Augment resources in areas of over-exploitation
- Achieve statutory quality standards for groundwater set up by BIS and ICMR
- Control discharge to groundwater system
- Close alliance with State Govt. to constitute State Groundwater Authority
- Educate public with regard to the adverse effects of decline in water levels and pollution in of groundwater through mass awareness programs

Actions Points for protection of groundwater

- Mapping of vulnerable areas of groundwater depletion and pollution
- Notification of critical areas of groundwater depletion and pollution
- Notification for banning commercial selling of groundwater
- Special studies on areas of high concentration carcinogenic element in groundwater
- Directives to industries / mining / commercial establishments for regulation of over with-drawl of groundwater
- Environmental impact study for groundwater in identified areas
- Campaigns to create public awareness for judicious use and conservation of groundwater

Courtesy : CGWB

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