Groundwater Resources, Its Pollution and Control

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Abstract- *Water, one of the fundamental resources is the universal solvent, which possesses extra ordinary ability to dissolve a broad range of substances. The Earth's atmosphere contains 0.02% to 4% water by volume, depending on the location. Water plays a major role in every part of human life. Groundwater is an increasingly important resource all over the world. 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.*

In specifying the quality characteristics of groundwater, chemical, physical, and biological analyses are normally required. Groundwater pollution may be defined as the artificially induced degradation of natural groundwater quality. Pollution can impair the use of water and can create hazards to public health through toxicity or the spread of disease. Most pollution originates from the disposal of wastewater following the use water for any of a wide variety of purposes. Thus, a large number of sources and causes can modify groundwater quality, ranging from septic tanks to irrigated agriculture. In contrast with surface water pollution, subsurface pollution is difficult to detect, is even more difficult to control and may persist for decades. With the growing recognition of the importance of underground water resources, efforts are increasing to prevent, reduce and eliminate groundwater pollution.

The principal sources and causes of groundwater pollution are listed under four categories – municipal, industrial, agricultural and miscellaneous. The miscellaneous sources of groundwater pollution include spills and surface discharges, stockpiles, septic tanks and cesspools, saline water intrusion, interchange through wells surface waters.

Pollutants in groundwater tend to be removed or reduced in concentration with time and with time and with distance traveled. Mechanisms involved include filtration, sorption, chemical processes, microbiological composition and dilution. The rate of pollution attenuation depends on the type of pollutant and on the local hydro-geologic situation. The attenuation process include filtration, sorption, chemical processes, microbiological decomposition and dilution.

Pollution of groundwater cannot be ceased but can be reduced or restricted to a permissible limit as described in the paper. This paper was our small attempt for creating awareness on the most untouched topic in the common human world.

I. INTRODUCTION

Water, one of the fundamental resources is the universal solvent, which 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 % 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.

Table 1: 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 yrs
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 yrs
Swamps	<0.1	<0.01	<0.01	0.007	1-10 yrs
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks-1 yr
Groundwater	130	60	4	120	2 weeks-10,000 yrs
Icecaps and glaciers	17.8	30	2	60	10-1000 yrs
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.

II. 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. 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.

III. ORIGIN AND AGE OF GROUNDWATER

Almost all groundwater can be thought of as a part of the hydrologic cycle, including surface and atmospheric (meteoric) waters. Relatively minor amounts of groundwater may enter this cycle from other origins.

Water that has been out of contact with the atmosphere for at least an appreciable part of a geologic period is termed *connate* water; essentially, it contains of fossil interstitial water that has migrated from its original burial location. This water may have derived from oceanic or freshwater sources and, typically, is highly mineralized. *Magmatic* water is water derived from magma; where the separation is deep, the term *plutonic* water is applied, while *volcanic* water designates water from relatively shallow depth (perhaps 3 to 5 km). New water magmatic or cosmic origin that has not previously been a part of the hydrosphere is referred to as *juvenile* water. And finally, *metamorphic* water is water that is or has been associated with rocks during their metamorphism.

The residence time of water underground has been a topic of considerable speculation. But with the advent of radioisotopes, determinations of the age of groundwater have become possible. Hydrogen-3 (tritium) and carbon-14 are the two isotopes that have proved most useful. Tritium with a half-life of 12.3 years is produced in the upper atmosphere by cosmic radiation; carried to earth by rainfall and hence underground, this natural level of tritium begins to decay as a function of time. Carbon-14 has a half-life of 5730 years and is also produced at an established constant level in the atmosphere. This isotope is present in groundwater as dissolved bicarbonate originating from the biologically active layers of the soil, where CO_2 is generated by root respiration and the decay of humus. Tritium is applicable for estimating groundwater residence times of up to 50 years, while carbon-14 spans the age bracket of a several hundred to about 50,000 years.

IV. OCCURRENCE OF GROUNDWATER

The subsurface occurrence of groundwater may be divided into zones of aeration and saturation. The zone of aeration consists of interstices occupied partially by water and partially by air. In the zone of saturation, all the interstices are filled with water under hydrostatic pressure. On most of the landmasses of the earth, a single zone of aeration overlies a single zone of saturation and extents upwards to the ground surface.

In the zone of aeration, vadose water occurs. This general zone may be further sub divided into the soil water zone, the intermediate vadose zone, and the capillary zone. The saturated zone extents from the upper surface of saturation down to underlying impermeable rock. In the absence of overlying impermeable strata, the water table, or phreatic surface forms the upper surface of zone of saturation. Actually, saturation extends slightly above the water table due to capillary attraction; however, water is held here at less than atmospheric pressure. Water occuring in the zone of saturation is commonly referred to simply a groundwater, but the term phreatic water is also employed.

Zone of Aeration:

Soil water zone: Water in the soil water zone exists at less than saturation except temporarily when excessive water reaches the ground surface as from rainfall or irrigation. The zone extends from the ground surface down through the major root zone. Its thickness varies with soil type and vegetation.

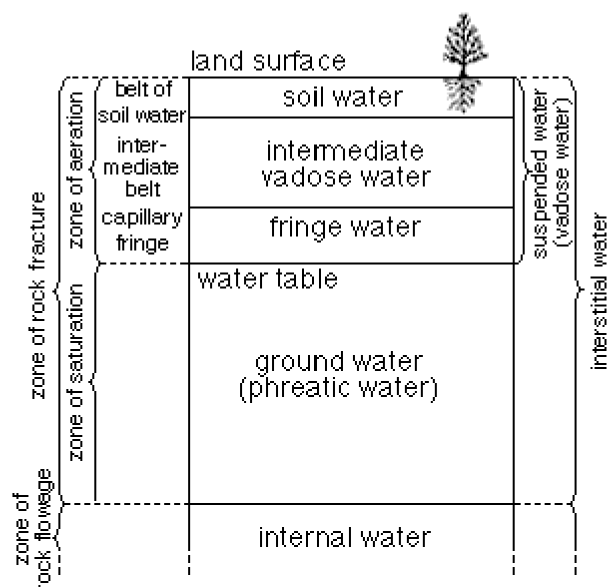


Fig. 1 – Division of subsurface water.

Intermediate vadose zone: Intermediate vadose zone extends from the lower edge of the soil water zone to the upper limit of the capillary zone. The thickness may vary from zero, where the bounding zones merge with a high water table approaching ground surface, to more than 100 m. under deep water table conditions.

Capillary zone: the capillary zone (or capillary fringe) extends from the water table up to the limit of capillary rise of water. If a pore space could be idealized to represent a capillary tube, the capillary rise can be derived from an equilibrium between surface tension of water and the weight of water raised.

- **Aquifer-** which can hold and also transmit significant quantities of water under ordinary hydraulic conditions;
- **Aquitard-** 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;
- **Aquifuge-** which can neither hold nor transmit water.

V. 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."

$$Q = \frac{K(h1-h2)}{L}$$

Q - Specific discharge;

K - Hydraulic conductivity;

h1-h2 - 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.

VI. 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. (refer fig. 2).

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'**.

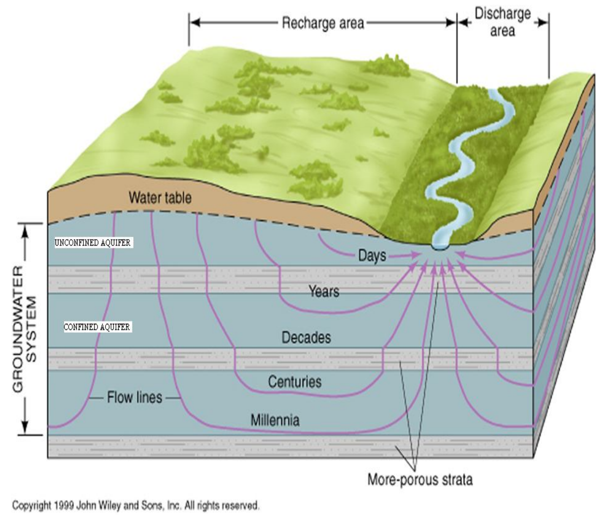


Fig. 2 – Aquifer System.

VII. GEOLOGIC FORMATIONS AS AQUIFERS

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.
- Glaciations and glacial deposits.
- Structural changes (fracture/joints) in igneous / metamorphic rocks.
- Formation of extrusive (void -containing) rocks at great depths.

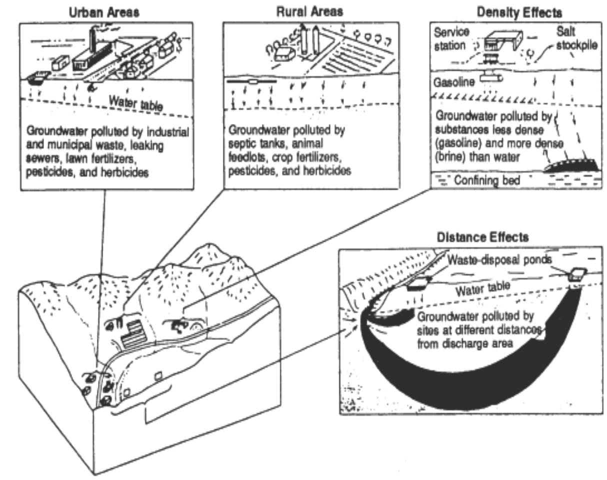
VIII. QUALITY OF GROUNDWATER

In specifying the quality characteristics of groundwater, chemical, physical, and biological analyses are normally required. A complete chemical analysis of groundwater sample includes the determination of the concentration of the inorganic constituents present; organic and radiological parameters are normally of concern only where human induced pollution affects quality. Dissolved salts in groundwater of normal salinity occur as dissolved ions; in addition, other minor constituents are present and reported in elemental form. The analysis also includes measurement of pH and specific electrical conductance. Depending on the purpose of water quality investigation, partial analyses of only particular constituents will sometimes suffice.

Properties of groundwater evaluated in a physical analysis include temperature, colour turbidity, odour and taste. Biological analysis includes tests to detect the presence of coliform bacteria, which indicate the sanitary quality of water for human consumption. Because certain coliform organisms are normally found in intestines of human and animals, the presence of these in groundwater is tantamount to its contact with sewage sources.

IX. GROUND WATER POLLUTION

Groundwater pollution may be defined as the artificially induced degradation of natural groundwater quality. Pollution can impair the use of water and can create hazards to public health through toxicity or the spread of disease. Most pollution originates from the disposal of wastewater following the use water for any of a wide variety of purposes. Thus, a large number of sources and causes can modify groundwater quality, ranging from septic tanks to irrigated agriculture. In contrast with surface water pollution, subsurface pollution is difficult to detect, is even more difficult to control and may persist for decades. With the growing recognition of the importance of underground water resources, efforts are increasing to prevent, reduce and eliminate groundwater pollution.



Groundwater pollution occurs in both urban and rural areas and is affected by differences in chemical composition, biological and chemical reactions, density, and distance from discharge areas.

Pollution in relation to water use:

The principal sources and causes of groundwater pollution are listed under four categories – municipal, industrial, agricultural and miscellaneous.

Municipal sources and causes:

Sewer leakage: Sanitary sewers are intended to be watertight; however, in reality leakage of sewage into the ground is a common occurrence, especially from old sewers. Leakage may result from poor workmanship, defective sewer pipe, breakage by the tree roots, ruptures from heavy loads or soil slippage, fractures from seismic activity, loss of foundation support, shearing due to differential settlements at manholes and infiltration causing sewage flow in to abandoned sewer laterals.

Sewer leakage can introduce high concentrations of BOD, COD, nitrate, organic chemicals and possibly bacteria into groundwater. Where sewers serve industrial areas, heavy metals such as arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, and mercury may enter the wastewater.

Liquid wastes: wastewater in an urban area may originate from domestic uses, industries, or storm runoff. Most of this highly variable mix of waters receives some degree of treatment and is then discharged into surface waters. Land applications of municipal effluent are accomplished by one of three methods: irrigation, infiltration – percolation, or overland flow. The selection of a method at a given site is primarily governed by the drainability of the soil, because this property determines the allowable liquid loading rate. In irrigation systems, wastewater is applied by spraying, ridge and furrow, and flooding; some water is lost by evapotranspiration. For the infiltration- percolation method effluent is applied by spreading in basins or by spraying; almost all of the water so applied reaches the groundwater. In the overland flow technique, wastewater is spread over the upper reaches of slope terraces and allowed to flow across a vegetated surface to runoff collection ditches; percolation to groundwater is minor here because surface runoff and evaporation account for most of the applied water.

Municipal wastewaters can introduce bacteria, viruses, and inorganic and organic chemicals into groundwater. Where the recharged water is later extracted for potable use, concerns exists regarding health aspects of this reclaimed water, particularly involving viruses, trace elements and heavy metals, and stable organics. Furthermore, chlorination of wastewater effluent can produce additional potential pollutants.

Shallow wells are widely employed to place runoff and sometimes treated municipal wastewater underground in fresh water aquifers. Such disposal wells have been criticized from a health standpoint because of the potential for pollutants to be released directly into an aquifer. The problem is most critical where disposal well are near pumping wells and where the beneficial effects of water passing through fine grained materials may be absent, such as in basalt and limestone aquifers.

Solid wastes: The land disposal of solid wastes creates an important source of groundwater pollution. A landfill may be defined as any land area serving as a depository of urban, or municipal, solid waste. Most landfills are simply refuse dumps, only a fraction can be regarded as sanitary landfills, indicating that they were designed and constructed according to engineering specifications. Leachate from a landfill can pollute groundwater, if water moves through the fill material.

The problem of pollution from landfills is greatest where high rainfall and shallow water tables occur. Important pollutant frequently found in leachate include BOD, COD, iron, manganese, chloride, nitrate, hardness and trace elements. Hardness, alkalinity and total dissolved solids are often increased, while generation of gases such as methane, carbon dioxide, ammonia and hydrogen sulphide are further byproducts of landfills.

Industrial sources and causes:

Liquid wastes: The major uses of water in industrial plants are for cooling, sanitation, and manufacturing and processing. The quality of the wastewater varies with type of industry and type of use. Cooling water that is softened before use to inhibit scale formation produces with salts and heat as important pollutants. Groundwater pollution can occur where industrial wastewaters are discharged into pits, ponds, or lagoons, thereby enabling the waste to migrate down to the water table.

Tank and pipeline leakage: Underground storage and transmission of a wide variety of fuels and chemicals are common practices for industrial and commercial installations. These tanks and pipelines are subjected to structural failures, so that subsequent leakage becomes a source of ground water pollution. Petroleum and petroleum products are responsible for much of the pollution. Leakage is particularly frequent from gasoline station and home fuel oil tanks. An immiscible liquid, such as oil, leaking underground moves downward through permeable soils until it reaches the water table. Thereafter, it spreads to form a layer on top of the water table and migrates laterally with a groundwater flow. Liquid radioactive wastes are sometimes stored in a underground tanks; leakage from such installations, which has occurred, can cause serious pollution problems in local ground water.

Mining activities: Pollution depends on the material being extracted and the milling process: coal, phosphate and uranium mines are major contributors; metallic ores for production of iron, copper, zinc and lead are also important; stone, sand and gravel quarries, although numerous, are chemically much less important. Both surface and underground mines invariably extend below the water table, so that dewatering to expand mining is common. Water, so pumped may be highly mineralized and is frequently referred to as acid mine drainage. Normal characteristics include low pH and high iron, aluminum and sulphate.

Oil-field brines: The production of oil and gas is usually accompanied substantial discharges of wastewater in the form of brine. Constituents of brine include sodium, calcium, ammonium, boron, chloride, sulphate, trace metals, and high total dissolved solids.

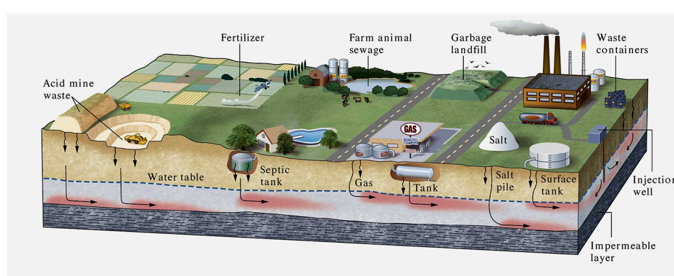


Fig. 3 - Pollution in relation to water use.

Agricultural sources and causes:

Irrigation return flows: Approximately 1 ½ to 2/3rd of water applied for irrigation of crops is consumed by evapotranspiration; the remainder, termed irrigation return flow, drains to surface channels and joins the underlying groundwater. Irrigation increases the salinity of irrigation return flow from 3 to 10 times that of applied water. The degradation results from the addition of salts by dissolution during the irrigation process, from salt added as fertilizers or soil amendments, and from the concentration of salts by evapotranspiration. Principal cations include magnesium, calcium and sodium; major anions include bicarbonate, sulphate, chloride and nitrate. Because irrigation is the primary use of water in arid and semi-arid regions, irrigation return flow can be the major cause of groundwater pollution in such regions.

Animal wastes: Where animals are confined within a confined area, as for beef or milk production, large amount of wastes are deposited on the ground. Thus, for 120 to 150 days that a beef animal remains in a feedlot, it will produce over a half ton of manure on a dry weight basis. With thousands of animals in a single feedlot, the natural assimilative capacity of soil can become overtaxed. Storm runoff in contact with manure carries highly concentrated pollutants to surface and subsurface waters. Animal waste may transport salts, organic loads, and bacteria into the soil. The nitrate nitrogen is the most important persistent pollutant that may reach the water table.

Fertilizers and soil amendments: When fertilizers are applied to the agricultural land, a portion usually leaches through the soil and to the water table. The primary fertilizers are compounds nitrogen, phosphorus, and potassium. Phosphate and potassium fertilizers are readily absorbed on soil particles and seldom constitute a pollution problem. But nitrogen in solution is only partially used by plants or absorbed by soils, and it is primary fertilizer pollutant. Fertilizers are extensively used and will undoubtedly increase in the future.

Pesticides: Pesticides can be significant in agricultural areas as a diffuse source of groundwater pollution. The presence of these materials in ground water, even in the minute concentration, can have serious consequences in relation to the potability of water. The impact of pesticides on groundwater quality depends on the properties of the pesticide residue, rainfall or irrigation rates and soil characteristics. Most pesticides are relatively insoluble in water, while others are readily absorbed by soil particles, or are subject to microbial degradation.

Miscellaneous sources and causes:

Spills and Surface Discharges: Liquid discharged onto the ground surface in an uncontrolled manner can migrate downward to degrade the ground water quality. At industrial sites casual activities may include the boilovers, losses during transfers of liquid, leaks from pipes and valves, and inadequate controls of wastes and storm runoff. Washing aircrafts with solvents and spills of fuel at airports can form a layer of hydrocarbons floating on the water table.

Stockpiles: solid materials are frequently stockpiled near industrial plants, construction sites, and large agricultural operations, like, raw materials awaiting use, or they may be solid wastes placed for temporary or permanent storage. Precipitation falling on unsheltered stockpiles causes leaching to occur into the soil; this may transport heavy metals, salts and other inorganic and organic constituents as pollutants to groundwater.

Septic Tanks and Cesspools: The most numerous and widely distributed potential sources of ground water pollution are septic tanks and cesspools.

Saline water intrusion: Salt water may invade fresh water aquifers to create point or diffuse pollution sources. In coastal aquifers, sea water is the pollutant; while in inland aquifers, underlying saline water may be responsible.

Interchange through wells: Because wells from highly permeable vertical connections between aquifers, they can serve as a avenues for groundwater pollution, where inadequate attention is given to the proper construction, sealing, abandonment of wells. Pollution occurs where there is a incomplete hydraulic separation within a well and where a vertical difference in hydraulic head exists between two aquifers.

Surface Water: Polluted surface water bodies that contribute to groundwater recharge become sources of groundwater pollution. The recharge may occur naturally from a losing stream, or it may be induced by a nearby pumping well.

X. 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.

Prime example of this include tracers for evaluating directions and velocities of groundwater flow, introduction of pollutants into the ground artificial recharge of water with one quality into an aquifer containing groundwater of another quality, and intrusion of saline water into fresh water aquifers. In general, the magnitude of dispersion for uniform sands can be measured in terms of only a few meters over a travel distance of 10^3 meters.

Groundwater tracers: A variety of tracers have been employed for studying dispersion and also for evaluating directions and rates of groundwater flow under field conditions. An ideal tracer should:

1. be susceptible to quantitative determination in minute concentrations,
2. be absent or nearly so from the natural water,
3. not react chemically with the natural water or be absorbed by the porous media,
4. be safe in terms of human health, and
5. be inexpensive and readily available.

No tracer completely meets all these requirements, but a reasonably satisfactory tracer can be selected to fit the needs of a particular situation.

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.

XI. ATTENUATION OF POLLUTION

Pollutants in groundwater tend to be removed or reduced in concentration with time and with time and with distance traveled. Mechanisms involved include filtration, sorption, chemical processes, microbiological composition and dilution. The rate of pollution attenuation depends on the type of pollutant and on the local hydro-geologic situation. Attenuation mechanisms tend to localize groundwater pollution near its source, they are also responsible for the interest in groundwater recharge as a water reclamation technique.

Filtration: Filtration removes suspended materials; hence this action is the most important at ground surface where polluted surface water is infiltrating into the ground. In groundwater filtration can remove particulate forms of iron and manganese as well as precipitates formed by chemical reactions.

Sorption: Sorption serves as a major mechanism for attenuation groundwater pollution. Clays, metallic oxides and hydroxides, and organic matter function as sorptive materials. Most pollutants can be sorped under favorable conditions with the general exception of chloride and to a lesser extent, nitrate and sulphate. The sorption process depends on the type of pollutant and the physical and chemical properties of the both solution and the subsurface materials; a substantial clay content in the strata above the water table is a key factor.

Chemical processes: Precipitation in groundwater can occur where appropriate ions are in solution in sufficient quantities. The most important precipitation reactions for the major constituents involve calcium, magnesium, bicarbonate and sulphate. Trace elements having important precipitation potential include arsenic, barium, cadmium, copper, cyanide, fluoride, iron, lead, mercury, molybdenum, radium and zinc. in the zone above the water table, oxidation of organic matter acts as an important attenuation mechanism.

Microbiological decomposition: most pathogenic microorganisms in the soil do not flourish in the soil and hence are subject to ultimate destruction, the timing of which depends on different species and environmental conditions. Bacteria and viruses are particulate matter suspended in water tend to move slower through a porous media than water. Field studies indicate that these pathogens are largely removed by passage through as little as one meter of soil, provided responsible amount of silt and clay are present.

Dilution: Pollutants in groundwater flowing through porous media tend to become diluted in concentration due to hydrodynamic dispersion occurring on both microscopic and macroscopic scales. These mixing mechanisms produce a longitudinal and lateral spreading of a pollutant within the groundwater so that the volume affected increases and the concentration decreases with distance traveled. Dilution is the most important attenuation mechanism for pollutants after they reach the water table.

XII. CONCLUSION

"Jal hi jeevan hai" – groundwater contributes about 25% of the total fresh water resources on earth, that is about 1.05% of the total water resource on the earth (1.54×10^{-7} km^3) and about 78% of the Indian population depends on this source of water. Conservation of every resource is very crucial on this verge of depleting resources and precaution to be taken for the groundwater to get polluted can a part conservation of groundwater resources. Pollution of groundwater cannot be ceased but can be reduced or restricted to a permissible limit as described in the paper. This paper was our small attempt for creating awareness on the most untouched topic in the common human world.

REFERENCES

[1] groundwater Hydrology, Second Edition, David Keith Todd, University of California, Berkeley; and DAVID KEITH TODD, CONSULTING ENGINEERS, INC. (John Willy and Sons publication).

[2] http//www.cpcb.nic.in