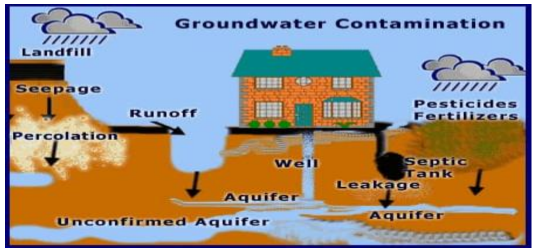
Project Report On

Effect Of Groundwater Contamination



Maulana Abul Kalam Azad University Of Technology

West Bengal

Hooghly Engineering And Technology College

Department of Electronics and Communications Engineering

2nd Year, 3rd Semester

In partial fulfilment of the requirements for the award of the Degree of

Bachelor of Technology in Electronics and Communications Engineering

By:-

Aditya Ghosh	**Ripa Ghosh**
Abisekh Dey	**Sayani Saha**
Dipti Bag	**Sk. Mofiz Hossain**

Under the guidance of

Dr. Aishwarya Mukherjee

HOOGHLY ENGINEERING AND TECHNOLOGY COLLEGE

DEPARTMENT OF ELECTRONICS AND COMMUNICATIONS ENGINEERING

CERTIFICATE OF APPROVAL

The foregoing Progress report is hereby approved as a creditable study of Engineering subject caried out and presented in a satisfactory manner to warrant its acceptance as a preliminary report of the ongoing project which is a prerequisite for the Degree of **'Bachelor of Technology in Electronics and Communications Engineering'**. It is understood that by this approval the undersigned do not necessarily endorse or approve the progress report only for the purpose for which it is submitted.

Board of Progress Report Examiner:-

ACKNOWLEDGEMENT

First and foremost, praises and thanks to the God, the Almighty, for His showers of blessing throughout our project work to complete the research successfully.

We cannot express our sincere gratitude to **Dr. Aishwarya Mukherjee** for her continuous support by helping us in doing a lot of research and we came to know about so many things from her. Also completion of this project could not have been accomplished without the support of our group **Aditya Ghosh, Abisekh Dey, Dipti Bag, Ripa Ghosh, Sayani Saha** and **Sk. Mofiz Hossain**. We want to thank the technical assistant teachers of our department for helping us by providing all the necessary equipments required from the workshop and laboratory.

Dated:-

Hooghly Engineering And Technology College

Department of Electronics and Communications Engineering

2nd Year, 3rd Semester

1)
2)
3)
4)
5)
6)

TABLE OF CONTENTS

TOPIC	PAGE NO.
Abstract	5
Introduction	6-8
Significance of Groundwater	9-13
Contamination Of Groundwater	13-18
Causes Of Groundwater	18-25
Effects Of Groundwater	25-29
Drinking Water Quality Standards	29-45
Positive Measures	46-48
Future Prospect	49-50
Conclusions and Policy Interferences	50-55

ABSTRACT

Groundwater contamination is a global problem that has a significant impact on human health and ecological services. Studies reported in this special issue focus on contaminants in groundwater of geogenic and anthropogenic origin distributed over a wide geographic range, with contributions from researchers studying groundwater contamination in India, China, Pakistan, Turkey, Ethiopia, and Nigeria. Thus, this special issue reports on the latest research conducted in the eastern hemisphere on the sources and scale of groundwater contamination and the consequences for human health and the environment, as well as technologies for removing selected contaminants from groundwater. In this article, the state of the science on groundwater contamination is reviewed, and the papers published in this special issue are summarized in terms of their contributions to the literature. Finally, some key issues for advancing research on groundwater contamination are proposed.

Groundwater is a major source of fresh water for the global population and is used for domestic, agricultural, and industrial uses. Approximately one third of the global population depends on groundwater for drinking water (International Association of Hydrogeologists 2020). Groundwater is a particularly important resource in arid and semi-arid regions where surface water and precipitation are limited. Securing a safe and renewable supply of groundwater for drinking is one of the crucial drivers of sustainable development for a nation. However, urbanization, agricultural practices, industrial activities, and climate change all pose significant threats to groundwater quality. Contaminants, such as toxic metals, hydrocarbons, trace organic contaminants, pesticides, nanoparticles, microplastics, and other emerging contaminants, are a threat to human health, ecological services, and sustainable socioeconomic development Over the past three decades, chemical contamination is a common theme reported in groundwater studies.

INTRODUCTION

Groundwater contamination is defined as the addition of undesirable substances to groundwater caused by human activities. This can be caused by chemicals, road salt, bacteria, viruses, medications, fertilizers, and fuel. However, groundwater contamination differs from contamination of surface water in that it is invisible and recovery of the resource is difficult at the current level of technology. Contaminants in groundwater are usually colorless and odorless. In addition, the negative impacts of contaminated groundwater on human health are chronic and are very difficult to detect. Once contaminated, remediation is challenging and costly, because groundwater is located in subsurface geological strata and residence times are long. The natural purification processes for contaminated groundwater can take decades or even hundreds of years, even if the source of contamination is cut off .

The numbers of classes of contaminants detected in groundwater are increasing rapidly, but they can be broadly classified into three major types: chemical contaminants, biological contaminants, and radioactive contaminants. These contaminants can come from natural and anthropogenic sources. The natural sources of groundwater contamination include seawater, brackish water, surface waters with poor quality, and mineral deposits. These natural sources may become serious sources of contamination if human activities upset the natural environmental balance, such as depletion of aquifers leading to saltwater intrusion, acid mine drainage as a result of exploitation of mineral resources, and leaching of hazardous chemicals as a result of excessive irrigation.

Nitrogen contaminants, such as nitrate, nitrite, and ammonia nitrogen, are prevalent inorganic contaminants. Nitrate is predominantly from anthropogenic sources, including agriculture (i.e., fertilizers, manure) and domestic wastewater. Groundwater nitrate contamination has been widely reported from regions all over the world. Other common inorganic contaminants found in groundwater include anions and oxyanions, such as F−, SO42−, and Cl−, and major cations, such as Ca^{2+} and Mg^{2+}. Total dissolved solids (TDS), which refers to the total amount of inorganic and organic ligands in water, also may be elevated in groundwater. These contaminants are usually of natural origin, but human activities also can elevate levels in groundwater.

Toxic metals and metalloids are a risk factor for the health of both human populations and for the natural environment. Chemical elements widely detected in groundwater include metals, such as zinc (Zn), lead (Pb), mercury (Hg), chromium (Cr), and cadmium (Cd), and metalloids, such as selenium (Se) and arsenic (As). Exposures at high concentrations can lead to severe poisoning, although some of these elements are essential micronutrients at lower doses. For example, exposure to hexavalent chromium (Cr^{6+}) can increase the risk of cancer. Arsenic is ranked as a Group 1 human carcinogen by the US Environmental Protection Agency (EPA) and the International Agency for Research on Cancer (IARC), and As^{3+} can react with sulfhydryl (–SH) groups of proteins and enzymes to upset cellular functions and eventually cause cell death. Toxic metals in the environment are persistent and subject to moderate bioaccumulation when they enter the food chain.

Organic contaminants have been widely detected in drinking water, and many of these compounds are regarded as human carcinogens or endocrine disrupting chemicals. In groundwater, more than 200 organic contaminants have been detected, and this number is still increasing. Some organic contaminants are biodegradable, while some are persistent. The biodegradable organic contaminants originate mainly from domestic sewage and industrial wastewater. Many of these organic substances are naturally produced from carbohydrates, proteins, fats, and oils and can be transformed into stable inorganic substances by microorganisms. They have no direct toxic effects on living beings but can reduce the dissolved oxygen levels in groundwater. Common organic contaminants include hydrocarbons, halogenated compounds, plasticizers, pesticides, pharmaceuticals, and personal care products and natural estrogens, among others. Many of the halogenated compounds are stable in the environment and can be accumulated and enriched in organisms, causing harmful effects in organisms from higher trophic levels, including humans. The persistent organic contaminants are mainly compounds used for agriculture, industrial processes, and protection of human health. Because these compounds degrade very slowly or even not at all, they may permanently threaten the quality of groundwater for drinking purposes.

Radioactive contaminants in groundwater can originate from geological deposits of radionuclides but also can originate from anthropogenic sources, such as wastes from nuclear power plants, nuclear weapons testing, and improper disposal of medical radioisotopes. Radioactive substances can enter the human body through a variety of routes, including drinking water. However, radioactive contaminants have been rarely detected in groundwater at levels that are a threat to human health.

Biological contaminants include algae and microbial organisms, such as bacteria, viruses, and protozoa. For microbial contaminants, more than 400 kinds of bacteria have been identified in human and animal feces, and more than 100 kinds of viruses have been recognized. Some of these microbial organisms originate from natural sources, but some include microscopic organisms that co-exist with natural algal species and compete for available resources. Drinking water contaminated by microbial contaminants can result in many human diseases, including serious diarrheal diseases, such as typhoid and cholera. Currently, the COVID-19 virus has resulted in pandemic affecting every corner of the world. This coronavirus is primarily transmitted from person-to-person through respiratory droplets. However, water contaminated by this virus also can threaten human health. Algal contamination is very common in surface waters, such as lakes and reservoirs due to eutrophication, but algae are rarely found at a high biomass in groundwater.

SIGNIFICANCE OF GROUNDWATER

Thinking about freshwater often brings to mind pictures of flowing streams and crystal clear lakes, but actually, almost all freshwater in the world (that is not frozen and locked away in ice caps and glaciers) is groundwater.

Groundwater is the water found underground in the cracks and spaces in soil, sand, and rock. It is held in aquifers—permeable water-bearing rock and/or sediment—and can be extracted through wells or bubbles up naturally through a spring or is discharged into lakes or streams. Even though it's underground, when it does bubble up or flow into streams, groundwater helps to replenish and maintain levels of surface water—the bodies of water that we are used to seeing such as rivers, lakes, streams. Groundwater helps to keep our rivers flowing.

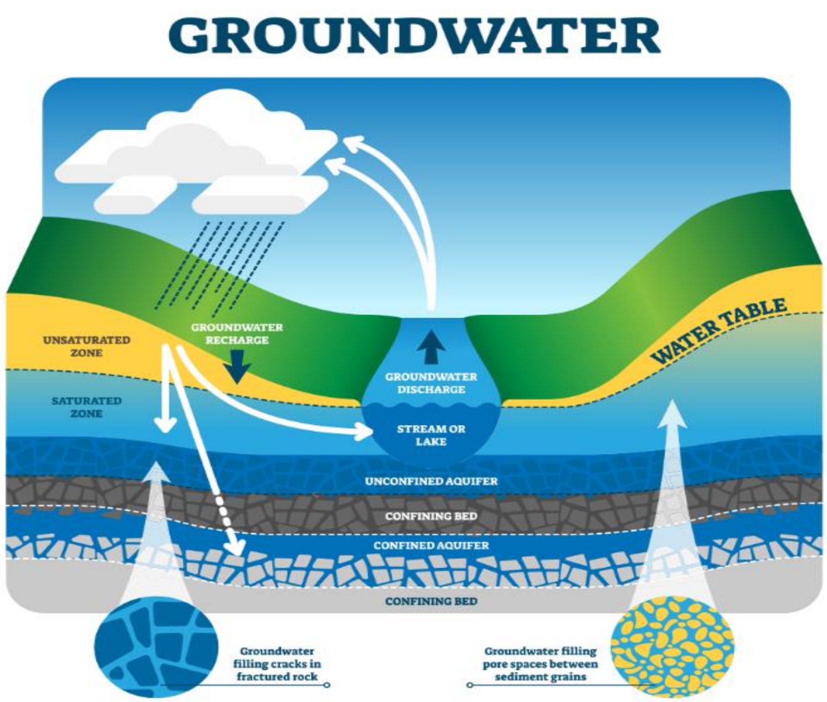
Groundwater is used for drinking water by close to 50% of the people in the United States, but its largest use is for crop irrigation and agricultural production.

One place that critically relies on groundwater is the Rio Grande/Rio Bravo (RGRB) river basin, which creates the border between southern Texas and Mexico. More than 16 million people in this region in both the US and Mexico depend on this resource; it accounts for 25% of the water that is used for irrigated agriculture and public supply in the basin.

Not just the people, but the local wildlife and the river itself also heavily rely on groundwater. In some stretches of the Rio Grande-Rio Bravo, such as the Big Bend region, more than 50% of the water that flows in the river comes from groundwater during the months when the river volumes get low. It's also the main source of water for wetlands and springs, which are of critical importance for freshwater biodiversity and migratory bird conservation.

One of the main challenges to protecting groundwater is that it is, of course, underground. Groundwater levels are not easily monitored with the naked eye and so supplies can be unknowingly polluted or even overdrawn, meaning that more is taken out of the ground than can be sustainably replenished. Groundwater can be polluted by landfills, septic tanks, leaky underground gas tanks, and from overuse of fertilizers and pesticides.

The water in RGRB is critically endangered. Surface water in the basin is 150% over allocated and the basin's groundwater resources are similarly overdrawn. The river itself has lost approximately 90% of its historic flows and has been declared one of the 10 most endangered rivers, nationally.



Climate change and rapid population growth in border cities are putting increasing pressure on the river's precious resources.

However, groundwater has the ability to be recharged and replenished. It can happen naturally when rain and snowmelt seeps down into the cracks and crevices beneath the land's surface, or artificially when people take action to restore groundwater levels by redirecting water so it will be reabsorbed into the ground through canals, basins, or ponds. Many reasons make groundwater a good choice for a water supply:

I. It is often present in those areas where there are limited surface water sources.
II. The quality of groundwater is usually very good, and it does normally require much less treatment than river water to make it safe to drink. The soil and rocks through which the groundwater flows helps to remove pollutants.
III. The quality doesn't change much through the year, which can be important for industry.
IV. Groundwater also responds slowly to changes in rainfall, and so it stays available during the summer and during droughts when rivers and streams have dried up.
V. Groundwater is relied on in many parts of Africa and the developing world, because it can often be found close to villages and it does not require the large costs which may be associated with capturing, treating and piping surface water.
VI. Groundwater doesn't require expensive reservoirs to store water in before it is used.

Groundwater is not an infinite resource; it's like drawing money from the bank without replenishing it, Simmons says. Over-exploitation can lead to a litany of problems.

Extracting groundwater causes drawdown. This can impact delicate ecosystems and biodiversity. For instance, groundwater feeds vegetation and replenishes intermittent streams that communities of fish and aquatic invertebrates depend on. Wet streambeds are also important sites of microorganism activity, carbon and nutrient recycling. Some areas may house species that live there exclusively.

In the Great Artesian Basin, Australia's biggest groundwater basin, for instance, 98 endemic species of flora and fauna have been identified, and these are at risk from drawdown. Subsidence is another problem that occurs when the ground level sinks from over-pumping and resulting depressurization.

"The land just compacts because there's reduced pressure," Simmons explains. "It's like taking air out of a tire; it just starts to collapse under the weight of the rock and soil." The most extreme example of this is in San Joaquin Valley, California, where the ground level has sunk by more than eight meters since the 1920s – that's nearly the height of a telegraph pole.

Seawater intrusion is another issue. It occurs naturally along the coastline but can be aggravated by extracting groundwater from nearby aquifers. This is a major problem in regions like Australia with high coastal populations. If the seawater seeps inland it can contaminate bores with salty water, wasting money and taking centuries to remedy. Excess pumping can also draw salt in by drilling deeper into the earth.

"So water quantity and water quality are often connected issues," says Simmons.

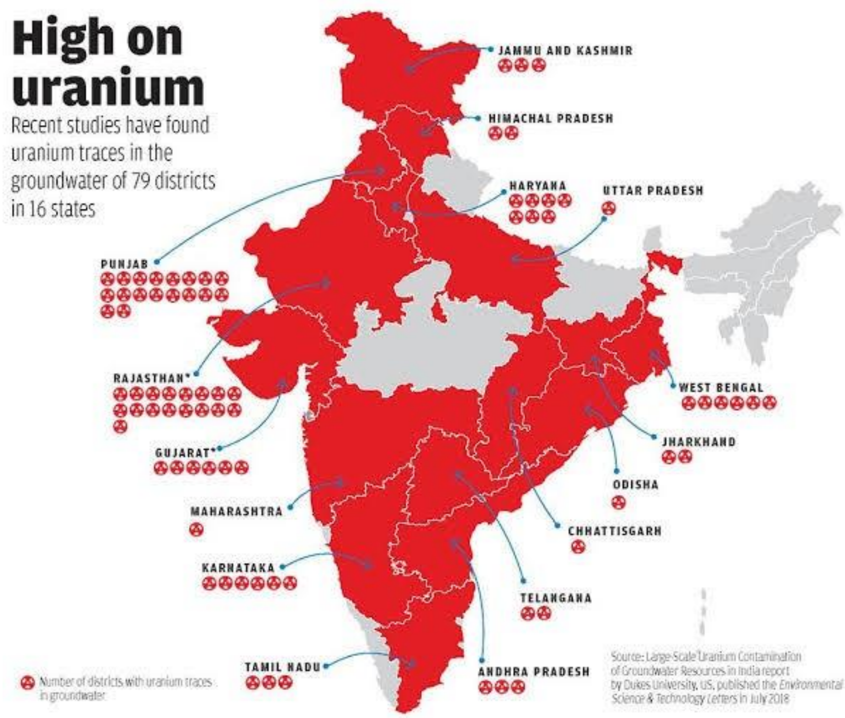
WWF-Mexico has made progress on an Aquifer Recharge project on the Mexican portion of the RGRB. The program has created a management plan focused on rainwater capture and ground infiltration to replenish the aquifers and stabilize ongoing usage. This work is considered a nature-based solution, which is a type of intervention that is aligned with nature and can help build resilience in the face of climate change.

As climate change worsens, groundwater stores will become more and more critical to maintaining our access to safe, drinkable water. What we need now to prevent groundwater pollution in homes and cities is to ensure proper disposal of waste and chemicals, promote aquifer recharge interventions at scale, support efforts to raise awareness such as the Global Groundwater Sustainability Call to Action, and to push local, state, and federal policymakers to protect groundwater and strengthen water governance by adding measures like the Sustainable Groundwater Management Act.

CONTAMINANTS OF GROUNDWATER

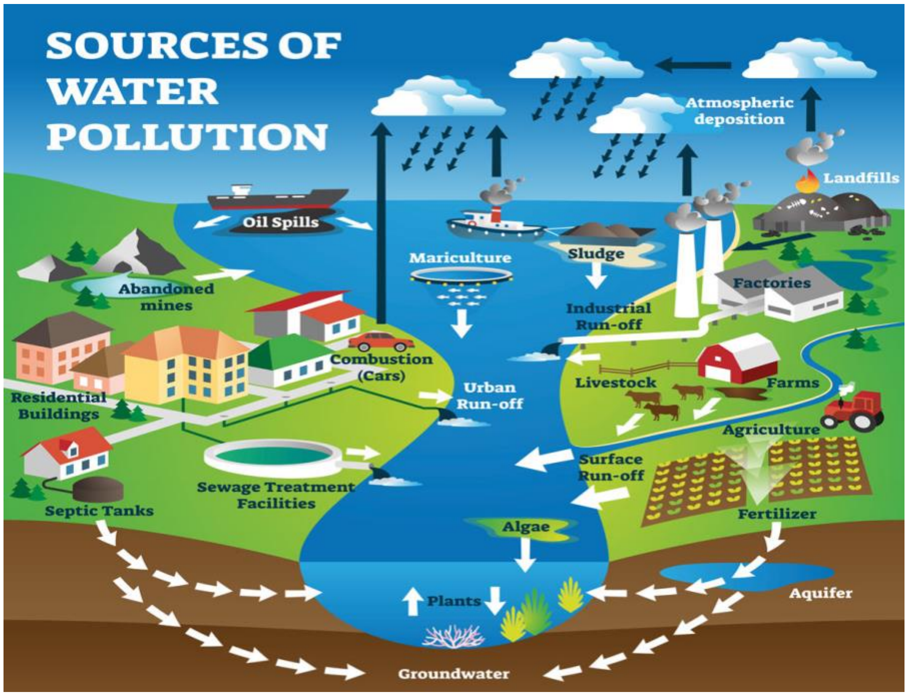
Contaminants in groundwater from natural resources:- In nature, even the cleanest water contains some impurities that come from the erosion of natural rock formations. Water dissolves and absorbs substances that it touches, including calcium, magnesium, silica, and fluoride from dozens of naturally occurring minerals.

So, the chemistry of water is influenced as it flows downward through soil and the unsaturated zone. Because groundwater is in contact with soil as it moves down to the aquifer, dissolved minerals are picked up by the water, leading to a higher mineral content than surface water. At low levels, most of these dissolved minerals do not cause health problems, and can even give water an appealing taste. Some of these minerals determine how “soft’ or "hard" our water is, and some may produce an unpleasant odour or taste.



At higher levels, minerals can be considered contaminants, and like manmade chemicals, can make water unpalatable or unsafe to drink. In some areas, iron, manganese, and sulphate occur locally in objectionable concentrations. For example, large amounts of iron in the rock in some areas, particularly the Piedmont and Blue Ridge, result in iron "staining" of toilet bowls and sinks. Sulphide in groundwater in parts of the Valley and Ridge where coal or natural gas is present can produce an obnoxious odour. Naturally occurring soil bacteria can also be found in groundwater, and may cause odour, taste, and discoloration problems. It is not unusual for a well in Virginia to have sulphur, iron, or manganese bacteria.

Contaminants in groundwater from human activities:- Most groundwater contamination is the result of human activity. Just as our surface freshwater resources (i.e., rivers, wetlands) are influenced by geologic processes and the activities of humans, so too is groundwater. Contaminants can seep into groundwater from leaking underground tanks, cesspools, septic tanks, and landfills. Pesticides and fertilizers used on farmlands and lawns can find their way into groundwater, as can substances discharged from factories.



Common pollutants include bacteria from septic systems, and nitrates from fertilizer applications and from septic systems. Other possible contaminates include petroleum products, pesticides, detergents, hazardous chemicals and polluted runoff from paved surfaces. Sources of contaminants can be very close to a well, or miles away. Since contaminants that reach the groundwater generally move very slowly, continued leakage in one spot will lead to gradually increasing levels of contaminants. Nitrate At high-enough levels, some pollutants found in groundwater are harmful to human health.

For example, well water with more than 10 parts per million nitrate-nitrogen should not be ingested by babies, as it can cause “blue baby syndrome.” There are also health risks for adults associated with excessive nitrate consumption.

Boiling water will not correct this problem, as boiling will increase the concentration of nitrates. The Virginia Department of Health recommends that private wells be tested annually for nitrate-nitrogen to detect contamination. See the lesson in this packet “Nitrate Levels in Wells” for information on this common groundwater pollutant, and how students can investigate this issue in your area. Fecal Coliform Bacteria, - According to the U.S. Environmental Protection Agency’s website on drinking water, “…the presence of coliform bacteria indicates that the water is potentially dangerous and should not be consumed unless boiled.”

Fecal coliform bacteria (including E. coli) originate in the intestinal tract of humans and warm blooded animals including cattle, swine, poultry, dogs, deer, and geese. Fecal coliform and E. coli are not usually health threats in themselves; they are used to indicate whether other potentially harmful bacteria or viruses may be present. Their presence in wells shows that the well casing is not correctly sealed, the well is improperly constructed, or the on-site sewage disposal system (usually a septic tank and drain field) has failed. The U.S. EPA's standard for coliform in drinking water is zero. Fecal coliform bacterial contamination is also the main reason that Virginia's surface waters are found to be polluted or impaired.

The Virginia Department of Health recommends that private wells be tested annually for coliform bacteria to detect contamination. This is the responsibility of the well owner. Technical advice is available from the Virginia Water Resource Research Centre or local health departments. According to studies conducted by the Virginia Cooperative Extension's Rural Household Water Quality Education Program, bacterial contamination is the most widespread problem in the wells they tested. Older, shallower wells that were dug or bored had higher incidences of bacterial contamination, while newer drilled wells, which tend to be deeper, had a lower incidence of contamination when the wells were correctly constructed to seal off the water table aquifer. For more information on groundwater quality, see the resources at the end of this chapter.

CAUSES OF GROUNDWATER CONTAMINATION

Groundwater pollution(or contamination), occurs when unwanted substances called pollutants, seep from the land surface into the groundwater during the groundwater recharge process.

Groundwater pollution (also called **groundwater contamination**) occurs when pollutants are released to the ground and make their way into groundwater. This type of water pollution can also occur naturally due to the presence of a minor and unwanted constituent, contaminant, or impurity in the groundwater, in which case it is more likely referred to as contamination rather than pollution. Groundwater pollution can occur from on-site sanitation systems, landfill leachate, effluent from wastewater treatment plants, leaking sewers, petrol filling stations, hydraulic fracturing (fracking) or from over application of fertilizers in agriculture. Pollution (or contamination) can also occur from naturally occurring contaminants, such as arsenic or fluoride.[1] Using polluted groundwater causes hazards to public health through poisoning or the spread of disease (water-borne diseases).

The pollutant often creates a contaminant plume within an aquifer. Movement of water and dispersion within the aquifer spreads the pollutant over a wider area. Its advancing boundary, often called a plume edge, can intersect with groundwater wells and surface water, such as seeps and springs, making the water supplies unsafe for humans and wildlife. The movement of the plume, called a plume front, may be analyzed through a hydrological transport model or groundwater model. Analysis of groundwater pollution may focus on soil characteristics and site geology, hydrogeology, hydrology, and the nature of the contaminants. Different mechanisms have influence on the transport of pollutants, e.g. diffusion, adsorption, precipitation, decal. The interaction of groundwater contamination with surface waters is analyzed by use of hydrology transport models. Interactions between groundwater and surface water are complex. For example, many rivers and lakes are fed by groundwater. This means that damage to groundwater aquifers e.g. by fracking or over abstraction, could therefore affect the rivers and lakes that rely on it. Saltwater intrusion into coastal aquifers is an example of such interactions.[2][3] Prevention methods include: applying the precautionary principle, groundwater quality monitoring, land zoning for groundwater protection, locating on-site sanitation systems correctly and applying legislation. When pollution has occurred, management approaches include point-of-use water treatment, groundwater remediation, or as a last resort, abandonment.

As per data available, more than 12 million people in India were affected by Arsenic in 2019, which is a lethal groundwater pollutant. Drinking arsenic-rich water over a longer period may cause cancer, high blood pressure, diabetes, and diseases of blood vessels. Another report of 2018 states that major toxins like nitrate, fluoride, iron, and heavy metals like lead, cadmium, and chromium are exceeding their permissible limits in many districts of India.

Identifying and knowing the cause of any problem is the key to its remediation. So, this article will explain some of the major causes of groundwater pollution. And we'll also look into some of the ways to prevent groundwater pollution.

Major Causes of Groundwater Pollution:-

The sources (or causes) of groundwater pollution can be landfills, effluents released from industries or wastewater treatment plants, leakage from sewers, petrol filling stations, or fertilizers/pesticides used in agriculture.

Interestingly, the cause of groundwater pollution can also be native(natural) due to arsenic or fluoride contamination.

1. Naturally Occurring(Gynogenic) Chemicals:-

Compounds of arsenic and fluorine formed under certain conditions in the

Arsenic - The Mother of Poison

Fluorine & Fluride Stones

aquifers are the major sources of Gynogenic(natural) groundwater pollution.

Arsenic is a naturally occurring metal present in the earth's crust. In its organic form, it's poisonous and quite lethal in nature. It gets dissolved in groundwater due to the anaerobic conditions produced by organic matter present inside the aquifers. Due to the microbial decomposition of the organic matter, the oxides of iron are released into the groundwater aquifers. These iron oxides then react with the arsenic and produce arsenic compounds – arsenate and arsenate, the former being more toxic than the latter.

The second major eugenic pollution occurs due to the compounds of fluoride found in the groundwater. These are present in aquifers that lack Calcium inside them. The permissible limit of fluoride concentration in groundwater is 1.5 mg/l as per WHO Guidelines since 1984. More than this may result in "dental fluorosis" a condition characterized by hypo mineralization of the tooth enamel.

2. Poor Sanitation Systems:-

Poor sanitation systems imply a drinking water source, like *water well* built too near to pit toilets or septic tanks. They can pollute the groundwater making it quite unfit for potable purposes.

Water from the sanitation systems can infiltrate the unsaturated zone and enter the aquifers.

The challenge that lies *here is* the appropriate distance between the septic tanks and the point where water can be extracted can't be determined easily. This is because it depends upon local hydrological conditions and thus, varies from place to place. Although the pathogens die in between the time travel before they reach the aquifer when water seeps into the ground, this process is quite complex in itself as it depends upon aquifer type, soil type, and other environmental factors. So this natural water treatment process, also known as SAT, doesn't guarantee a pathogen-free liquid entering into the aquifer.

3. <u>Improper Sewage Disposals:-</u>

Poorly treated sewage water disposed on the ground surface or local water bodies is also a reason for groundwater pollution. This problem arises in the areas where there is a poor infrastructure of sewage treatment plants or poorly maintained sewer systems.

Also, if there are micro-pathogens like hormones, pharmaceutical residues and other micro-contaminants that are found in urine or feces is present in the sewage, then even the conventional treatment plants may not be able to remove such impurities. An example of this was found in several locations of **Germany where pharmaceutical residues of the order of 5-ng/L were present in groundwater**.

4. <u>Excessive Use of Fertilizers and Pesticides:-</u>

Pesticides and commercial fertilizers, or even natural fertilizers like manure are nitrogen-based compounds that can introduce nitrates into the groundwater and pollute it. This is mainly because only a certain portion of the nitrogen is used by plants and the rest may get either washed off to enter water bodies or seep into the ground polluting the aquifers.

Also, animal manure may also contain pharmaceutical pollutants if the animals were subjected to veterinary treatmentstreatmen.

5. Leakage from Industrial Pipes and other industrial releases:-

Leakage from the underground industrial pipes and oil tanks is also causing groundwater pollution around industrial areas. Mining of ore and metal may introduce toxic metals like arsenic into the groundwater due to improper waste disposal. The acidic nature of their waste also helps other harmful metals to get

easily dissolved into it and seep into the aquifers.

Similarly, gasoline stations may cause groundwater pollution if their storage tanks leak and release benzene and other low-density compounds into the ground. These substances will float on the top surface of the water table due to their lower densities than water and will make them unfit for household use.

6. Over pumping of groundwater:-

Pumping groundwater aggressively may release arsenic into the water and also cause land subsidence(sudden sinking of land).

Arsenic is mainly present in the clayey layer of the underground surface and little of it seeps into the water while groundwater is pumped. But if overdone, a substantial amount may get entered into aquifers due to the high hydraulic gradient created.

7. Improper Landfill practices:-

One of the major examples of groundwater pollution due to landfill leachate is

the Love Canal, an aborted canal project near Niagara Falls,

New York. In 1978, the area started reporting quite a number of cases of cancer and birth defects in the population residing around. The investigation followed after traced it to the organic/inorganic toxic contaminants leaching into the groundwater from the industrial landfill present in the area.

EFFECTS OF GROUNDWATER CONTAMINATION

All living organisms are threatened by groundwater pollution. It doesn't affect humans or plants alone but cuts across. So, the following are some of the effects of groundwater pollution.

1. Health Issues:-

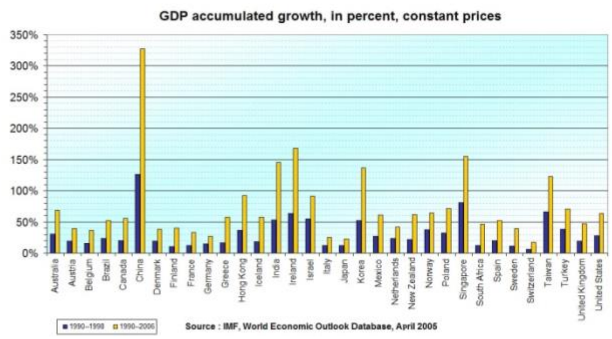
Contaminated groundwater has detrimental effects on human health. In areas where septic tank installation is not set up correctly, human waste may contaminate the water source. The waste may contain hepatitis-causing bacteria that may lead to irreversible damage to the liver.

Also, it may cause dysentery, which leads to severe diarrhea, dehydration, and, in some cases, death. Additional health problems include poisoning that may be a result of the use of excessive pesticides and fertilizers or natural chemicals. The chemicals leach into water sources and poison them. Drinking water from such a source may lead to serious health effects.

2. Affects economic growth:-

Contamination of groundwater sources renders the area incapable of sustaining plant, human, and animal life. The population in the area reduces and the land value depreciates. Another effect is that it leads to less stability in industries relying on groundwater to produce their goods.

Therefore, the industries in the affected areas will have to outsource water from other regions, which may turn out to be expensive. In addition, they may be forced to close down due to the poor quality of water.



3. Lack of Enough Drinking Water:-

Due to groundwater pollution, many countries are having challenges finding clean drinking water. These effects are adverse because people are not able to drink clean water which leads to health complications.

4. Waterborne Diseases:-

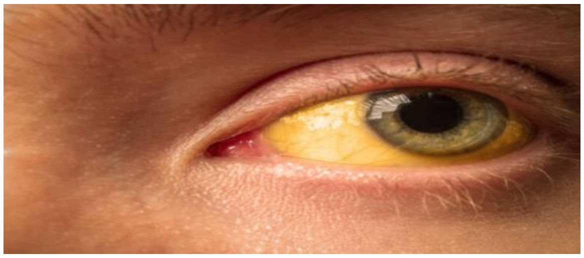
When groundwater is polluted or contaminated it may lead to waterborne diseases. For example, in Bangladesh World Health Organization found out that the groundwater is polluted which leads to increase of waterborne diseases annually. Therefore, groundwater pollution may lead to waterborne diseases to humans and possibly lead to death.

5. Dental Fluorosis:-

This is a dental problem where the teeth become brown in color. This usually due to high amounts of fluoride in water. High amounts of fluoride in groundwater is due to lack of calcium in the water. This is one of the effects caused by pollution of the groundwater.

6. Hepatitis:-

Lack of well-built sewerage systems may lead to contamination of groundwater causing Hepatitis. This is because human waste contaminates the groundwater. And , Hepatitis is a disease that affects the liver. So, when it is positioned correctly to avoid such instances.



7. Valueless Land:-

No one can leave or buy land where there is no clean water for drinking and home use. Consequently, if land is situated in a location where groundwater pollution is peak then the value will reduce. This because plants, animals, and people cannot survive in this land.

8. Lack of Clean Water for Industries:-

Most of the industries release effluents that cause groundwater pollution. At long last, some of these industries suffer from a lack of clean water. Without clean water, no production can go on. Leading to the closure of the industries and loss of jobs.

9. Final Verdict:-

Groundwater pollution has enormous effects on the economy, human life, plant life, and animal life. So, the effects of this type of pollution cut across all people. But the sources that are man-made should reduce in order to decrease the amounts of groundwater pollution around the globe.

In addition, tough legislation should be enacted in order to punish those who promote this type of pollution.

DRINKING WATER QUALITY STANDARDS

Concern for water quality for drinking use is not new. By 1855 people were aware of the role of water in transmission of diseases such as typhoid, bacillary dysentery, cholera, amoebic dysentery and infectious hepatitis etc. In 1914, the U.S. Public Health Service established drinking water standards for public water supplies.

As on date several quality standards for drinking use are available. These recommendations/guidelines apply to all public, private, individual or small community water supplies which are used for drinking purpose. It must be cleared that the guideline values recommended are not mandatory limits worldwide. Such limits are based on socio-economic and environmental condition set by National/ Regional/international Authorities using a risk-benefit approach

Standards available at National level

The most widely used standard in India is Bureau of Indian Standard: IS 10500-2012. However, there are some other standards proposed and also in vogue in certain sectors of which an important one is that proposed by Indian Council of Medical Research, Report No.44 of 1975. For packaged drinking water and mineral water, the following two additional user-specification standards are available

1. *IS: 14543, specification for packed drinking water.*
2. *IS: 13428, specification for Mineral water.*

Standards available at International level

Most of the countries have their own standards. Besides many international organizations have formulated standards and advised guidelines. The international guidelines accepted widely are given below;

3. *World Health Organization (WHO) Guidelines 2011*
4. *European Economic Community (EEC) Norm*
5. *U S Environmental Protection Agency (USEPA) Norms*

<u>Commonly adopted standards for contaminants under discussion</u>

Two yardsticks are adopted while considering portability of water; “desirable” and “maximum permissible levels”. The limits described as ‘desirable’ apply to water which will be generally acceptable to the consumers. In case of absence of any other source the prescribed ‘maximum permissible level’ should be adhered to.

Table. Commonly accepted Drinking Water Quality Guidelines

Constituent	**Drinking water standards recommended by BIS and WHO (in mg/l)**			**Undesirable effect when present beyond acceptable limit in drinking water**
	BIS (2012)		**WHO (2011)**	
	Acceptable Limit	**Permissible limit in the absence of alternate source**	**guideline values**	
ARSENIC	0.01	0.05	0.01	It is a cumulative poison, Carcinogenic
TOTAL CHROMIUM	0.05	No relaxation	0.05	Hexavalent Chromium is Toxic and causes Ulcers & Dermatitis

STRONTIUM				Can cause problems with bone growth. Radioactive strontium is more harmful, it may cause anemia and oxygen shortages, and at extremely high concentrations it is even known to cause cancer.
DISSOLVED SOLIDS	500	2000	1000	Causes Gastrointestinal irritation
SILICA				Silicon compounds cause silicosis leading to tuberculosis, bronchitis, and chronic obstructive pulmonary disease. Harmful in boiler scale and steam of high-pressure boilers to form deposits on turbine blades.
MANGANESE	0.1	0.3		Aesthetic taste / appearance are affected, has adverse effect on domestic uses and water supply

				structures.Total concentration of Manganese (as Mn) and Iron (as Fe) shall not exceed 0.3 mg/l
FLUORIDE	1.0	1.5	1.5	It is completely absorbed in the body, required for prevention of Dental Caries. High concentration causes Fluorosis
IRON	0.3	No relaxation		Aesthetic taste, essential for human health [Heamoglobin Synthesis] Excess stored in Spleen , Liver , Bone marrow & causes Haemochromatosis. Total concentration of Manganese (as Mn) and Iron (as Fe) shall not exceed 0.3 mg/l
SELENIUM	0.01	No relaxation	0.01	Very low selenium status in humans has been associated with juvenile, multifocal myocarditis called Keshan disease and chondrodystrophy called Kaschin-Beck disease. Symptoms in people with high urinary selenium levels include

				gastrointestinal disturbances, discoloration of the skin and decay of teeth .
URANIUM			0.015	Carcinogenic, liver damage or both. Long term chronic intakes of uranium isotopes in food, water, or air can lead to internal irradiation.
NITRATE	45	No relaxation	50	Beyond this methaemoglobinamia takes place/may be indicative of pollution
RADON				Radon is the primary cause of lung cancer

METHODOLOGY FOR GROUNDWATER QUALITY SURVEY

SAMPLING

Metropolitan Cities

Criteria for selection of Bore Wells/Tube Wells/Hand pumps

For selection of groundwater quality survey location the following criteria were kept inmind:

- Drinking water wells;
- Wells closer to polluting sources like industries, urban wastewater drains, garbage dumpsites etc.;
- Wells suspected for natural contaminants like fluoride, iron, arsenic or such pollutants.

- Sample collection, transport, preservation and analysis

Samples were collected from one of the following three types of wells: *i) Open dug wells* in use for domestic or irrigation water supply, ii) *Tube wells* fitted with a hand pump or a power-driven pump for domestic water supply or irrigation; iii) *Hand Pumps*, used for drinking. Open dug wells, which are not in use or have been abandoned, were not used for sampling. For collection of samples a weighted sample bottle or sampler was used to collect sample from an open well. Samples from the production tube were collected after running the well for about 5 minutes. For bacteriological samples, when collected from tube wells/hand pump, the spout/outlet of the source was sterilized under flame by spirit lamp before collection of sample in the container. From open wells the samples were collected directly in to the pre- sterilized glass bottles. The samples were transported to the laboratory. The samples were analyzed immediately for the parameters like Coliform, BOD, COD and nutrients. Other parameters were analyzed within a week time.

Total twenty five ground water samples from each metropolitan cities were collected each during pre-monsoon (June 2003) and post-monsoon (December 2003) seasons from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good aerial and vertical representation and preserved by adding an appropriate reagents as and when required. The hand pumps were continuously pumped prior to the sampling, to ensure that ground water to be sampled was representative of ground water aquifer. The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (2 mL/lit.) Samples for pesticides analysis were collected in glass bottles while samples for bacteriological analyses were collected in sterilized high-density polypropylene/Glass bottles covered with aluminum foils. All the samples were stored in sampling kits maintained at $4^{o}C$ and brought to the laboratory for detailed chemical and bacteriological analysis. The standard methods (APHA, 20th Edition) adopted for each parametric analysis of groundwater samples. The details of sampling locations and source and depth wise distribution are given at each section city wise in the following chapter.

Sampling Locations

The groundwater quality survey locations were chosen (dug/open wells, tube well, bore well etc.) so that they depict the influence (if any) of the prevailing anthropogenic activity as well as industrial activity of the Metro city limit area. The groundwater survey covers mainly 18 dug wells, 42 tube wells, 34 bore wells, 109 hand pumps and others one well totaling to 204 groundwater sampling locations as presented in Table 2.

Table 2: Groundwater monitoring in Metropolitan cities

S. No.	**Name of Metro cities**	**State**	**DW/OW**	**TW**	**HP**	**BW**	**Others**	**Total**
1.	Agra	Uttar Pradesh	-	-	25	-	-	25
2.	Meerut	Uttar Pradesh	-	04	21	-	-	25
3.	Chennai	Tamilnadu	01 (Open Well)	-	24	-	-	25
4.	Coimbatore	Tamilnadu	09 (Open well)	-	-	16	-	25
5.	Ludhiana	Punjab	-	29	-	-	-	29
6.	Lucknow	Uttar Pradesh	-	09	15	-	01	25
7.	Madurai	Tamilnadu	07	-	-	18	-	25
8.	Vijaiwada	Andhra Pradesh	01	-	24	-	-	25
Sub total			**18**	**42**	**109**	**34**	**01**	**-**
Grand total			**204**					

Note: On 204 sampling locations, two times samples were taken during the period i.e. Pre-monsoon and Post- monsoon

2.3.4 Sampling Period in Metropolitan Cities

The sampling was done in pre-monsoon (June) and post-monsoon (December) at all the twenty- five locations of each metropolitan city.

2.3.5 Parameters selection in Metro-cities

The physico-chemical analysis was performed following standard methods. The brief details of analytical methods and equipment used in the study are given in the Table 3.

Table 3: Analytical methods and equipment used in the study

Sl. No.	Parameter	Method	Instruments/Equipment
A.	**Physico-chemical**		
1.	pH	Electrometric	pH Meter
2.	Conductivity	Electrometric	Conductivity Meter
3.	TDS	Electrometric	Conductivity/TDS Meter
4.	Alkalinity	Titration by H_2SO_4	-
5.	Hardness	Titration by EDTA	-
6.	Chloride	Titration by $AgNO_3$	-
7.	Sulphate	Turbidimetric	Turbidity Meter
8.	Nitrate	Ultraviolet screening	UV-VIS Spectrophotometer
9.	Phosphate	Molybdophosphoric acid	UV-VIS Spectrophotometer
10.	Fluoride	SPADNS	UV-VIS Spectrophotometer
11.	Sodium	Flame emission	Flame Photometer
12.	Potassium	Flame emission	Flame Photometer
13.	Calcium	Titration by EDTA	-
14.	Magnesium	Titration by EDTA	-
15.	Boron	Carmine	UV-VIS Spectrophotometer
16.	BOD	5 days incubation at 20^{o}C followed by titration	BOD Incubator
17.	COD	Digestion followed by titration	COD Digestor
B	Bacteriological		
18.	Total coliform	Multiple tube fermentation technique	Bacteriological Incubator
19.	Faecal coliform		
C.	Heavy Metals		
20.	Iron	Digestion followed by Atomic spectrometry	Atomic Absorption Spectrometer
21.	Manganese		
2	Copper		

2.			
23.	Nickel		
24.	Chromium		
25.	Lead		
26.	Cadmium		
27.	Zinc		
D.	Pesticides and Polynuclear Aromatic Hydrocarbons		
28.	Aldrin	Gas chromatography	Gas Chromatograph with ECD, NPD and FID
29.	DDT		
30.	DDE		
31.	DDD		
32.	A-BHC		
33.	B-BHC		
34.	γ-BHC		
35.	δ-BHC		
36.	Methoxychlor		
37.	Endosulphan		

Sl. No.	Parameter	Method	Instruments/Equipment
38.	Thionazin		
39.	Sulfotepp		
40.	Phorate		
41.	Dimethoate		
42.	Disulfoton		
43.	Methyl Parathion		
44.	Ethyl parathion		
45.	Famphur		
46.	Chlorpyriphos		
47.	Ethion		
48.	PAHs		

A) Groundwater quality survey in Problem areas

The groundwater quality survey locations were chosen (dug wells, tube well etc) so that they depict the influence (if any) of the prevailing industrial activity of the problem area besides views from the public were also considered. The GW survey locations covers mainly 40 dug wells, 27 tube wells, 33 bore wells, 11 hand pumps and one sump well totaling to 112 GW sampling locations as stated in Table 4) a).

Table 4) a): Groundwater survey details in Problem Areas

Sl. No.	Problem area	State	DW	TW	HP	BW	Others	Total
1.	Durgapur	W.Bengal	3	2	-	-	-	5
2.	Howrah	W.Bengal	1	4	-	-	-	5
3.	Dhanbad	Jharkhand	-	6	-	-	-	6
4.	Angul Talcher	Orissa	11	12				23

5.	Singrauli	Uttar Pradesh	1	-	4	-	1	6
6.	Vishakapatnam	Andhra Pradesh	-	-	-	7	-	7
7.	Bolaram-Patancheru	Andhra Pradesh	-	-	-	7	-	7
8.	Bhadravathi	Karnataka	-	-	-	3	-	3
9.	Greater Cochin	Kerala	7	-	-	-	-	7
10.	Manali	Tamilnadu	2	-	1	3	-	6
11.	North Arcot	Tamilnadu	10	-	3	1	-	14
12.	Ankleshwar	Gujarat	-	-	-	3	-	3
13.	Vapi	Gujarat	-	-	1	1	-	2
14.	Chembur	Maharashtra	2	-	-	4	-	6
15.	Tarapur	Maharashtra	1	-	2	4	-	7
16.	Digboi	Assam	2	3	-	-	-	5

The surveys were carried out for duration of two year. Samples were collected from the groundwater structures already in existence. Samples were transported to the laboratories and analyzed for the relevant parameters as per the procedures explained earlier.

2.3.6 Sampling period in Problem Areas

The sampling was done in post-monsoon (September), Winter (January) and pre-Monsoon (May).

2.3.7 Analytical parameters in Problem areas

The Table 4) b) below provides list of parameters that were analyzed for the groundwater samples in problem areas.

Table 4) b): Analysis of Groundwater parameters in problem areas

Heavy metals (ug/l)	**Pesticides (ng/l)**	**Bacteriological parameters (MPN/100 ml)**	**Physico-chemical (mg/l except pH)**
Mercury	Aldrin	F. Coliform	pH
Nickel	Dieldrin	T. Coliform	Conductivity
Zinc	Lindane		Total hardness
Cadmium	DDT		Fluoride
Copper			Chloride
Chromium			Sodium
Iron			Nitrate
Manganese			Phosphate
Lead			Magnesium
Arsenic			Calcium
			Total Dissolved Solids
			Cyanide
			Sulphate
			Alkalinity

B) Comparison of Groundwater Samples with Indian Drinking Water Standards (BIS- IS 10500: 1991 and WHO Guideline, 1996) in Metropolitan cities and Problem areas

Water is a prime natural resource, a basic human need and precious natural asset. The provision of drinking water that is not only safe is a matter of high priority. The supply of water that is un- satisfactory in this respect will undermine the confidence of consumers leading to complaints and possibility of using water from less safe sources. Looking to the seriousness of groundwater contamination is now a great concern. Therefore, all the groundwater samples collected from drinking sources have been compared with present Indian standards in this report. The BIS – 10500 and WHO Guideline has been presented in the form is given below:

S. No.	Parameter	BIS, Indian Standards (IS 10500:1991)		World Health Organization (WHO Guideline)
		Desirable Limit	Permissible Limit	Maximum allowable concentration
1	Colour	5 Hazen Units	25 Hazen Units	15 True Colour Units
2	Turbidity	5.0 NTU	10 NTU	5.0 NTU
3	PH	6.5-8.5	No relaxation	6.5-8.5
4	Total Hardness (as $CaCO_3$)	300 mg/L	600 mg/L	500 mg/L
5	Chlorides (as Cl)	250 mg/L	1000 mg/L	250 mg/L
6	Residual Free Chlorine (When Protection against viral infection is required it should be *Min* 0.5 mg/L)	0.2 mg/L	-	-
7	Dissolved Solids	500 mg/L	2000 mg/L	1000 mg/L
8	Calcium (as Ca)	75 mg/L	200 mg/L	-
9	Sulphate (as SO_4^{2-})	200 mg/L	400 mg/L	400 mg/L
10	Nitrate (as NO_3^-)	45 mg/L	100 mg/L	10 mg/L
11	Fluoride (as F^-)	1.0 mg/L	1.5 mg/L	1.5 mg/L
12	Phenolic Compounds (as C_6H_5OH)	0.001mg/L	0.002 mg/L	-
13	Anionic Detergent (as MBAS)	0.2 mg/L	1.0 mg/L	-
14	Mineral Oil	0. 01 mg/L	0.03 mg/L	-
15	Alkalinity	200 mg/L	600 mg/L	-
16	Boron	1.0 mg/L	5.0 mg/L	-
Micro Pollutants (Heavy Metals & Pesticides)				
17	Zinc (as Zn)	5.0 mg/L	15 mg/L	5.0 mg/L
18	Iron (as Fe)	0.3 mg/L	1.0 mg/L	0.3 mg/L
19	Manganese (as Mn)	0.1 mg/L	0.3 mg/L	0.1 mg/L

20	Copper (as Cu)	0.05 mg/L	1.5 mg/L	1.0 mg/L

S. No.	Parameter	BIS, Indian Standards (IS 10500:1991)		World Health Organization (WHO Guideline)
		Desirable Limit	Permissible Limit	Maximum allowable concentration
21	Arsenic (as As)	0.05 mg/L	No relaxation	0.05 mg/L
22	Cyanide (as CN)	0.05 mg/L	No relaxation	0.1 mg/L
23	Lead (as Pb)	0.05 mg/L	No relaxation	0.05 mg/L
24	Chromium (as Cr^{6+})	0.05 mg/L	No relaxation	0.05 mg/L
25	Aluminium (as Al)	0.03 mg/L	0.2 mg/L	0.2 mg/L
26	Cadmium (as Cd)	0.01 mg/L	No relaxation	0.005 mg/L
27	Selenium (as Se)	0.01 mg/L	No relaxation	0.01 mg/L
28	Mercury (as Hg)	0.001 mg/L	No relaxation	0.001 mg/L
29	Total Pesticides	Absent	0.001 mg/L	-

S. No.	Parameter	BIS, Indian Standards (IS 10500:1991)		World Health Organization, (WHO Guideline)
		Desirable Limit	Permissible Limit	Maximum allowable concentration
1	Sodium	-	-	200 mg/L
2	Aldrin &dieldrin	-	-	0.03 µg/L
3	DDT	-	-	1.0 µg/L
4	Lindane	-	-	3.0 µg/L
5	Methoxychlor	-	-	30.0 µg/L
6	Benzene	-	-	10.0 µg/L
7	Hexachlorobenzene	-	-	0.01 µg/L
8	Pentachlorophenol	-	-	10.0 µg/L

POSITIVE MEASURES

What We Can All Do To Reduce Groundwater Pollution

➢ **Why Groundwater is Important**

Groundwater has been called the great hidden resource. It conjures up images of vast underground rivers or lakes, pure and pristine, flowing from distant places. In fact, groundwater is quite different from that. It's more like the water within a saturated sponge, moving slowly through the earth's pores and cracks and it is replenished locally. Most available fresh water is groundwater. Groundwater is an important source for our drinking water and stream flow. Although most of our groundwater supplies are clean, they are, due to human neglect and carelessness, vulnerable and threatened.

➢ **Some facts and fictions about ground water:**

FICTION	FACT
• groundwater is inexhaustible • groundwater moves in strange and unknown ways • spring water is always pure • groundwater comes from underground rivers • groundwater moves long distances within the earth in Connecticut	• use can exceed supply, drying up streams and wells • groundwater flow can be investigated and determined • it can be polluted like all water • it is recharged locally from precipitation falling on surrounding land areas • it rarely moves more than a few miles, but can take years to flow that far

➢ What can I do to reduce pollution?

Groundwater contamination can last for years and be difficult and expensive to clean up. Pollution prevention is the key. We urge you to look at the ways you can help.

- AT HOME

- properly dispose of all waste; don’t dump chemicals down drains or on the ground
- test underground fuel oil tanks for leaks; if possible, replace them above ground
- safely store all chemicals and fuels
- minimize the use of chemicals; always use according to directions
- have on-site septic systems pumped and inspected every five years
- examine on-site wells and surrounding land areas; test wells as often as pollution risk demands

- AT WORK
- **Waste disposal:**

- properly dispose of all waste
- ensure proper waste water discharge connections; if possible, eliminate floor drains
- properly use and maintain on-site septic systems
- plug and cover waste dumpsters

- **Hazardous materials:**

- safely store, handle, and use chemicals and fuels
- monitor underground fuel and chemical tanks; if possible, replace above ground
- contain storage and loading areas
- reduce or substitute use of chemicals

- **Storm water:**

- keep chemicals and waste safe from rain
- isolate drains from storage and loading areas
- use deicing salt and pesticides sparingly

- **Other good management practices:**

- conduct an environmental audit
- develop a pollution prevention plan
- regularly inspect high risk areas
- devise an emergency response plan

- IN TOWN

- ensure that land use plans and regulations protect important water supply aquifers and well fields
- support protection legislation and programs
- inform and educate residents and businesses about groundwater
- consider important aquifers when acquiring open space
- monitor and inspect important well fields and recharge areas
- conduct household hazardous waste collections
- ensure that town facilities practice good pollution prevention

FUTURE PROSPECT

It has become evident that the global rise in population and food demand has become more and more dependent on ground water. With this development, all of humanity has to figure out ways of reducing the spread of toxins into our groundwater or prevent the contamination all together.

One thing which we know for sure is that it is 100% impossible to eliminate groundwater contamination due to its wide complex interaction between man and organisms that continuously produce contaminants which eventually find its way percolating to the groundwater. So, what are we to do to most effectively mitigate this ground water contamination? it has already been established that prevention is better than remediation in this fight against ground water contamination.

The following measures must be implemented:-

A. A careful classification of aquifers and the restriction of their use to the intended purpose. Thus a comprehensive protection and control system must be developed for all aquifers, continuous monitoring and delineation of critical zones, controlling and eliminating sources of pollution and public awareness on the value and vulnerability of aquifers.

B. Restriction of unnecessary over pumping of wells as this system usually causes some water from one aquifer to move to the other thereby minimizing the transmission of contaminants between the two aquifers.

C. Chemicals and hazardous waste in landfills should be fixed prior to the leachate leaving the landfill.

D. Utilization of volatilization by injecting air into the dumpsite to drive off volatile organic compounds (VOC's) that are captured and destroyed at the same time.

E. Strict laws and policies should be imposed on industries which release their effluents directly into the water bodies. These effluents must be of acceptable standards before being discharged into the water bodies thereby reducing the purification processes of obtaining drinking water from the same water bodies.

CONCLUSION OF GROUNDWATER CONTAMINATION

1. The rate at which water infiltrates into the ground depends on the permeability of the rocks and the state of the ground surface. Below the ground surface there is an unsaturated zone which has air in the pore spaces, and a saturated zone which has all the pores filled with water. The water table is the boundary between the unsaturated zone and the saturated zone, and is the level at which water stands in wells. Water below the water table is called groundwater. The water table follows the topography of the ground surface but with more gentle gradients.
2. Groundwater will flow in response to differences in elevation and pressure. Darcy's law relates the rate of the groundwater movement (*Q*) to the hydraulic conductivity (*K*), the cross-sectional area (*A*) and to the hydraulic gradient or slope of the water table (*h*/*l*): $Q = KAh/l$ The hydraulic conductivity depends on the permeability of the rock and on the properties of the water. Water generally flows in the direction of the hydraulic gradient and slope of the water table.
3. A cone of depression is formed in the water level around a well from which water is being pumped. The difference in height between the water table before pumping and the water level in the well during pumping is called the drawdown.
4. There is usually saline groundwater under the land at a coast, with a wedge of denser saline groundwater under the fresh groundwater. The depth to the saline groundwater depends on the height of the water table above sea level and on the densities of the fresh and saline water.
5. The porosity of a rock is the proportion of its volume that consists of pores: $$\text{porosity (\%)} = \frac{\text{pore volume}}{\text{total volume}} \times 100\%$$ Porosity is a measure of how much water a rock can store. The permeability of a rock is a measure of the

properties of the rock which determine how easily water can flow through it. The porosity and permeability are generally greater in unconsolidated sedimentary rocks, particularly sands and gravels, than in consolidated sedimentary, igneous or metamorphic rocks. Both porosity and permeability can be increased by processes that occur after the formation of the rock, such as solution or fracturing. These are called secondary porosity and secondary permeability.

6. An aquifer is a body of rock that can store water, and through which water can flow. For a rock to be an aquifer it must be sufficiently porous and it must be permeable. Igneous and metamorphic rocks seldom make good aquifers unless they have both secondary porosity and secondary permeability.
7. The proportion of water that can be recovered from a saturated aquifer is known as the specific yield. This is less than the total amount of water stored in the aquifer (represented by the porosity) because some of the water is retained by surface tension around the individual grains (specific retention). Specific yield, like porosity, is expressed as a percentage of the total volume of the rock. The highest porosities are found in fine-grained sediments, but the greatest specific yields are in medium-grained sediments. The exploitable storage of a saturated aquifer is the volume of water it will give up when pumped or allowed to drain.
8. Aquifers can be unconfined or confined. Unconfined aquifers crop out at the ground surface; water normally has to be pumped to the surface from the water table in these aquifers. Confined aquifers are separated from the ground surface by an impermeable layer. Water in confined aquifers is called artesian water, and wells that penetrate confined aquifers are called artesian wells. The water in an artesian well may be under sufficient pressure to reach the surface of the ground without pumping (a flowing artesian well).
9. The potentiometric surface is an imaginary surface joining the heights to which water will rise. For an unconfined aquifer, the potentiometric surface is the water table.

The safe yield of an aquifer is the maximum rate of extraction of water that does not produce a long-term decline in the average water table level or have any other adverse effect, such as a significant reduction in the flow to springs and rivers. Exceeding the safe yield (i.e. 'mining' groundwater) would necessitate pumping from progressively greater depths to obtain water, and might lead to a reduced flow to springs and rivers, and a deterioration in water quality.

POLICY INTERFARENCES OF GROUNDWATER CONTAMINATION :

Among the barrage of threats to human survival – economic crises, terrorism, inequality – perhaps the most urgent but least prioritized lies underfoot: groundwater. The World Economic Forum ranks water crises the world's third greatest risk by impact, and extreme weather the top risk by likelihood. According to a 2016 study, aquifer depletion in agricultural regions could threaten nearly half the world's food sources and deny 1.8 billion people reliable access to water by 2050. The same study projects that aquifers in India's Upper Ganges basin may be depleted within 25 years. This alarming vulnerability calls for immediate policy action from national and local governments. India, despite its history of weak national- and state-level water policies, has an opportunity to be a global exemplar.

- **Mounting Evidence of Crisis**

Statistics about India's groundwater depletion are depressing. The array of problems cuts across urban and rural areas, and the scale is nationwide. According to a 2016 report by the Indian parliamentary committee on restructuring the Central Water Commission and the Central Ground Water Board, "the growing dependence on groundwater has taken the form of unsustainable over-extraction, which is lowering the water table and adversely impacting drinking water security." India extracts more groundwater than any other country in the world. India accounts for 25 percent of the world's extracted groundwater, more than the next two countries, China and the United States, combined.

India's groundwater depletion is a national crisis. More than half of wells show declining groundwater levels. Declining surface water availability is further prompting desperate and agitated farmers to increase groundwater extraction. The challenge is particularly acute in northwestern India, where baseline water stress is extremely high. If current trends continue northern India may face steadily declining agricultural outputs and severe shortages of potable water."

Parts of Delhi consistently suffer serious water shortages every summer. The crisis, however, is not isolated to the north. A recent decade-long study of wells in Maharashtra, a west-central state, found that 70 percent show a decline in groundwater levels.

In addition to scarce supply, water quality is a serious threat. India's groundwater reserves are not only overexploited and 60 percent vulnerable, but also contaminated. The parliamentary report stated that deep-level groundwater is contaminated by sewage, fluoride, arsenic, and uranium. Incidence of arsenic contamination, as measured by number of affected habitations, doubled between 2013 and 2016. In early 2017, the Union Minister for Water Resources River Development and Ganga Rejuvenation stated that the need to raise awareness about arsenic contamination is urgent. In one West Bengal village, residents have been drinking arsenic-contaminated water unwittingly for two decades. All 200 wells are affected and NGOs are intervening to provide villagers with affordable water.

- **Exacerbating factors**

Groundwater is under constant threat from both agricultural and urban uses. Declining rates of natural replenishment are threatening the sustainability of aquifers in the Indo-Gangetic Basin, which constitute one of Asia's most densely populated and agriculturally productive regions.

In the early 1980s, groundwater overtook surface water as the primary source for irrigation. It now serves more than 60 percent of India's net irrigated area compared to 30 percent for surface water. The Indus Basin, which accounts for a significant share of India's population and food production, was declared in a 2015 NASA study to be the second most overstressed aquifer in the world.

At the same time, urban groundwater is threatened by untreated effluent and a dearth of sewage treatment facilities. According to India's 2011 census, only one third of urban residents have access to piped sewage infrastructure. Given the increasing importance of cities in the Indian economy, this crisis has the potential to impact not only public health but also further economic development. This threat is especially urgent with growth water-intensive industries like thermal power and mining, particularly as poor treatment of industrial waste has created concentrated areas of contamination throughout India. For example, Gujarat, well known as an economic beacon, suffers high levels of industrial pollution affecting water bodies and aquifers.

Although estimated time horizons vary, United Nations estimates that India will become the world's most populous country in 2024. With rapid population growth, increased demands for food and energy and consistent poor management, water stress is worsening in regions where groundwater is already overdrawn. While air pollution has drawn recent attention due in part to stunning visual evidence circulated in the global media, the invisible crisis underground has been mostly ignored even though it is likely to have an equally calamitous impact. There have been no meaningful public outcries or effective policy interventions.

- **Policy Interventions: From Evidence to Action**

Fortunately, there are many policy options for addressing groundwater depletion. Unfortunately, political will seems lacking. According to ANU's Quentin Grafton, the global water crisis "is not just a water problem; it is a people problem." This implicates not only individual consumption behaviors but also the priorities of politicians and planners. Assuming Indian policymakers are willing to heed overwhelming evidence, a good place to start will be data. Reports by the World Bank and satellite-generated maps from NASA may capture global headlines, but more granular evidence linking local groundwater depletion to declining public health and welfare is needed. Agencies at both the national and local levels should cooperate by monitoring the same variables, committing to the same frequency and robustness of data collection, and sharing the results even if they generate competitive pressure or embarrassment. Water is a greater public concern than individual political image. This approach is possible with proper incentives from federal government.

As data begins to provide a more comprehensive view of the groundwater crisis, a reasonable assumption could be that more government policy attention and resources will be devoted to mitigation efforts. There are several areas for such intervention. First, unplanned and rapidly expanding urban areas contribute to steadily declining groundwater levels. Urban development boundaries can curtail sprawl encroachment on sensitive wetlands and agricultural areas, while permeable pavement and other "sponge city" measures can increase rainwater absorption and minimize the shock effect of flash floods. Second, Indian cities have haltingly adopted rainwater harvesting programs. Scaling up such efforts through implementable policy frameworks and additional incentives can significantly improve water availability. Cities like Singapore provide examples of how harvesting and catchment planning can be done effectively.

Third, existing delivery infrastructure must be improved to more efficiently manage the water that is extracted. Delhi's water system currently loses 40 percent of supply through leakages and thefts. This needs to be reduced to single-digit. Good maintenance should be neither politically nor technically complicated.

Finally, treatment and reuse of wastewater practices and processes must be significantly improved. Much groundwater contamination is a product of untreated wastewater discharged into urban water bodies. Thus, more intensive treatment measures are essential. Additionally, Indian cities should more aggressively adopt wastewater reuse programs, including purification systems that enable water to be cycled back for agricultural, industrial, and even household use. The latter will depend on public trust of government actions, largely absent in India.

These measures, in addition to conservation awareness campaigns and innovative technologies can arrest continued groundwater loss and possibly reverse it. They would also boost the quality and supply reliability of urban water, reducing incentives for households to install private water pumps which exacerbate groundwater depletion. Until now, many local initiatives have proven insufficient. They have lacked sustained political backing, foresight, and coordinated guidance from the federal government. Elevating the groundwater crisis to the national policy agenda is essential, and the federal government must oversee a system that is at once distributed, standardized and robustly monitored. National un-governability of water can no longer be a cop-out. India's social, environmental and economic future will pivot on water. Politicians and public must respond.