"TO THE STUDIES ON POLLUTION OF UNDER GROUND WATER MAU CITY"

A THESIS

Submitted Towards the Requirement for the Award of

DOCTOR OF PHILOSOPHY

IN

CHEMISTRY

UNDER THE FACULTY OF SCIENCE

By

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(Anurag Yadav)

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LIST OF ABBREVIATION

Acronym	Abbreviation
AAS	Atomic Absorption Spectrophotometer
AS	Arsenic
BIS	Bureau Of Indian Standards
BOD	Biochemical Oxygen Demand
CM	Correlation Matrix
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
EGPI	Entropy Groundwater Pollution Index
ERI	Ecological Risk Index
GWQI	Groundwater Quality Index)
HHRA	Human Health Risk Assessment
HMEI	Heavy Metal Evaluation Index
HMPI/HPI	Heavy Metal Pollution Index
ICMR	The Indian Council of Medical Research
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
IWQI	Irrigation Water Quality Index
MH	Magnesium Hazard
MPN	Most Probable Number
PCA	Principal Component Analysis
pH	Potential of Hydrogen
PIG	Pollution Index Of Groundwater
PTD	Piper Trilinear Diagram
SAR	Ratio Of Sodium Adsorption
SSP	Soluble Sodium Percentage
TDS	Total Dissolved Solids
TH	Total Hardness
THI	Total Hazard Index
TSS	Total Suspended Solids
USPHS	The U.S. Public Health Service Drinking Water Standards
WHO	World Health Organization
WQI	Water Quality Index

LIST OF TABLES

LIST OF FIGURES

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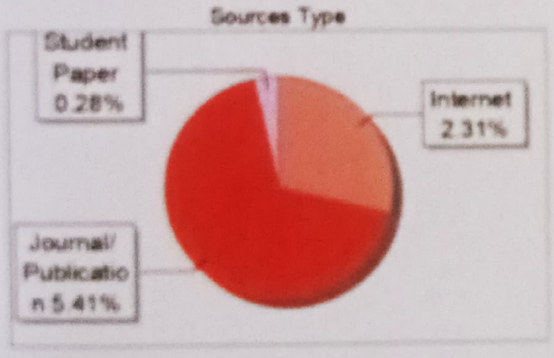

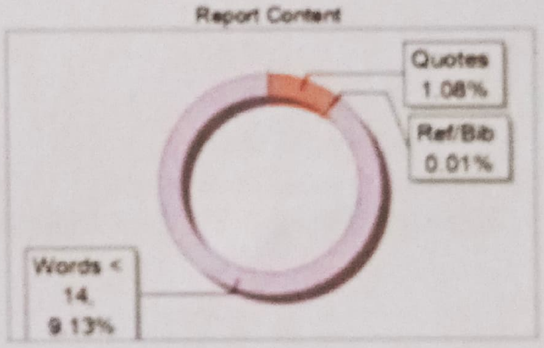

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ABSTRACT

As water is a noble commodity, its scarcity and pollution have become major global problems. This paper concentrates on analyzing ground water quality in Mau City, Uttar Pradesh, India, with respect to urbanization, industrial input, and agricultural runoff. Assessments are made in this paper on the contamination of groundwater through physico-chemical parameters viz. pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and heavy metal inputs consisting of iron (Fe), lead (Pb), and manganese (Mn).

Sample testing of groundwater and appraisal of pollution through indices such as WQI and HMPI were used in the collection of data. Severe contamination of groundwater was found, where dissolved solids in groundwater have crossed the permissible limits prescribed by the World Health Organization (WHO) and Bureau of Indian Standards (BIS). The limits of heavy metals have also crossed the threshold limits. These pollutants mainly arise from untreated industrial discharge, inappropriate agricultural practices, and an unorganized system of waste management.

The results show a severe degradation of the nature of groundwater, especially in highly industrialized regions and massive over-extraction. Excessive use of water along with meager management of water in ground has increased the condition.

It is concluded that the need for immediate intervention is dire since the regulatory measures for industrial effluents should be stringent and sustainable agricultural practices coupled with an efficient recharge of water should be there. In such ways, safe groundwater will be available for human consumption and agriculture.

Keywords: Groundwater pollution, Water quality, Heavy metals, Pollution indices, HMPI, HMEI, TDS, WQI COD, BOD,

TABLE OF CONTENTS

Chapter 01

Introduction

Background

Nature has given us three invaluable resources that are vital to our existence on Earth: soil, water, and air. Since water is the primary medium for the genesis of life, it is the most important element among them. The demand for water grew sixfold between 1900 and 1995, more than twice as quickly as the rate of population growth.[1] The Stockholm U.N. Conference in June 1972, which concentrated on the environment as it relates to humans, was the first major attempt to bring environmental issues to the attention of the world.

Water is the basis of all life and a vital natural resource. It is the most important thing we need in our daily lives. Water is necessary for every kind of economic activity, including industry and agriculture. The amount of water on Earth that can be used as fresh water is quite little. Since 97% of ocean water is too salty, it cannot be used for cultivation, manufacturing, or consumption. 3 percent is made up of fresh water. Roughly 2.997% of it is either trapped in glacier ice caps or buried so deeply that its extraction would be very costly. Merely 0.003% of the overall water volume is accessible as groundwater, which may be replenished by water vapor, soil moisture, lakes, and streams. Of the 40% of stream flow water, 12% is utilized for irrigation, 4% for industry, 2% for home consumption, and 8% for the production of electricity. Out of the entire 1869 billion liters of water that are accessible, only 1122 billion liters are useable. This includes 432 billion liters of subsurface water and 690 billion liters of surface water. An estimated 50 million liters of ground water exist on Earth, of which 4 million are deemed suitable for human use. Water buried deep in limited aquifers, water that does not drain from tiny pore pores, and salty water are not included in this image. The total estimated groundwater reserve in India is 3,700 million acre meters at a depth of 300 meters.

After then, ideas like the environment, sustainability, and Earth's carrying capacity have taken center stage in global policy discussions (Gupta, 2001) [2]. Global water resources have been examined and discussed by Gleick (1993) [3]. Falkenmark (1993) emphasised in his research the importance of clean water and its usefulness in the near future. [4]. Edwards et al. (1989) addressed a multifaceted aspect of water [5]. Dugan (1972) [6] has studied the chemical and biological elements of contaminated water as well as their interconnections. In comparison to rural areas, urban civilization uses more water, and the discharged water has a higher chemical toxicity. Panesar et al. (1985) [7] conducted research on Amritsar city's waste water's chemical makeup and provided a report on the water's suitability for a range of uses. When Olaniya et al. (1976) [8] investigated the pollution in the Chambal River near Kota, they found that majority of the survey locations had moderately dirty water. Mitra (1982) [9] conducted a comparative study of the surface water's chemical properties in the Krishna, Tungbhadra, and Godavari rivers. Bhargava (1977) [10] has carried out a comparable comparison comparing the Ganga, Yamuna, and Kali rivers. In 1951, Ganpati and Chacko conducted experiments in Rajamundhary on the chemistry of the Godavari River [11]. Mishra (1993) [12] oversaw the upkeep of Varanasi's freshwater pond. Hakim (1984) conducted research on pollution on the Gandak River near Samastipur [13]. The majority of research have shown in tandem that the quality of the water is becoming worse every day. Academicians have issued a warning to check for water contamination.

1.1 Water contamination is a worldwide issue:

The production of completely clean water is now more of a theoretical than a practical aim due to water's high solvent power [14]. Even the best-quality distilled water contains some dissolved particles and gasses. Therefore, the challenge has been figuring out what water quality is needed to fulfill a certain goal and then coming up with workable solutions to get that quality. Every use of water, including washing, irrigation, flushing, disposing of trash, chilling, manufacturing paper, and so on, adds something to the water, which makes the issue more difficult. The addition of extra materials to water that endangers people, animals, or desirable aquatic life, or that significantly disrupts the regular operations of different living groups in or around bodies of water, is referred to as "water pollution" [15]. According to the National Water Commission, water becomes contaminated if its quality isn't good enough to be used for whatever purposes people may have in the future or for their highest purposes now.

Water pollution is the exact factor that alters the quality of our surface and subsurface waters to the point that it is no longer suitable for human use or for supporting the normal life processes of humans. [16]. The majority of human waste is dumped into rivers, streams, lakes, and eventually the ocean.Waste is often disposed of in the same bodies of water that are used to extract drinking water. Sewage, industrial waste, and agricultural runoff all have disastrous effects on the plant and animal life found in enclosed bodies of water. Lake Washington in Seattle, Lake Erie, the seven lakes in Madison, Wisconsin, and Lake Zurich in Switzerland have all experienced entrophication due to an overabundance of plant nutrients. For the reading that comes next, a functional definition of water contamination is required. As we go, specific definitions will be created; but, for the time being, let us to define it as: Any alteration in water that is brought about by humans and deemed unacceptable by humans or other living things. Any human activity that harms the use of water as a resource is essentially considered water pollution. Pollution varies depending on how water is supposed to be used. Water so pure it might be used to make beer. Is it acceptable to utilize water of lower quality for irrigation, fishing, sailing, or leisure?[17]. The issue is that there is a lot of water in the globe that may be used for many purposes but isn't because it is contaminated. A significant worldwide environmental issue is water pollution.

II. **Theory**

The primary supply of drinkable, industrial, and agricultural water is groundwater. Therefore, a meaningful evaluation of the risks or hazards associated with groundwater pollution issues and the development of efficient mitigation strategies depend on the capacity to forecast the behavior of chemical contaminants in flowing groundwater. Only by understanding the mechanisms governing contaminant mobility will it be possible to make accurate predictions and measurements of pollutant movement among them are [18]

1. Reactions involving matter, chemicals, and biology that modify their solubility in groundwater,
2. Dispersion of hydrodynamics
3. Progression.

The most common issues with groundwater pollution are:

4-Keep pollutants from entering an aquifer.

5. To successfully safeguard the biosphere, anticipate the passage of pollutants and remove them if they are introduced. Since treating groundwater sources may be costly and complex due to its significance, precautions are often made to avoid early contamination. These precautions can include guarding against inadvertent pollution of the surface well head and the whole aquifer [19].

The following subjects are frequently covered in groundwater pollution studies:

- knowledge of the physical, chemical, and biological mechanisms governing the fate and transport of pollutants in the subterranean environment.
- The use of mathematics in transport models to forecast the flow of contaminants.
- The use of various techniques to determine various model parameters in the lab and in the field.
- The creation of transport models to forecast the flow of pollutants in the event that they are introduced.
- The creation of management models that regulate and/or stop the entrance of pollutants into aquifers and provide safe disposal procedures for hazardous material.
- The creation of a mechanism for the removal of toxins to the degree required to adequately safeguard the biosphere. Water supplies become contaminated by point-to-point pollution, which is not the source of the contamination [20]. One example of an unexplained source of pollution that is more elusive and challenging to identify is the application of pesticides and fertilisers in agricultural areas. Research has shown that a higher concentration of microorganisms in water may be attributed to several factors such as animal waste, sewage, runoff from metropolitan areas, and agricultural land [21]. The characteristics of a point source of water contamination are: a It is possible to precisely quantify pollution, to a limited actual degree. When pollutants are introduced to water to change its chemical makeup and endanger human health and the ecology, it is considered water pollution [22]. Elevations in indices that impact water quality, such as turbidity, electrolysis (EC), hydrogen ion concentration (pH), and microbial content, may further deteriorate groundwater quality in addition to chemical pollution [23].

There are several ways that contaminants might enter groundwater:

- Returns from irrigation and inter-aquifer leakage [24].

- Leaked from fractured sewage pipes or lines and soluble solids near the surface.

- Liquid splashed over land percolating [25].

- Leachate from landfills [26].

- septic effluent and sewage discharge [27]. Groundwater has always been a dependable source of potable water that needs little to no treatment. [28]. It is also generally considered to be pure.

Uttar Pradesh Scenario [29]

Because of its abundant water resources, Uttar Pradesh, which includes a portion of the Ganga basin, is regarded as one of the most productive and fertile states. Thick alluvial layers that cover much of the state provide enormous groundwater reserves. Nowadays, groundwater is the preferred water supply source for practically every user sector, including infrastructure, industry, drinking water, and agriculture. Its significance has steadily grown over time. The growth of groundwater-based irrigation systems has enhanced the state's food production and agricultural productivity in a number of ways. Once independence was achieved, the net irrigated area increased from 3.2 mha to 14.4 mha. It is now crucial to the state's overall economic growth. It has also been used indiscriminately, yet since it is an unseen resource, it may be the state's most underappreciated, unmanaged, and underestimated resource. One-fifth of the nation's total groundwater extraction, or over 90% of the state's entire extraction, is anticipated to reach 46 bcm, is still used by the agriculture industry, making it the state's top user of groundwater. As a result, Uttar Pradesh is now the biggest exploiter in the country. However, no comprehensive management structure has been established to prevent and control this overconsumption and exploitation. Although the state has a vast network of canals with sufficient irrigation potential, these canals only make up a small portion of the irrigation water supply overall. This is only one of 20 factors contributing to the state's growing reliance on groundwater as a reliable supply of water. In numerous regions of the province, this over-reliance has also made it possible to remove groundwater indiscriminately, disregarding other environmental factors like shifting ecosystem dynamics and behaviour or the state's overall ability to replenish alluvial aquifers. Groundwater abstraction is rising quickly, and more regions are under extreme stress. Overall, overexploitation, contamination, and other related factors, along with inadequate policy implementation, have left Uttar Pradesh's groundwater in extremely critical condition. As a result, it is necessary to critically analyse and review the situation in order to determine why different management initiatives and efforts were unsuccessful on the ground. Resource planning and management require an evaluation of groundwater resources. However, for the purpose of calculating and validating base flows and natural discharges to specific rivers and streams, particularly those fed by groundwater, and assessing the improvement of drinking water supplies from the allocated groundwater component, their field extensions have not yet developed, so the distributions made in the estimation of resources for organic emissions (4.6 bcm) and usage at home (5.96 bcm) for the entire state need to be clarified. Even though groundwater is becoming less available, Under the State Ministry's water supply by pipes initiative of the large-scale "Jal Jeevan Mission," which was launched by the Govt. of India, it is probably going to continue to be the primary choice for supplying substantial amounts of water. [30]

Outstanding Difficulty: Achieving the sustainability of groundwater in the state is a significant issue and a tough task, as managing it becomes an extremely complicated endeavor, particularly in light of the state's substantially depleted alluvial aquifers and the growing number of contamination cases from various regions. It is very hard to establish a consistent management system for the whole state due to the different hydrogeology, uneven groundwater consumption patterns, non-uniform groundwater extraction, and quality degradation. Any plan for the scientific management of groundwater should, first and foremost, take into account the local hydrogeological conditions and include feasible and area-specific strategies.

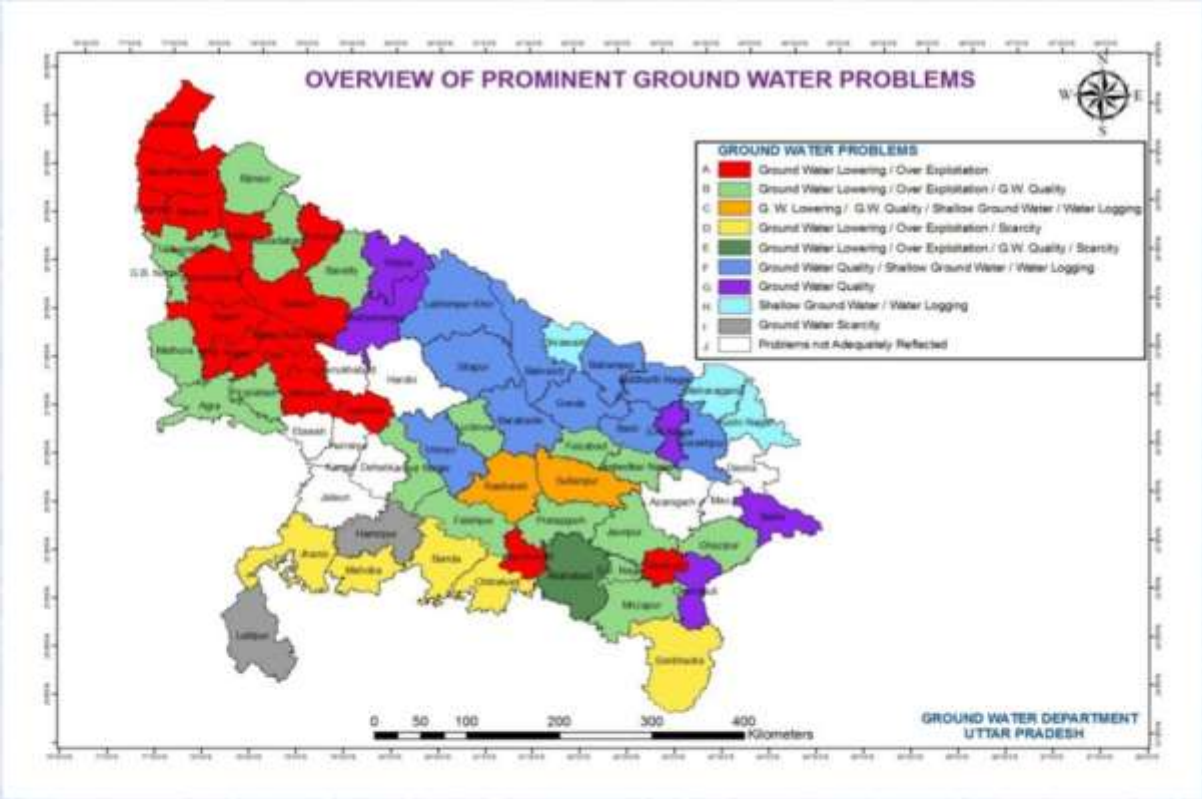

Figure 1.1 (Source : Sinha, R.S. - 2008) [31]

The importance of the several data sets required for managing groundwater as a whole must now be taken into account. The accuracy of the data is essential to any project or plan, additionally if information is obtained, in the situation of groundwater, examined, when fully comprehended and identified, area-specific issues can be precisely recognized, diagnosed, and, and the best actions can be taken with a robust Decision Support System to restore the depleted aquifers in the Ganga basin. The objective of groundwater sustainability would not be accomplished without it. Handling the growing urban water shortage and the frequently disregarded problem of subterranean water logging in canal controls by combining water usage management, removing Bundelkhand-Vindhayans from the water crisis, and identifying, assessing, and mapping contamination of ground water and related health risks for defence and ensuring potable supplies are all crucial areas of focus for Uttar Pradesh. [32].

In over 70% of the state's blocks and most of its metropolitan centers, groundwater levels are fast dropping as a result of unchecked and unregulated extraction. The state of groundwater has become worse due to people's growing reliance on it and their tendency to use as much groundwater as they can. Moreover, despite many attempts to preserve and safeguard the resource, the intended outcomes have not always been achieved. It's ironic that the groundwater crisis hasn't improved despite the passage of roughly 23 years. Despite the court's decision, groundwater abstraction has remained uncontrolled by the Central Ground Water Authority, which was created by the Indian government in 1997 in compliance with “the Environment Protection Act of 1986” to safeguard, control, and manage groundwater nationwide. In a petition, the Hon'ble National Green Tribunal pointed out that over the past few years, the problem of diminishing groundwater levels has been worse rather than better. This remark is very relevant and noteworthy in this respect. This discovery serves as a wake-up call for all previous projects and attempts that failed to control and stop the nation's groundwater levels from continuously declining. This essentially means that, in order to inform future groundwater management reforms, it is imperative to determine the cause of these previous projects' and measures' failures. Over the past 20 years, numerous state and federal policies have been developed to manage groundwater, along with new technological approaches and practices. Numerous programs and schemes have also been launched to manage resources and conserve them. However, we have not adhered to scientific guidelines or designated designated individuals for their implementation, which has prevented us from achieving the desired results.

iii. In general, Uttar Pradesh's groundwater status is in dire need of attention, and many resource-related issues have been found across the state. The issues are clearly illustrated by the following: a) the evident effect of negligent and uncontrolled mining on the decline of groundwater levels in cities as well as rural areas; b) Large regions are no longer suitable for crop production due to subsurface water logging and salt encrustation caused by improper water use practices in canal commands; and c) the high prevalence of heavy metals and other chemical contaminants, which have been linked to extremely contaminated groundwater in a number of places.

iv. Upon examining the state's regional scenarios, stark differences in groundwater conditions are observed: a. Western U.P. is primarily affected by severely depleted aquifers and declining water levels; b. Waterlogging has lowered agricultural production in Eastern U.P. [33].

c. A serious groundwater issue has resulted from a lack of knowledge about the geomorphology of watersheds and significant run-off in the Bundelkhand-Vindhyan area.

v. **Growing Demand:** These are the significant challenges that need for quick administrative and policy changes. On the other hand, meeting the growing demand for water for sustainable supply presents additional difficulties. Due to the increasing population, there is a need for increased crop output, necessitating the irrigation of additional agricultural land. In addition, there is a growing need for water in both industrial and drinking contexts.

vi. Decrease in Water Availability: The state's population is growing at a decadal pace of around 25%. There will probably be rivalry for water resources across different user sectors, especially in the drinking, household, and industrial sectors, as a result of this population increase tendency. Water availability for irrigated agriculture is thus probably going to decrease. The primary source of irrigation is tube wells, which are followed in importance by canals, ponds, and lakes, increasing the reliance on groundwater relative to surface water. It will be necessary to give this problem top consideration.

vii. In order to sustainably maximise the system's performance efficiency, therefore, an integrated approach must be used to plan, develop, and manage surface water and groundwater, the two most important resources for irrigation. The tendency of declining rainfall should also be considered when estimating future demand and availability of total water resources.

viii. Potential Outcomes Even More Concerning: Given the state's expanding population and its demands for residential, industrial, and agricultural water, it is anticipated that by 2028, groundwater extraction will have progressed from its current level of 45.84 billion cubic meters (based on an assessment from 2017) to almost 70.00 billion cubic meters. The anticipated stage of groundwater extraction would exceed the recharge component if the current rainfall level continued to decline. This would result in a further decline in the yearly groundwater recharge and a negative dynamic groundwater availability. The anticipated yearly replenishable recharge is 69.92 bcm, despite the fact that the extractable resource was 65.32 bcm in 2017. It is not anticipated that the recharge component would rise any further because rainfall is steadily decreasing. Therefore, by 2028, the estimated 70 bcm of extraction might surpass the estimated amount of groundwater recharge. If this anticipated scenario materializes, the state as a whole may probably approach an overdraft stage. Therefore, the water managers and planners should view this circumstance as a warning. This precarious state may be made worse by the effects of climate change, which would further add stress to it [34].

1.4.4 Groundwater mining and overdraft

In general, "groundwater mining" refers to a gradual decrease in the amount of water stored in a groundwater system, as happens in semiarid regions like Uttar Pradesh when aquifers are frequently mined. "Groundwater mining" has nothing to do with water resource management techniques in hydrology. When groundwater is drawn from an aquifer at rates deemed excessive, the term "overdraft" describes the degree of over-development that results. Therefore, groundwater mining that may result in adverse groundwater withdrawals could be referred to as overdraft.

Stage of Extraction: The ratio of groundwater extraction to the total amount of extractable groundwater resource determines the stage of groundwater extraction. The extraction step is determined using the following formula:

“Ground Water Extraction / Extractable Resource x 100 = Stage of Extraction (%)”

Appropriately Described Overexploitation

At what point does an aquifer become "overexploited"? The economic definition that states that "the net benefits of groundwater use exceed the overall cost of the negative impacts of groundwater exploitation" is the most applicable. However, it may be just as challenging to foresee, evaluate, and calculate the costs of these effects.

1.6 Water Availability Per Capita: A Novel Approach

“Total precipitation: 4000 bcm”

“Annual water availability: 1869 bcm”

“Utilizable water: 1122 bcm (about 60%)”

“Surface water: 690 bcm”

“Groundwater: 432 bcm”

“GW Utilization: 249 bcm”

The "Falkenmark Water Stress Indicator" has been used since 1951 to calculate the water availability per capita based on the nation's overall water levels. The graph below illustrates how per capita availability has declined over time as a result of population expansion. (Fig. 2)

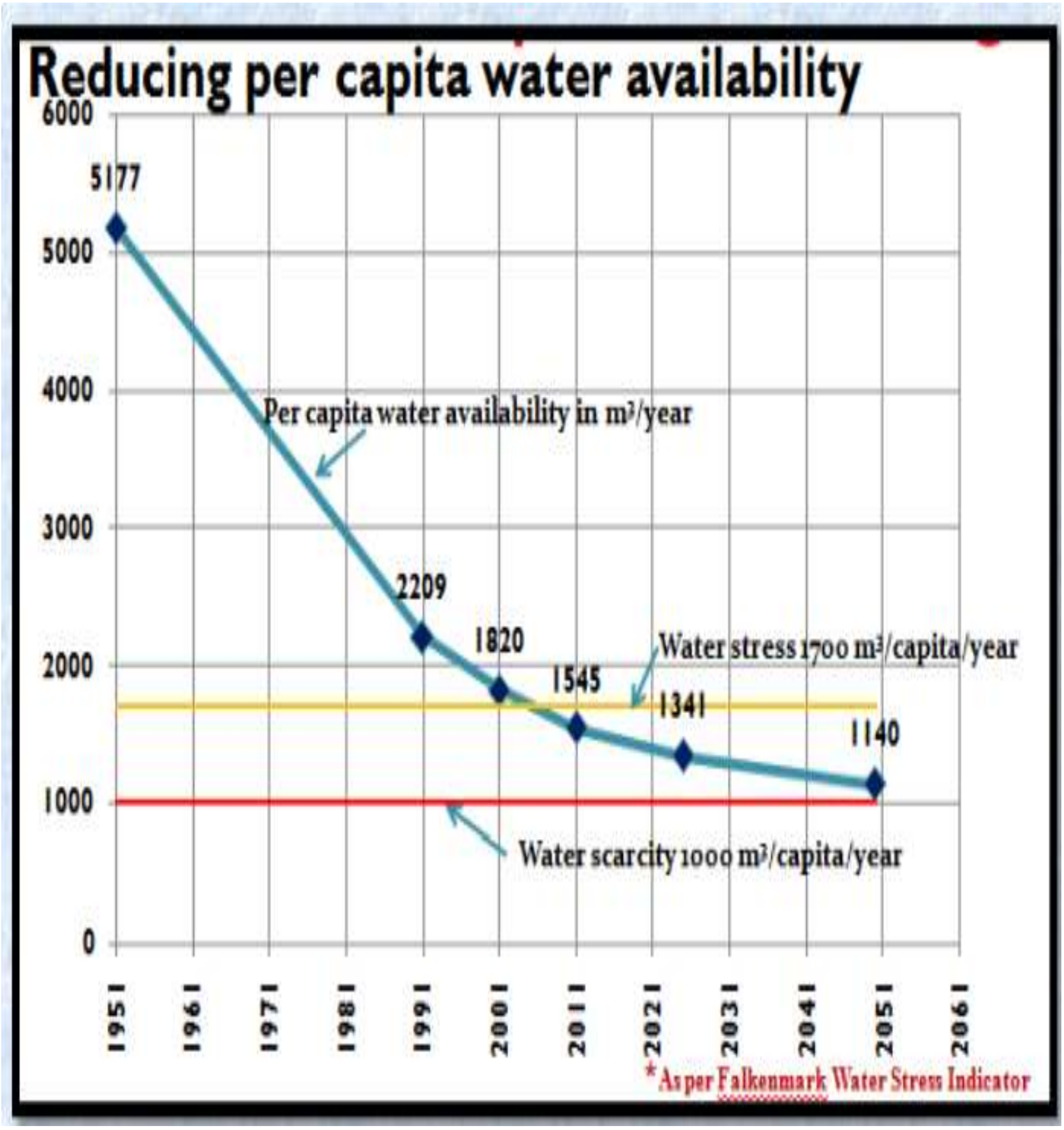

Figure 1.2 “Per Capita Water Availability : (Source : R.C. Jain, 2018)” [35]

The graph displays the national per capita water availability for various time periods starting in 1951.

ii. It is clear that throughout the last 60 years, the per capita availability has drastically decreased, and as of right now, we have surpassed the threshold set for water stress, which is maintained at 1700 m^3 per capita annually. There is growing worry about the falling per capita supply while the aggregate demand is expanding in numerous proportions.

iii. The facts unequivocally show that we have been under "water stress" since 2004 and that the current national water crisis poses a significant obstacle to satisfying the demand of the residential, industrial, agricultural, and infrastructure sectors.

iv. The yearly per capita water availability has already risen to 1364 m3 as of 2019, implying a shift to a far more important stage. The annual water scarcity level of 1000 m3 per person is upheld, a sign that we are rapidly approaching this very concerning state of affairs.

v. since the present scenario for water availability per capita was created using the expected 1869 bcm of total annual water availability for the country. Essentially, though, the Utilisable Water—roughly 60% of the 1122 bcm of total accessible water—is the primary consideration for planning for all sectoral water needs and supply across the country.

vi. New Perspective

More difficult: The situation would be more difficult if we used the Falkenmark Water Stress Indicator to calculate the relative water stress and per capita availability based on the Utilizable Water component. A scenario that makes use of the Utilizable Water component is created. Comparing the anticipated numbers for various time periods to the current situation of per capita water availability used for planning, it is seen that the latter is more essential.

Mau City Map

Description of study area

Figure 1.3 Mau (Uttar Predesh) Map [36]

l.l Types of water pollutants

Water pollutants are categorised as:

(i) wastes that require oxygen.

(ii) substances that cause disease.

(iii) plant-based nutrition.

(iv) artificial organic substances.

(v) Petroleum.

(vi) mineral and chemical substances that are inorganic.

(vii) soils.

(viii) radioactive substance.

(ix) Heat.

Agents that cause disease: It is important to recognize that in each community, a certain proportion of people may get unwell and may thus introduce different pathogens into the water supply. Furthermore, hospitals dispose of their used water products into groundwater systems and waterways. The MPN (most likely number) approach is often used in regular water supply monitoring since, regrettably, identifying particular infectious agents in a water supply requires the examination of several samples using laborious and complicated technologies. The most likely amount of intestinal bacteria present in a particular water sample is determined by this examination. Even if these organisms haven't proved harmful, their concentration may serve as a pretty accurate predictor of potential harmful contamination in a particular water source. Waste water discharged from sanitoria, tanning and slaughter industries, towns, and boats may include bacteria or other microbes that may infect humans and animals, including cattle. The same sick people are likely to live in any reasonably large town at any given moment, which means that sewage nearly always contains disease-causing microorganisms [37].

(i) Oxygen-Waste Demanding:-. A body of water is considered contaminated when its DO Concentration falls below what is required to support a healthy biota in that body of water.

(ii) 2. The presence of materials referred to as oxygendemanding wastes has been the main factor contributing to water deoxygenation. These are materials that, when exposed to oxygen, are readily degraded or broken down by microorganisms. Bacterial activity has eaten the available dissolved oxygen, hence the presence of such items rapidly causes the dissolved oxygen to be depleted.

The majority of wastes that need oxygen are organic compounds that bacteria oxidize to produce carbon dioxide and water. These compounds have caused harm because freshwater and marine systems suffer from oxygen loss due to their composition. Additionally, they weaken the recreational value of waterways and emit offensive smells that endanger water supplies.Fish and other aquatic life are harmed or even killed by sewage and other oxygen-demanding wastes, which are regarded as water pollutants because they lower oxygen levels. Additionally, they can create scum and sediments that make the water unsafe for human use, as well as offensive odours that change the colour, taste, and odour of domestic and livestock water sources. Although this category includes some inorganic elements, organic chemicals make up the majority of wastes that need oxygen. Sewage, paper mill wastes, animal and domestic industrial wastes from food processing facilities, tanning byproducts, and effluent from slaughterhouses and meat-packing facilities are some of the typical sources of the pollutants in this category. Because the effects of adding these components to water have dependent on the amount of water available for dilution, low DO concerns have been especially prevalent. frequent in late summer and early fall when water levels are lower (-2.0).

Carbon is the most prevalent element in the majority of the chemicals that contribute to this kind of pollution.One process they go through with the aid of bacteria is the oxidation of carbon to CO_2:

$$C + O_2 \longrightarrow CO_2.$$

To oxidize 12 grams of carbon in this process, 32 grams of oxygen are required. Based on this, the carbon may be said to need almost three times its weight in oxygen for the reaction to occur. About 3 ppm of dissolved carbon would need to react with 9 ppm of oxygen.This is equivalent to a reaction between a little drop of oil and the dissolved oxygen in a gallon of water. It becomes evident how fast dissolved oxygen in water may be lost [38].

(3) Nutrients for plants:

All plants have major nutrient-related growth limitations. Nitrogen and phosphorus in plants have the ability to promote the development of aquatic plants, which impede water consumption and eventually decompose to release disagreeable odors and raise the water's BOD content. Overgrowth of algae is especially dangerous because it reduces dissolved oxygen levels, complicates industrial and municipal treatment, and obstructs recreational activities. Soluble inorganic nitrogen and phosphorus concentrations have generally been the most important, and care must be made when describing the amounts to differentiate between elements and compounds, such as between phosphates and phosphorus. In water, plant nutrient concentrations have been represented as milligrammes per it (mg/I) or parts per million (ppm) by weight. A naturally occurring biological process called eutrophication adds nutrients to water. The phrase "well nourised" was derived from two Greek terms.This enrichment triggers further gradual processes that together are known as lakes' natural aging. The following are the stages of a lake's aging and eutrophication:

(i) A freshly created lake's water becomes more fertile as a result of streams from a drainage basin progressively introducing dirt and nutrients.
(ii) As a result of the higher fertility, aquatic plant and animal life begins to proliferate.
(iii) The lake becomes shallower, warmer, and more nutrient-rich as a result of the accumulation of organic deposits and living stuff on the bottom.
(iv) Plants begin to take root from the bottom and progressively take up more and more area. Their leftovers hasten the basin's filling.
(v) Due to an overabundance of flora, the lake eventually transformed from a marsh to a field or woodland.

(4) OIL: The production, use, and distribution of such substantial annual amounts lead to some environmental damage from oil. Not all of this pollution is unintentional.

(5) Minerals and inorganic chemicals –

This class of water contaminants has been including mineral acids, inorganic salts, and metal complexes or finely split metals. These substances get up in natural water due to mining drainage, metallurgical chemical industry activity, and other natural processes. Three general consequences are brought about by their presence: the water may become more noxious, salinized, and acidic.

Many forms of inorganic chemicals find their way into water systems via urban runoff and industrial and municipal waste flows. They may also be expressed in mg/L or ppm by weight. These contaminants have the power to harm or kill fish and other aquatic life, as well as to make water unfit for human or commercial consumption. Numerous inorganic substances are not only harmful but also have a tendency to accumulate in the food chain. Acid mine drainage is a significant issue as well. It is the primary source of impurities that cause water to become more acidic. Soluble iron compounds and sulfuric acid (H2SO4) have been identified as the real contaminants found in mine drainage. These materials are created when pyrite (Fe"S2) [39] found in coal seams reacts with air, water, and other elements. Although certain bacterial species have been implicated in the process, their exact function is yet unknown. Both surface and underground mines may experience this response. Currently, a lot of work is focused on either preventing acid mine drainage from forming or chemically treating contaminants before discharging the flow into natural rivers. The following three techniques have been widely employed:

Sealing abandoned mines

(a) prevents air or water from entering the mine, and

(b) by removing at least one of the necessary reactants, it aids in preventing the basic reactions that lead to the production of acid mine drainage. One issue with this approach would be its difficulty to achieve tight seals.

(c) Drainage control: Gathering water from the various sources that are available to an underground mine is difficult. An attempt is made to shorten the duration of interaction between pyrite and water.

(**d) Chemical Treatment:** Several operational mines use this technique. Hydrated lime has been added to the mine output before it is transferred to a nearby treatment facility.

The water has now been aerated after this. The water's buffering ability has been overloaded by large inflows of strong water, resulting in precipitous pH level reductions. The sludge created by the procedure sinks to the bottom of the enormous lagoons where the water is put, and a clear overflow is discharged into the natural waters. The extent of the pH decrease involved determines the impact of these modifications. Following are a few outcomes.

(e) Death of aquatic life: All vertebrates, the majority of invertebrates, and a large number of microorganisms are eliminated at pH values below 4.0. Only a few bacteria and algae remain after the majority of higher plants are destroyed. Fish deaths have acid mine drainage as one of its main causes. The issue is exacerbated by excessive precipitation, which raises the production of mine drainage. In some places, reports have shown that the pH of the water might drop as low as 2.5 during the winter and spring high water season.

(f) Corrosion: Too much corrosion may occur in plumbing systems, boats, piers, and associated structures when the pH of the water is less than 6.0.

(g) Crop damage in agriculture: Because the soil acts as a buffer, issues with acidity and alkalinity of irrigation water are mostly mildly concentric across a pH range of 4.5 to 9.0. If the pH falls below 4.5, however, problems may occur.

(h) Such acidic water makes minerals like iron, aluminum, and magnesium more soluble. These ions have sometimes proved hazardous to plants at high remelting concentrations. Salinity in water has been seen often. In the form of salt water, oceans and seas contain over 97% of all the water on Earth. It is well known that such water is unfit for human consumption. Although the last 3% is categorized as fresh water, salt may and does accumulate in it. There are many different sources of salinity.

(i) Industrial effluents: A common component of many industrial effluents is inorganic salts. Acid-base neutralization produces salts, many of which are used in the metallurgical, chemical, and smelting industries. acid Salt formation may also result from 43 mine drainage.

(j) Irrigation: As water percolates through soil, it may dissolve significant quantities of minerals.

(k) Sait Brines: Occasionally, typically pure water is exposed to salt brines discharged by oil wells or mines.

(l) Ocean Salt: The constant discharge of large rivers usually prevents the ocean's salt water from backing up. Salty water may move many miles upstream during periods of low runoff when river currents are overpowered by tidal flow from the sea.

(m) Highway use: In rural parts of several nations, the practice of using salt on roadways to melt winter ice and snow has been causing major problems. The nearby treas and shrubberies of frontage homesteads have been devastated by salt from the high roads; worse, the salt has gotten into the ground waters and contaminated rural wells. Sediments: Storms and floodwaters carry soil and mineral particles from exposed croplands, overgrazed pastures, strip mines, roadways, and urban areas that have been bulldozed. Sediments have the ability to clog water filters, cover fish nests, spawn, and food sources, erode pumping stations and power turbines, fill reservoirs and stream channels, cut down on sunlight for green aquatic plants, and decrease fish and shelfish populations. Because of the natural process of erosion, sediments are practically considered a kind of pollution. The process does result in sediments, which are the most pervasive contaminants in surface waterways. According to estimates, the amount of suspended solids that have entered natural waterways is at least 700 M.–45 times more than the amount of solids that come via sewage discharge [40].

Sources of contamination

Generally speaking, pollution comes from three major sources:

(i) wastewater discharged into the river;

(ii) untreated industrial wastewater that is discharged into a river; and

(iii) surface drainage from farms that use fertilisers, insecticides, pesticides, and manures. As a result, swimming or drinking in river water is dangerous.

A typical list of contaminants found in freshwater ecosystems includes acids and alkalies, anions (like cyanide, sulphur, and sulfurite), detergents, household sewage, farm manure, food processing water, gases, chlorine, and ammonia, heat, metals (like lead, zinc, and cadmium), nutrients (like phosphates and nitrates), oil and oil dispersants, organic toxic wastes (like formaldehydes and phenols), pathogens, pesticides, polychlorinated biphenyls, and radionuclides. Domestic wastewater contains a wide range of substances, including metals, nutrients, pathogens, detergents, and oxidisable materials (Tripathi et al., 1990). [41]. Many different elements are being employed these days to investigate pollution. Chen and Twillery (1999) [42] described a change in the biology of contaminated water. In fresh water, silica and nitrate were investigated. Dwivedi (2000) [43] examined the biological characteristics of ponds in relation to their physico-chemical properties. Several studies have implicated urban sewage, farming drainage, and the discharges of both major and small-scale companies as contributors of contamination. Ray and David (1966) [44] investigated the impact of sewage on the Ganga river's quality in Kanpur. Singh and Bhowmik conducted the same investigation in Patna in 1985. Oake (1985) discovered heavy metals in sewage sludge [45]. Lee and Bang (2000) conducted research on the chemistry of urban runoff water [46]. A similar investigation was carried out by Kothandaraman et al. (1963) [47] in the Ahmedabad sewage. Studies have been done on the impact of sewage disposal on the chemistry of aquatic bodies. Sutton and Ornes (1977) [48] investigated the biology of sewage. Sewage overflow pollution was investigated by Balmforth (1990) [49]. Agarwal (1983) [50] examined how sewage altered the Chambal River's chemistry. Sauer et al. (1999) [51] investigated the chemistry of runoff water that included animal and avian excrement.

One major factor contributing to water contamination is said to be crude farming practices. Blanchard and Lerch (2000) found evidence of pesticides in river water [52]. River water has also been found to include herbicides used in agriculture (Galiulin et al., 2001) [53]. Cereals, fruits, vegetables, and milk are all contaminated with heavy metals and pesticides, as indicated by the test findings above. These elements would have either directly or indirectly arrived at this goal and accumulated through biomagnification. The amount of organic stuff in a river rises when deceased corpses are burned on funeral pyres. A large amount of wastewater produced by industries eventually ends up in streams or rivers. Toxic and hazardous compounds released by industries into the waterways are one of the main causes of severe pollution. The manufacture of chemicals, which leads to the creation of poisonous and hazardous compounds that have been steadily increasing over the last several decades, is primarily responsible for industrial progress.

Commercial sources

The point and non-point sources as you are aware, factories, drain pipes, tubes, and other point sources are the producers of pollutants. [54]. It is significant in relation to the other causes of pollution. If you don't know where the poisons come from, these are non-point sources. It is difficult to control and has several roots, including the generation of plant food and barren. [55]. In the US, this is the main reason why water becomes contaminated. The biological, physical, and chemical techniques that can be applied to point and non-point sources are well explained in this article. Standard procedures such as centrifugation, adsorption, purification, and ultrafiltration can be used to remove garbage and make water clearer.[56]. Pollution of the groundwater when contaminants (bacteria, viruses, protozoa, etc.) enter the water column, the groundwater becomes contaminated. Contaminated water becomes unsafe for domestic use and human consumption when it seeps below the surface. Numerous diseases, including cholera, can be brought on by contaminated water. [57]. In Romania and Bulgaria, nitrates in groundwater lead to childhood disorders known as "blue babies." When nitrate levels rise above 10 mg/L, the risk of developing syndrome also rises. [58]. Water contamination is also caused by plant food that has a high nitrate content. The majority of nitrates accumulate in the earth and eventually find their way into groundwater, while the plant only needs a little quantity of nitrate. Water contaminated with fluorides damages teeth and bones [59]. Colourized industrial effluent Parts of various colours are frequently used. Paper, textile, leather, food, cosmetics, and medicine are just a few of the industries that use colour in their products. Excess emissions into the water from these businesses lead to water pollution. The paper and cloth industries absorb the additional energy and dyes. The paper industry distributes trash into the environment and damages aquatic life by producing toxic colours, products, slime, and other things. [60]. The components of sewage are determined by the colouring compounds used in factories or on the final product. A range of yeses, including swing, sulphur, acidic, basic, and liquefy solids, are used in the manufacturing. Over a million dyes are used annually in production to create 70,000 tonnes. [61].

Pesticide-related pollution of ground water

The growth of agriculture and pesticide usage are strongly intertwined. Despite the fact that the application of pesticides has improved agricultural output and prevented losses due to insect attacks, these excess chemicals are poisoning ground water supplies. [62] The persistence of pesticides in soil is intimately linked to pesticide contamination in ground water. A pesticide's capacity to absorb determines whether or not it will seep into groundwater. Pesticides that have inadequate soil surface adsorption or absorption will seep into the ground and contaminate it. There are several reports on the pesticide residues that are contaminating ground water. Because pesticides are quickly soluble in fat and may build up in target species, they pose a major risk to human health in living systems (Agrawal et al., 2010 [63]). 56 superficial specimens of groundwater were gathered from farmland in China's Taibu basin by Li et al. (2013) [64]. Thirteen distinct types of organo-chlorine pesticides were discovered in the groundwater. Samples of ground water were collected from Chinese sweet potato growing locations in Shandong and Hebei. Pharate, terbulos, and aldicarb were found in the ground water, according to an analysis (Kong et al 2004 [65]). Similarly, groundwater was found to contain the very deadly pesticide Aldicarb, according to Stover and Guitjens, 1990 [66]. Afterwards, the quantity of aldicarb in the ground water of Wisconsin's Central Sand Plain was also reported by Rothschild et al. 1982 [67]. The study's conclusions suggested that whereas deep wells, which were situated 60 feet below the water table, had no aldicarb content, shallow wells, which were situated just above the water table, had the greatest concentration of the substance. Eight states in the United States also have high concentrations of aldicarb (> 10 mg/L), as well as aldicarb sulfones and sulfoxides (Moye and Miles, 1988 [68]). The ground water in the Howrah (West Bengal, India) districts has been shown to be contaminated by high pesticide levels, making it unsafe for human consumption (Chaudhary et al., 2002 [69]).

Water quality requirements

Standards for different types of water have been established by various health organisations (Lester, 1969). The World Health Organisation (1992) [70], the ICMR\ (1962), and the USPHS (1962) are a few organisations of this type. Since the quality of the water directly affects human health, standards are required. The water quality standards that different authorities have established for inland water are listed in Table

TABLE NO- 1.1

Table 1 Water Quality Standards for Inland Waters

Parameter	WHO	USPHS	ICMR	BIS
Temperature 0C	-	-	-	40.0
pH	7.0 - 8.5	6.0 - 8.5	6.5 – 9.2	6.0 – 8.5
BOD mg L – 1	-	-	-	< 3.0
DO mg L – 1	-	> 4.0	-	> 5.0
EC Sm – 1	-	0.03	-	0.075
Chloride mg L -1	200	250	250	250
COD mg L – 1	-	-	-	< 20.0
Alkalinity mg L – 1	-	-	81-120	-
Phosphate mg L – 1	-	0.1	-	-
Total hardness mg L – 1	100	500	300	300
Nitrate mg L -1	45.0	10.0	20.0	50.0
Total solid mg L -1	500	500	-	-
Sulphate mg L – 1	-	250	200	150
Chloride mg L – 1	200	250	250	250
Potassium mg L – 1	-	-	20	-
Sodium mg L – 1	50	-	30	-
Magnesium mg L – 1	-	50	-	30
Calcium mg L – 1	75	100	75	75

Remediation

The majority of the organic and inorganic pollutants found have been traced back to closed and operating industrial sites. It is projected that when today's polluted land turns into tomorrow's groundwater pollution issue, the effects of previous human activity will be more noticeable in groundwater. Therefore, remediation is quickly emerging as a viable solution to maintain or improve groundwater quality as well as eliminate or restrict sources of pollution. The target concentration group's needed treatment range is identified. Corrective goal levels of the site and non-specific target levels of non-site hazards are the two primary types of therapeutic aims [71]. One of the biggest obstacles to identification and delimitation is the existence of contamination in groundwater. To effectively and precisely determine the source of the pollutants, treating the polluted site necessitates the use of an optimal decision-making system [72].

1.1 Acidification: Over the last 25 to 30 years, it has been apparent that acid precipitation may have an adverse effect on the ecosystem. Numerous studies on the consequences of acidity on lakes, streams, and their surroundings, as well as on soil and other continuous materials, have been published. Tickle (1990) conducted a recent review. In contrast, save for one significant British Geological Survey study [73], not much research has been done on groundwater acidification.

1.2 Contaminated Land: After contaminated land sites have been identified, assessing the possible dangers associated with the site is essential before initiating a thorough investigation or remediation effort. In recent years, risk assessment procedures have drawn a lot of attention and several different approaches have been created [74]. To evaluate risk and suggest mitigation options, more study on contaminated land is often needed to better understand the influence on groundwater quality. This entails gathering information on the amount of contaminated land-related groundwater pollution, keeping an eye on the efficacy of remediation techniques, and gaining a deeper comprehension of the mechanisms governing and influencing the kind and degree of pollution [75].

1.3 Heavy Metals: The behaviour and mobility of trace metals in groundwater have been the subject of an increasing number of studies during the past decade. Numerous studies have examined how pH and Eh conditions affect solubility, specifically with regard to organic materials, clay minerals, hydrous iron, and manganese oxides. [76].

1.4 Nitrogen ($NO^{-}3$): In all intensive agricultural regions, groundwater contamination with nitrogen ($NO^{-}3$) (pollution from non-point sources) is a serious problem. An examination into the selective removal of nitrate ions from groundwater connected to the agricultural community was carried out by Reddy and Lin (1999) [77] via a catalytic reduction technique. In this study, three catalysts were used: rhodium, platinum, and palladium. The study's catalytic reduction method is helpful in eliminating NO-3 from groundwater linked to non-source contamination. In central western Minnesota, Puckett and Timothy (2001) [78] looked at the nitrate transfer in the aquifer in connection to age, land-use practices, and oxidation processes. The researchers discovered that nitrate concentrations are high and that they decrease with depth and age, just as oxygen does.

VI. Public health and water quality

There are several connections between public health and water quality [79]. Potable water is fundamental to human existence. Numerous hypotheses have proposed that water has played a significant role in the development of numerous water-borne illnesses by contaminating drinking water with bacteria, which is the biggest risk factor for the spread of illnesses that may result in illness and death [80]. Waterborne illness transmission has been noted to be a serious worry, despite international efforts and the availability of sophisticated means for producing safe drinking water. There is evidence of drinking water contamination during storage, a lack of restrictions, and low public knowledge and awareness [81]. Even with the finest treatment system and disinfection procedure, water quality might sometimes deteriorate due to mechanical failure, human mistake, or source water quality deterioration [82]. High chemical concentrations in drinking water may pose health problems, although in the case of bacterial contamination, the number of germs that might harm a person's health is quite modest. Numerous water-borne illnesses have been linked to poor drinking water quality, often known as excrement, environmental pollution, or chlorinated water, as the primary mode of transmission, according to epidemiological research [83]. One way that waterborne infections might spread is via direct or indirect food preparation-related consumption of untreated, insufficiently treated, or polluted water.

2. Contaminated water contact with the body, including swimming pools, ocean, and freshwater. A number of artificial chemicals and microorganisms have the potential to contaminate groundwater. Drinking water contaminated with germs or viruses increases your risk of contracting cholera or hepatitis. Water with high nitrate content may contribute to methemoglobinemia, often known as Blue Baby Syndrome, a disorder that affects babies. Lead poisoning has been linked to serious health impacts, including cognitive disabilities in children, brain, kidney, and liver issues, and an increased chance of pregnancy [84].

Growing Urban Population and Growing Need for Drinking Water

According to the trend of urbanization, the proportion of people living in cities will rise even more as a result of population growth in those areas and rural-urban movement. The majority of groundwater sources are now being used, sometimes to unfavorable degrees, to satisfy the growing demand of the urban population. Thus, ongoing removal will undoubtedly have long-term effects on urban groundwater reserves' geoenvironment. The negative aspect of hasty and quick urbanization is that intense building operations are either concretizing or paving over the urban ground, which prevents rainwater from percolating naturally. Furthermore, the majority of cities are seeing a worsening of the groundwater issue as a result of vertical urban expansion and high-rise building. This is because these developments have increased the demand for resources on all of these properties to an excessive degree.

ii. It is evident in most metropolitan areas that the land, which once provided for relatively modest water requirements owing to tiny housing units with typically 5–6 people, is now carrying the weight of enormous resource demands as a result of high-rise structures with many occupants. On the same plot of land, the demand for water would have inevitably increased in multiple proportions, and if groundwater was the source of the supply, resource extraction would have surely exceeded the threshold and resulted in unfavorable circumstances.

iii. According to the 2011 census, Uttar Pradesh is the most populated state in the country, with 22.27 percent of its people residing in cities and towns.

Tubewell Mushrooming in Cities

In most metropolitan areas, the primary source of urban water supply is groundwater, and the demand for drinking water is satisfied by tube wells and hand pumps. The growing needs of the industrial and infrastructure sectors are also being satisfied by groundwater. This demonstrates the vital function that groundwater has played in the urban water system, even if this resource is rapidly depleting in an urban setting that is changing as a result of concrete development, which has a major effect on the natural replenishment of the groundwater regime. The bulk of Uttar Pradesh's 653 large and minor townships are situated on the alluvial aquifers of the Indo-Gangetic plain. Groundwater is easily accessible, and as a result, private tube well building is proceeding uncontrolled. Submersible borings and private tube wells have therefore proliferated in apartment complexes and multi-story structures. As a result, groundwater usage and exploitation in large cities have significantly expanded. A lack of municipal water supplies to meet the growing demands of the residential, commercial, industrial, and other associated sectors may be the reason for the over reliance on groundwater to meet all urban water demands. Second, the development of tube wells is proceeding indiscriminately since there is no rule against them [85].

Groundwater Dependent Municipal Supplies: In the bulk of the 653 urban bodies, groundwater-based municipal supplies provide between 75 and 80 percent of the total demand for drinking water, according to U.P. Jal Nigam statistics from September 2018. According to the statistics, the state's metropolitan regions' groundwater-dependent supply is anticipated to be 5975 mld (million liters per day), or 2180 billion liters (2.18 bcm) yearly. Furthermore, according to the data, just 31 of the 653 urban organisations primarily rely on surface water-based sources, whereas 622 of them only use ground water resources.

3.5.3 Falling Levels of Urban Groundwater

Monitoring the hydrological regime through groundwater level measurement is essential for both scientific and planned resource management, especially in metropolitan areas where concrete land use prevents the appropriate use of indirect measurement methods. Nearly all of the main cities, including Lucknow, Kanpur, Meerut, Ghaziabad, Agra, Noida, and Varanasi, are impacted by the serious issue of groundwater scarcity. Since the mining of static groundwater sources has already begun, groundwater in these places is expected to become an extremely limited resource, which is a severe matter that requires immediate action.

Metropolitan Groundwater Level Monitoring: Beginning in 2006–2007, a tight network of piezometers was used to monitor groundwater levels in the state's metropolitan districts. Data on groundwater levels collected over the last ten to twelve years using urban piezometers has shown a worrisome trend of rapidly dropping water levels. The groundwater problem has become quite serious in around 20 major cities. Groundwater levels are declining at a rate of 0.5 to more than 1.0 meters per year in locations such as Lucknow, Kanpur, Agra, Aligarh, Meerut, G.B. Nagar, and Ghaziabad. A graphic representation of the average annual drop for notable cities is shown in Figure-3, this is predicated on the historical trend of some cities' declining groundwater levels.

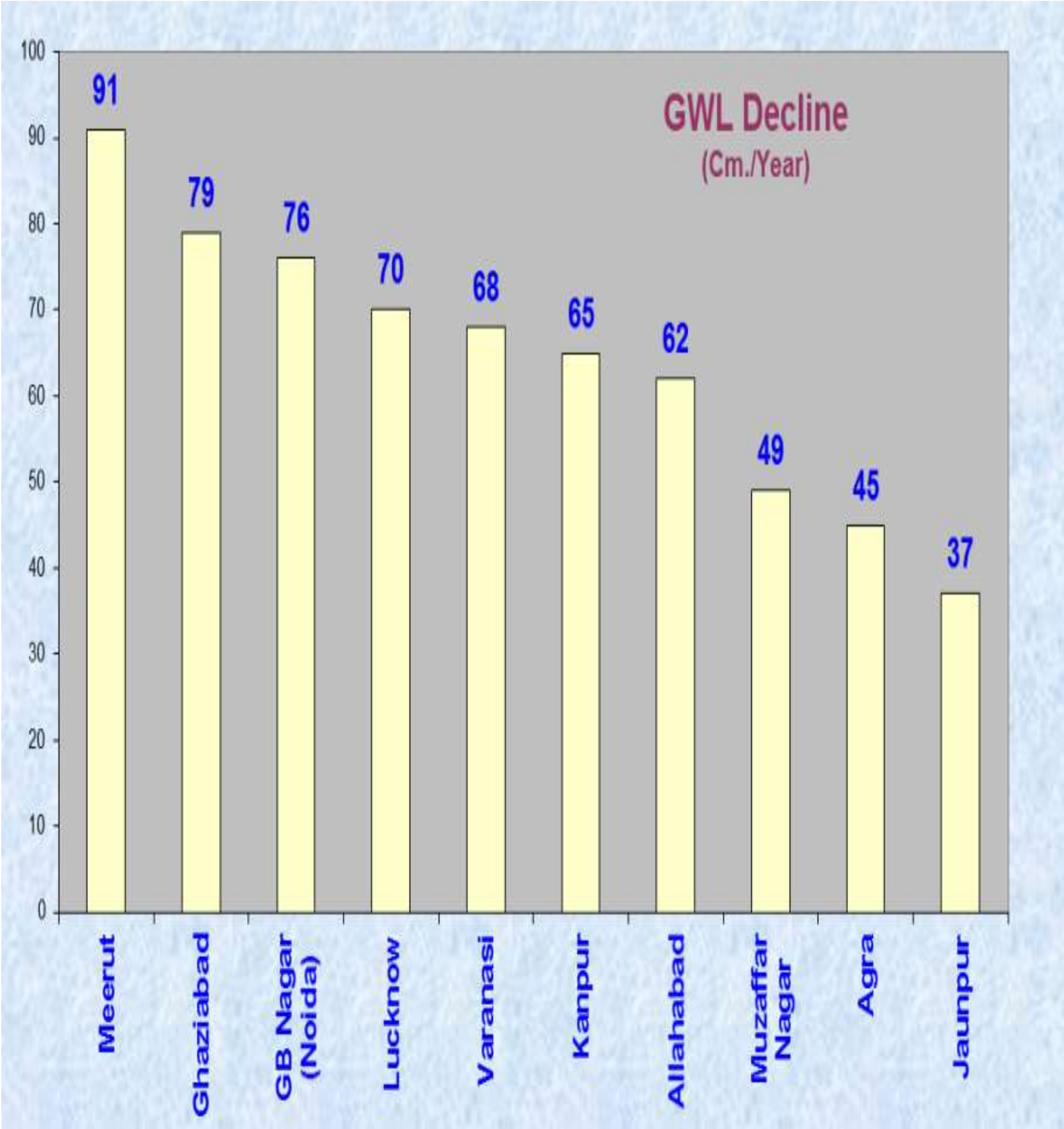

Figure 1.4 Average Yearly Decline in Major Cities

It is clear that the rapid decline in groundwater levels and the excessive aquifer depletion would make it difficult to ensure a supply of drinking water in most urban areas in the future. Apart from the needs of other industries developing at a quicker rate, by 2025, it is probably expected that the annual water supply in urban areas would have increased to at least 2500 billion litres.

3.5.4 Major Cities' Groundwater Depletion

According to statistics from groundwater level monitoring, the groundwater regimes of important cities (Kanpur Nagar, Agra, Lucknow, Ghaziabad, G.B. Nagar, and Aligarh) have significantly declined between post-monsoon 2006 and 2015. Over the course of ten years, the zone of groundwater level below 25 meters has drained into bigger regions in the corresponding cities due to a persistent reduction in the level of groundwater, underscoring the urgency of the problem.

Table 1.2 Groundwater Depletion in Major Cities

CITY	Zone of depth to groundwater level more than 25 m (sq km)	
	2006 (Post Monsoon)	2015 (Post Monsoon)
MAUNATH BHANJAN	16.6	52.9
AZAMGARH	29.2	113.82
LUCKNOW	30.2	127
GHAZIPUR	0.4	38.76
BALLIA	NILL	71.45
GORAKHPUR	NILL	28.21

In addition to these cities, the area of groundwater level between >15 and 25 m in Varanasi city has grown as well, increasing to 87.95 sq km after the 2015 monsoon, from 36.84 sq km after the 2006 monsoon.

ii. In most cities, Groundwater levels are dropping to much deeper depths, and the overall pattern of this decline is getting worse.

3.5.5 Evaluation of Groundwater in Urban Environments

The GEC-2015 approach incorporates this option for the first time for assessing groundwater resources in metropolitan areas; nevertheless, as the arrangement is based only on extremely preliminary ad hoc rules, results may not be definitive. Ten cities with a population of more than 10 lakhs are chosen for the 2017 Assessment. These cities include Varanasi, Ghaziabad, Ghaziabad, Moradabad, Bareilly, Prayagraj, Lucknow, Kanpur Nagar, Aligarh, Agra, and Ghaziabad [86].

Since metropolitan areas are concrete jungles, the GEC-2015 approach considers 30% of the rainwater infiltration factor when evaluating the recharge component as an ad hoc remedy until field investigations are finished. It is recommended to incorporate seepages from sewage, flash floods and leaking from sewer line leaks when estimating. The methodology also notes that the extraction data that is currently available will not be reliable in the absence of a well census. Therefore, the method proposes to compute the sewer from ground water resources as the distinction between the supply from surface water sources and the actual demand. Uttar Pradesh's urban water supply situation is very different, though, as the majority of supplies are derived from groundwater, and the majority of metropolitan areas lack surface water sources. In order to evaluate urban groundwater resources, depletion results from water supply tube wells should have been included; however, this estimate study did not do so. Therefore, a review and reevaluation of the estimate in ten cities is required. Table 3 provides the resource estimate per city as per GEC-2015.

Table1.3 Urban Ground Water Resource Estimation 2017

S No.	City	Area (sq km)	Extractable Ground Water Resource (ham)	Ground water Extraction (ham)	Stage of Extraction (%)	Decline/Year (cm)		Category
						Pre-mon.	Post-mon.	
1	Agra	141.97	1402	1309	93	43	13	C
2	Aligarh	68.5	1040	3572	343	32	39	OE
3	Bareilly	134	2197	5111	232	15	52	OE
4	Ghaziabad	210	3461	9115	263	97	110	OE
5	Kanpur Nagar	278	4212	4311	102	51	47	OE
6	Lucknow	340	5451	9656	177	44	54	OE
7	Meerut	141	2136	5262	246	27	47	OE
8	Moradabad	91	1759	5414	308	27	34	OE
9	Prayagraj	82	2562	3810	149	Rising	Rising	OE
10	Varanasi	68	2445	4913	201	15	Rising	OE

(OE stands for over-exploitation; C for critical. Only Agra is categorised as critical in the aforementioned Assessment-2017; the other nine cities are over-tapped.

Since 2006, Lucknow has been monitoring its groundwater levels, and the results show a consistent downward trend in several areas of the city.

ii. According to the statistics, groundwater levels are dropping quickly and are becoming lower. This has led to a generalized drying out of wells and tubewells as well as a reduction in the yield from these wells.

iii. Generally speaking, the city's groundwater levels are dropping between 70 cm and 1.0 m each year, or even more. In addition to other places, the most severely impacted areas of the city are “Mahanagar, Aliganj, Gomti Nagar, Indiranagar, Chowk, New Hyderabad, Lalbagh, Cantonment, Hazratganj, Alambagh, and Vrindavan colony.”

iv. Tubewell yield decreased: Over the course of 20 to 30 years, it has been noted that severe groundwater depletion has also caused a major decrease in tubewell yields, which have gone from 1200 liters per minute to about 600 liters per minute or less. This has mostly occurred as a result of aquifers drying up from prolonged drought and reduced storage capacity brought on by ongoing extraction [87].

Chapter 02

Review of literature

1. In Dhanbad District, Jharkhand, Bhumika S. (2024) conducted a study on the variation and management of groundwater quality. The study examined the important problem of groundwater contamination in the region that is significantly affected by industrial activity. In the geographic centre of the Damodar River basin sits Dhanbad, an ancient coal mining district in India. The location's groundwater movement is determined by the fracture network and weathered zone, both of which have different sizes, openness, thickness, and extent. Typically, the depth of groundwater is 2 to 10 meters below the surface of the earth. Rapid urbanisation and population expansion have altered the area's slope and landform. Additionally, this has had an impact on surface water drainage, which has an impact on hydrogeology. The groundwater table has dropped as a result of a decrease in the rate of water intrusion. Pollution of groundwater results from operating and closed coal mines, waste dumps, coal washeries, coking coal plants, thermal power plants, refractories, steel, fertiliser, and cement facilities, as well as other coal-related companies' inadequate environmental safeguards. This study examined the Dhanhad district's ten blocks' groundwater quality. Based on whether or not there were handpumps or tubewells in each block, five villages were chosen at random. The pH, EC, TDS, salinity, Fe, Mn, and Zn levels of the water samples were measured and examined. The assessment and management of groundwater quality were also included in the article. [88]
2. In order to better understand the geochemical processes causing fluoride and nitrate to exist in groundwater and the potential health effects on humans, Maurya S. et al. (2024) conducted a case study. Samples from the Sadar Region, Pratapgarh district, Uttar Pradesh, India, were analysed for a variety of chemical parameters. The results show that the groundwater has an alkaline character, mainly due to the occurrence of facies of the Na-K-SO4-Cl and Ca-Mg-SO4-Cl types. The water pollution index showed that samples were deemed "extremely polluted" in pre-monsoon 47.5%, monsoon 50%, and post-monsoon 48%. A WPI score of greater than 1 meant that the water was unfit for human use. Total Hazard Index (THI) values are computed, and it is shown that 12 sample locations demonstrate

significant contamination; the highest levels of contamination are found in nearly 65% of males, 83% of females, and 90% of children who had THI values greater than 1.0. Health risk assessments draw attention to how more susceptible women and children are to possible health risks. Strong acid dominance over weak acid waters is prevalent, as seen by the Piper plot, which shows the dominance of Cl- and some SO42-type waters. Analysis of the cation composition shows that alkaline earth metals, which are mostly constituted of Ca2+ with some Mg2+ type water, predominate over alkali metals. This study highlights the necessity for comprehensive mitigation techniques in the Indo-Gangetic alluvium and the urgency of tackling groundwater contamination and its possible health implications. [89]

3. In an area currently supplied solely by groundwater, the study by Ramaswamiah S et al., (2024) investigates long-term options for supplying clean drinking water. This area's contamination of groundwater has reached severity and is uranium and fluoride poisoned. Since the area only has a few tiny, seasonal streams, roof-water harvesting and the use of tank or lake water are being investigated as potential alternatives for the supply of potable water. The research area is in eastern Karnataka, India's Chikkaballapura district, where there is 700 mm of annual rainfall on average. While not sufficient to cover all household water needs, the amount of roof water that can be collected from the constructed structures within the research area can suffice to meet drinking water requirements. An almost permanent lake that only requires regular filtration and chlorination is situated in the upper part of the micro-watershed, holding 301 million litres of water. This study demonstrates how lake water use and roof water collecting are examples of sustainable water management techniques that can take the place of contaminated groundwater for drinking. [90]
4. Using the Heavy Metal Pollution Index (HPI), Chaudhari et al.'s (2024) study evaluated the level of heavy metal contamination in Gujarat's groundwater. Taking into account the state's varied topographical, climatic, physical, and geographical characteristics, the study examined the whole area. The HPI scores derived from distinct research demonstrate the degree of contamination attributed to heavy metals. The combined results highlight the serious issue of heavy metal pollution in Gujarat's groundwater and the health hazards that come with it. As instruments to evaluate contamination levels, a number of additional pollution indicators are

presented, such as the Water Pollution Index, Metal Index, Degree of Contamination, and Heavy Metal Evaluation Index. These indices assess the degree of pollution by comparing the amounts of various heavy metals with set limitations. The objective was to give policymakers and investors useful information for developing plans to control and lessen heavy metal pollution throughout the state. The study also examined practical, affordable, and ecologically sound treatment methods for eliminating heavy metals from aquatic systems in order to protect the ecosystem. This research contributed to the direction of efforts to lessen the effects of heavy metal contamination in Gujarat's groundwater by using pollution indicators and corrective measures. [91]

5. A case study on ground water quality trend analysis was conducted by Ali et al., (2024). Uttar Pradesh experiences water stress as a result of little precipitation. Additionally, the country's fast population expansion combined with an increase in industrial and agricultural activities has put additional strain on Uttar Pradesh's water supply. Data on a number of ground water quality characteristics, including pH, calcium, total dissolved solids (TDS), electrical conductivity (EC), and total hardness (TH). The 27 districts of Uttar Pradesh, including Prayagraj, Azamgarh, Bahraich, Ballia, Basti, Mirzapur, Pratapgarh, Gonda, Sultanpur, Jaunpur, Ghazipur, Varanasi, Chandauli, Ayodhya, Gorakhpur, Deoria, Shrawasti, Balarampur, Sidharth Nagar, Sant Kabir Nagar, Maharajganj, Kushinagar, Mau, Sonbhadra, Sant Ravidas Nagar, Ambedkar Nagar, and Barabanki were among the 27 districts of Uttar Pradesh that are included in this study. Groundwater management, groundwater level, and the five hydro-geochemical elements in 27 Uttar Pradesh districts all depend on trend analysis of groundwater levels. The Mann-Kendal test and Sen's slope estimator are two well-known trend analysis techniques that are the subject of this paper. A statistical test confirms the graphical exploratory analysis that forms the basis of trend analysis methodology. R studio software was used to perform the Mann-Kendal test for trend analysis. Sen's estimator was employed to determine the trends' magnitudes. The temporal trend analysis was conducted using the Mann-Kendall non-parametric test. because it offers substantial information regarding the trend of ground water that is either increasing or diminishing. [92]

6. Siddiqui N et al. (2024) examined the Uttar Pradesh Groundwater (Management and Regulation) Act, 2019 and the UP Groundwater (Management and Regulation) Rules, 2020, and following a case study of the Indian state of Uttar Pradesh, reached three conclusions: “First, the primary motivation behind the 2019 Groundwater Act and the 2020 Draft Groundwater Rules is concerns regarding the sustainability of resources, particularly in areas where the water table is steadily declining; Second, some regionally defined fundamental components are crucial for promoting sustainability and, to a lesser extent, groundwater justice; neither of these texts, however, suggests any proactive groundwater justice initiatives”. The ultimate conclusion is that community practices and state-led groundwater law must coevolve in order to create groundwater arrangements that promote sustainability and groundwater justice. [93]
7. Soni DK et al. (2024) carried out a case study on the potential health risks associated with arsenic-contaminated groundwater in the eastern region of Uttar Pradesh, India. Due to the presence of arsenic (AS), which poses a worldwide health risk, groundwater intrusion has stimulated in-depth study and research on a number of features of AS's spatial distribution and mobilisation in aquifers. Since arsenic is known to cause cancer, it is critical to comprehend the health concerns before putting mitigation measures in place. The district of Ballia in Uttar Pradesh, India, which is contaminated by AS, was chosen for this study's extensive groundwater monitoring and health risk assessment. For analysis, 195 groundwater samples overall from nine blocks were gathered. A thorough monitoring of AS in the groundwater samples was conducted in conjunction with the analysis of other physicochemical water quality indicators. 32% of the groundwater samples overall showed AS concentrations over the World Health Organization's (WHO) acceptable level. The report also emphasised the concerns to human health related with possible AS contamination of groundwater. The majority of monitoring stations had computed hazard quotients (HQ) and cancer risks (CR) higher than the US Environmental Protection Agency's guidelines ($CR > 10^{-6}$; $HQ > 1$), suggesting a serious risk to the local population. [94]
8. To assess the current level of heavy metal pollution in and around Moradabad city, Husain and Ali (2024) conducted a study. Because of its enduring character, capacity to build up in the food chain, and detrimental impacts on the environment and human health, heavy metal contamination in water has emerged as a global

issue. Water degradation may result from its fluctuating concentration. In this study, thirty water samples from Moradabad city's surrounding areas were selected, and their concentrations of heavy metals "(Zn, Fe, Cd, Mn, Pb, Ni, Cu, and Cr)" were assessed. In 2017, measurements of the following elements were made in water samples: "Cd, Mn, Fe, Cu, Pb, Zn, Ni, and Cr". Based on the analysis of the samples, the following order of heavy metal contamination is found: Premonsoon 2017 heavy metal values are "Ni>Fe>Pb>Cd>Cr>Cu>Zn>Mn"; postmonsoon season heavy metal values are "Fe>Pb>Ni>Mn>Cr> Cu>Zn>Cd". The pre-monsoon 2017 HPI average score was 13.07, indicating good groundwater quality. The average HPI score in the post-monsoon season is 159.26, indicating low to mediocre water quality. After evaluation, the correlation matrix reveals a positive correlation between the items. Leachate is generated by the massive amount of industrial solid waste produced in Moradabad municipal and its inappropriate disposal, which results in heaps stacked outside of the municipal limits. Both surface and groundwater resources could be contaminated by heavy metals that leak from these dumping sites. The results of the investigation demonstrated that a variety of anthropogenic and natural causes of contamination led to a discernible increase in the concentration of heavy metals in water. [95]

9. In Sikar City, Nussi et al., (2024) conducted a thorough review on the assessment and mitigation of groundwater pollution. Water pollution is a serious worldwide environmental problem that has an impact on the environment, public health, and economic growth. Water pollution must be evaluated and reduced in order to protect the ecosystem and the general public's health. It entails locating the sources of pollution, calculating the effects on the environment and human health, and putting reduction plans into action. Sikar is among of the Rajasthani cities dealing with a severe contamination of the water crisis. Both surface and groundwater are significantly contaminated, underscoring the pressing need for sustainable water management techniques. In addition, excessive irrigation, wasteful water usage, and little recharge are raising groundwater levels in Sikar. This development puts infrastructure and agriculture at risk, aggravating problems with water quality. This study assessed the consequences of the current levels of water pollution in Sikar City by evaluating key markers of water quality (pH, BOD, COD, etc.) while contrasting findings to national and international standards. It also discussed the problem of rising groundwater levels brought on by things like over-irrigation,

wasteful water use, and restricted recharge. After evaluating pertinent or comparable case studies and research publications on water pollution in Sikar and related places, the study suggested mitigating techniques. [96]

10. In Dehradun, Uttarakhand State, Nayak et al., (2024) evaluated potentially harmful components in groundwater using chemometric approaches, pollution indices, and interpolation. Their study sought to measure the levels of harmful components in freshwater in the Dehradun Industrial Region of Uttrakhand, India, for the first time, as well as the health hazards that come with them. Potentially hazardous elements (PTEs) Fe, Cd, Mn, Cu, Cr, and Pb, Zn, Ni are measured by AAS and compared to drinking safety standards set by BIS and WHO. All groundwater samples had mean trace element concentrations in the following order: Fe > Zn > Cu > Ni > Co > Cd > Pb. During the research period, HPI was found to be greater than high class (HPI > 30), although it still fell below the severe contamination limit of 100. Throughout the study period, iron's MI and PI values were continuously over the threshold limit. Additionally, some harmful elements were found abnormally close to the threshold limit, suggesting a serious future impact on groundwater quality. Maximum levels of toxic elements in groundwater in the Dehradun region are linked to land use patterns, anthropogenic activity, industrial activity, leaching of fertiliser and pesticides, and residential waste into the aquifer system, per PCA (principal component analysis), CM (correlation matrix), and potential health hazard. By implementing appropriate monitoring and mitigation measures, the results of this study may help local planners and policymakers reduce health concerns associated with contaminated aquifers. [97]
11. In Lucknow, Uttar Pradesh (India), Singh and Patel (2024) conducted research to characterise leachate and evaluate groundwater contamination near the Shivri dump site. In order to examine leachate infiltration and potential contamination of groundwater quality, groundwater and leachate samples were taken from the Shivri landfill site, waste management facility, and surrounding area. The purpose of assessing the groundwater and leachate samples was to determine the concentration of heavy metals in both the leachate sample and the groundwater sample, among other physical and chemical properties. The following heavy metals were tested for: Pb, Zn, Cd, Cr, Cu, and Fe. Due to the landfill site's effective leachate collecting system, very low amounts of various ions, including Cl−, SO42−, NO3−, Cd, Cr, Cu, Zinc, and Iron, were found in the groundwater sample, indicating that

leachate had no effect on the nearby groundwater. The leachate percolation was not sufficiently linked to a slightly higher concentration of TDS, COD, alkalinity, or TH. Moreover, there was no discernible impact of distance on any of the water quality indicators other than Cr, which was only seen at sampling location 1. The main findings of the study were that practically all of the groundwater's parameters were found to be within a range that is safe for human consumption, and there was no leachate contamination in the groundwater. It was useless to recommend corrective action because the landfill site was already engineered and there was no evidence of leachate pollution. Therefore, the current analysis indicates that the Shivri waste site has no effect on groundwater. [98]

12. In the Bhatinda District of Punjab, India, Bansal et al., (2024) conducted a review on groundwater quality and associated risk. Water contamination is currently the world's biggest threat. This is due to its effects on the earth's vegetation and wildlife. It has a variety of effects on human health. Due to their long half-lives and inability to biodegrade, the majority of pollutants that have an effect on human health are inorganic and organic. Compared to biodegradable compounds, these contaminants have a greater dangerous effect because of their prolonged buildup. The disposal of garbage into water bodies and the overuse of pesticides and other agricultural chemicals are the main causes of water contamination. People now face significant challenges when consuming this contaminated water, and if they continue to do so, there may be a risk because many of the chemicals are carcinogenic. Water pollution adds to the already numerous health problems caused by today's lifestyle, which also prolongs the chronic disease cancer. Even if the problem is global, we cannot overlook the high exposure in developing nations since these nations are pursuing increased industrialisation at the expense of little or moderate medical facilities. This is because cancer prevention strategies must be ongoing in order to effectively combat the exposure to carcinogens. Therefore, the purpose of this review was to identify the common carcinogenic contaminants, their sources, and the health concerns they provide. The authors also presented the experimental findings of their use of the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) technology to detect metal ions in the ground water of the Bhatinda region. [99]

13. A review on groundwater pollution and its assessment was conducted by Sultana Q and Sultana A (2024). A crucial factor in any area's development is groundwater. It is a vital supply for the industrial and agricultural sectors. Groundwater pollution is caused by both natural and human activity. While natural processes like geological weathering and aquifer features may be responsible for the elevated levels of some inorganic elements, human activities also frequently contribute significantly to groundwater pollution. Conversely, the presence of organic contaminants is mostly brought about by a variety of human activities. Groundwater contamination is also caused by extensive groundwater extraction, the mixing of groundwater and other surface water bodies in underground conduits, and leaking subsurface buried equipment. In India, the Central Ground Water Board and State Groundwater Agencies are primarily responsible for monitoring groundwater quality, and each of these organisations sets up its own monitoring network. However, because of the insufficient density of the monitoring station network, there are concerns about the suitability of the scientific data that is accessible from them. Critical parameters that aid in detecting pollution from pesticides, fertilisers, heavy metals, and other toxic effluents are not included in water quality analysis. The scientific data that is available, especially regarding pollution, comes from civil society institutions, and there aren't many of these institutions that are able to handle such difficult, technically complex, and frequently politically touchy tasks. The primary cause of groundwater pollution is typically pumping-induced geo-hydrochemical activity. There is no way to stop contamination once it begins other than to outright forbid pumping. This is difficult because irrigated agriculture and livelihoods are dependent on groundwater for countless rural Indian communities. Any legislative or regulatory actions that prohibit pumping would entail the denial of customary rights to communities. Landowners have the freedom to extract groundwater beneath their properties, even if the rights to this resource are unclear. Although nitrate pollution can be effectively managed by applying fertilisers according to recommended dosages, rotating crops, applying fertilisers at the right times, and using organic manure rather than chemical fertilisers, there are no institutional regulations controlling the use of fertilisers or the disposal of animal waste. In order to ensure sustainability, policies should focus on enhancing the technical skills of line agencies that deal with water quality management, water supplies, and pollution

control. They should also be reframed to properly handle water quality management, enforce pollution control laws, and assist in the implementation of environmental management projects. [100]

14. An analysis of the distance as a function of the variance of the estimation error between the measured and presumed location of a point source of contamination in groundwater was proposed by Kovažc et al., (2023) The Varaždin wellfield, which was closed because of an abnormally high groundwater nitrate concentration, was one of the study sites in the north of the Republic of Croatia. Spatial distribution models were constructed using seven distinct interpolation techniques. Every approach offered a distinct model, a varying estimation error variance, and estimations of the pollutant source's location. The distance and the variance of the estimation error were shown to have a nonlinear and monotonic relationship, leading to the fitting of logarithmic and rational quadratic models to the scatter point data. The models were linearised, a t-test was run, and the results indicated that the models can be regarded as dependable. This conclusion was supported by the linearised models' coefficients of determination. Planning further research to pinpoint the precise site of the pollution source can be done using the results acquired. The research approach employed is global and transferable to other sites where elevated levels of specific pollutants have been found in groundwater in alluvial aquifers. [101]
15. In coastal communities in Gujarat, India's Khambhat region, Bhavsar and Patel (2023) assessed the potability of the groundwater. 57 groundwater samples were subjected to chemical analysis in order to look at significant indicators of drinkable water. The entropy weighed groundwater pollution index (EGPI) and the weighted arithmetic groundwater quality index (GWQI) were evaluated in order to divide the groundwater into discrete zones of contamination and drinkable water quality. Additionally, based on computed GWQI and EGPI, geographical maps representing the geographic distribution of groundwater pollution zones and drinkable groundwater quality were created utilising a variety of geospatial analysis techniques. The mean GWQI value that had been computed was 265.66. The maximum and minimum GWQI values were 479.57 and 93.45, respectively. In 26.32% of the samples, the GWQI values were greater than 300, meaning that the groundwater's quality is unsuitable for drinking. With an average EGPI value

of 2.35 and a range of 0.8 to 4.13, it's clear that over 66% of groundwater samples fall into the very high to extremely high polluted category. [102]

16. Ismail et al.'s (2023) study used hydrochemistry and electrical resistivity tests to analyse the groundwater's potentiality and suitability for a range of applications. The research area's groundwater potential was evaluated using 24 vertical electrical soundings (VESs), and the quality of the groundwater was evaluated using 57 groundwater sample analyses. To determine if the collected water samples were suitable for irrigation, they were evaluated using a variety of indicators, including EC (salinity index), Na% (salt hazard), SAR (ratio of sodium adsorption), chloride dangers, SSP (soluble sodium percentage), MH (magnesium hazard), and others. Within the study area, four levels are specified by the constructed geoelectrical cross-sections. The first is composed of silt and clay from the Nile River, while the second is composed of sandy clay with a resistivity range of 15 to 32 Ohm.m and a range thickness of 2 to 68 m. Dry limestone makes up the third layer; its thickness ranges from 75 to 95 m, and its resistivity ranges from 1222 to 3000 Ohm.m. The final layer is the Eocene aquifer in the study area, with resistivity values between 602 and 860 Ohm.m. and a thickness of almost 250 m. None of the collected groundwater samples are acceptable for domestic use because of their extreme hardness, but the majority are safe to drink. RSC, KR, PI, SAR, and US figures show that the majority of Pleistocene and Eocene groundwater samples are appropriate for irrigation. [103]
17. In order to better understand urban groundwater contamination and its effects on drinking water quality and related health hazards, Singh KK et al. (2023) conducted research in the Upper Gangetic Alluvial Plains of northern India, which is home to several businesses. Numerous industries in the Udham Singh Nagar district, including paint, textile, sugar, petrochemical, paper, and automobiles, pollute groundwater and release a variety of pollutants into the environment, including heavy metals. Thus, for the current study, fifty groundwater samples were taken from this area and examined for four metals (calcium, magnesium, sodium, potassium), six heavy metals (Fe, Mn, Zn, Pb, Cd, Cr), and seven physicochemical parameters (pH, electrical conductivity, total dissolved solids, bicarbonate, chloride, sulphate, nitrate). By computing and analysing heavy metal pollution indicators (heavy metal pollution indices -HPI, m-HPI; heavy metal evaluation index - HEI) and risk assessment parameters (hazard quotient - HQ and hazard

index - HI), the amount of heavy metal contamination in the groundwater was determined. In order to classify groundwater quality and determine the sources of heavy metals, multivariate statistical analysis was also performed. Fe, Mn, and Cr concentrations in water samples at 14%, 16%, and 18% were higher than desired. The bulk of groundwater samples, according to the piper diagram, were of the Ca–Mg–HCO3 type. According to the HPI calculation, no groundwater sample was found to be highly contaminated. Three groundwater samples were determined to fall into the undesirable category based on m-HPI, although HEI and m-HPI showed that 90% and 82% of the samples were deemed fit for potable use. There were no cancer-causing risks noted, which could be because of the high chromium level. Groundwater pollution was attributed to geogenic, anthropogenic, and industrial activities, as determined by principal component analysis (PCA) and cluster analysis (CA). Both the adult (13 samples) and younger (9 samplings) values of HQ for Cr are more than unity. HI readings showed that samples of groundwater from 14 locations were unfit for human consumption. It's the first attempt to analyse the health risk and heavy metal pollution in Uttarakhand's Udham Singh Nagar area. [104]

18. The quality and possible noncarcinogenic health concerns associated with nitrate in groundwater in the El Milia plain, Kebir Rhumel Basin, Algeria, were examined by Breall et al., (2023). The hydrochemical parameters in the groundwater were analysed for their geographical distribution pattern using Moran's I and the ordinary kriging (OK) interpolation approach. Strong spatial autocorrelation was observed in the hydrochemical parameters Ca, Cl, and HCO3 in the El Milia plain, suggesting that these parameters are spatially dependent and cluster in the groundwater. The entropy water quality index (EWQI) was used to assess the quality of the groundwater. The findings indicated that the moderate groundwater quality category included about 86% of the research area's total groundwater sample count. The hazard quotient (HQ) was used to evaluate the possible noncarcinogenic health concerns for adults and children related to nitrate contamination of groundwater through the drinking water channel. The findings showed that the HQ limit for adults was exceeded by about 5.7% of the total groundwater samples, suggesting possible health concerns. Furthermore, a greater proportion of the total groundwater samples—14.28%—exceeded the HQ limit for

children, underscoring the fact that they are more susceptible to non-carcinogenic health risks connected to nitrate contamination in the research location. [105]

19. The West Bank region of Palestine's groundwater resources was assessed for quality utilising the human health risk (HHR) evaluation and the water quality index (WQI) by Zohud et al., (2023). Due to the limited availability and difficult access of groundwater on the West Bank, as well as the region's aquifers' inherent characteristics, groundwater is now thought to be highly polluted. There is also a great deal of concern about the water quality in this area because human health is directly impacted by it. High levels of potassium and nitrate are seen in several areas of the West Bank groundwater. Overall, the quantities of nitrate (38.8%) and potassium (10%) in the well samples were higher than the WHO and PSI-approved limits. As a result, health issues could potentially affect the quality of life and welfare in this area. Additionally, it was determined that 87.7% of the samples had extremely hard water. 78% of the well samples had good quality, based on the WQI values. Health risk evaluations were used to determine the levels of fluoride and nitrate in drinking water for adults, children, and neonates. Based on age, the projected Total Hazard Index (THI) main values showed a varied impact on the local population from the data analysed on the health risk assessments. The THI ranges in each of the sampling locations varied significantly and went from 0.29 to 3.08 for children, 0.302 to 3.21 for babies, and 0.093 to 3.01 for adults. These findings generally suggest that newborns are more vulnerable to health hazards. [106]
20. In Kodsuwa Digod, Rajasthan, India, groundwater samples were collected during a year in the first week of each month for a physico-chemical study conducted by Chanddak and Trivedi in 2021. Standard procedures were used to analyse the physico-chemical parameters from the samples. The study's findings indicate that all parameters, with the exception of magnesium and calcium, were found to be below the permissible limit of drinking water standards (IS 10500). [107]
21. Ahmed Salman et al. (2022) examined groundwater contamination in a northern Indian developed alluvium downstream of the Yamuna River, focussing on heavy metal regions. A thorough assessment of the risks associated with contamination was conducted in order to track and prevent contamination of the groundwater in the basin. Through the process of infiltration, human activity contributes significantly to the polluted groundwater of the Yamuna River's alluvium

watershed in the Mathura region. Several groundwater pollution indices, including ERI, HMPI, PIG, and multivariate approach, or PCA, were employed to identify the contaminated sites in the research area. 110 groundwater samples were taken from shallow hand pumps during the study in order to assess the quality of the groundwater based on specific principal ions, mainly chloride, sulphate, nitrate, and fluoride, as well as heavy metals, including zinc, lead, nickel, cadmium, iron, manganese, and copper. The results show that the average levels of heavy metals exhibit the following patterns: The order is as follows: Ni (2.92 mg/L) > Pb (2.06 mg/L) > Fe (1.73 mg/L) > Zn (0.76 mg/L) > Cr (0.66 mg/L) > Cd (0.45 mg/L) > Mn (0.40 mg/L) > Cu (0.02 mg/L). Similarly, the ERI results imply a considerable potential ecological danger in the research area. Using this data, the scientists divided the groundwater samples into three categories: extremely poor (77.3%), bad (13.6%), and good (9.10%) quality. The hotspots are found in the Northwestern portion of the study area. The findings demonstrate that the expansion of city garbage, industrial waste, and agricultural uses and practices have an impact on the alluvium watershed of the Yamuna River both directly and indirectly. This comprehensive analysis facilitates the creation of an appropriate mitigation strategy for pollution control and effective water resource management. [108]

22. A chapter on "Contamination of water resources: With special reference to groundwater pollution" was written by Neegam N and Kumar S (2022). They clarified that there is a direct correlation between the state of technology today and the environment. There is serious concern over the daily depletion of natural resources. Early action is required to address the supply of safe water, in terms of both quality and quantity. Groundwater was regarded as the safest natural resource for human use before human activities. However, groundwater can become contaminated when undesirable elements seep through the soil into the groundwater. An overview of the importance of groundwater, different forms of contamination, groundwater pollution, and sources of groundwater pollution is given in this chapter. Arsenic concentrations exceeding 0.01 mg/L have been found in portions of 152 districts across 21 states and Union Territories, with Bihar, West Bengal, and Uttar Pradesh being the states most affected, according to a comprehensive study on arsenic contamination in Indian groundwater carried out by the Central Ground Water Board, Ministry of Jal Shakti, India. The most likely source of arsenic pollution in groundwater in these states is the soil that has alluvial

formation. It is unacceptable for drinking water to have an arsenic concentration higher than 0.01 mg/L since this could seriously harm people's health. Long-term use of arsenic can result in skin conditions such as hyperkeratosis. The best way to obtain arsenic-free groundwater for communal use in places impacted by arsenic and having a multi aquifer system is to tap into a deeper, arsenic-free aquifer. Groundwater tainted with arsenic can be substituted with arsenic-free surface water as an alternate supply. One workable way to supply water free of arsenic is to lightly treat surface water using a structured piped water delivery system. [109]

23. In the study by Lutterodt G et al., (2022), Three communities near the University of Cape Coast in Ghana had their hand-dug wells' shallow aquifers analysed for chemico-physical and microbiological quality. Physical properties such as pH, electrical conductivity, dissolved oxygen (DO), and others were evaluated in real time using probes, and each well location underwent a sanitary risk evaluation. Through the use of membrane filtering, the microbiological groundwater quality was investigated. Two pollution indicator anions, nitrate and chloride, were detected in water samples. The study also examined whether bacteria might survive in groundwater conditions without the presence of predator organisms. Exponential, second-order polynomial, and linear distribution models were used to fit the data. According to the results of the sanitary risk inspection and the microbiological quality study, every well was at risk due to the presence of total coliforms from on-site sanitation. 7 out of the 28 wells, or 25% of the total, had DO concentrations that were within permissible bounds by drinking water regulations (> 5 mg/L). Both the average chloride level of 360.5 mg/L (range: 46 mg/L to 844 mg/L) and the average electrical conductivity value of 1.5 mS/cm (range: 213 µS/cm to 2.7 mS/cm) exceeded the WHO-recommended limits. Aquifer mineralisation was indicated by the acidic conditions (pH < 6.5) seen in water samples. The deposition of dry air aerosols and potential mineral breakdown in the aquifer were the causes of the elevated EC values and chloride content observed in groundwater. The results of our bacteria regrowth experiment show that, in the absence of antagonist predators, the second-order polynomial distribution best characterises the rates of bacterial inactivation. The amount of extra time needed for bacteria to completely inactivate in a groundwater environment ranged from 0.1 to 4 years, showing that bacteria may live for a very long time in aquifers. It was determined that all of the wells are potentially contaminated by airborne pollutants and faeces. [110]

24. In Udham Singh Nagar, Kumaun Himalaya, Uttarakhand, Singh S et al., (2022) conducted a groundwater quality assessment. Groundwater contamination is unavoidable because the Udham Singh Nagar district has an abundance of fertile land, water resources, and is highly suited for industrial expansion. This has led to a rapid increase in industrialisation and urban growth. The need for groundwater has increased recently due to the district's Integrated Industrial Estates (IIE) in Pantnagar, Kashipur, and Sitarganj areas as well as the area's faster pace of urbanisation. In order to meet the urgent needs for irrigation as well as the speed of rapidly increasing urbanisation and industrialisation, proper planning and monitoring of groundwater resources at the regional level are necessary. In order for this strategy to be effective, the sustainable approach that should be used in a given location will depend on the spatial distribution of water quality. The purpose of this study was to evaluate the hydrochemical quality of the groundwater in Uttarakhand's Udham Singh Nagar district (which has an area of 3055 km^3). After undergoing significant elemental analysis, the groundwater samples taken from the aquifer revealed anomalous values of Total Hardness (TH), Total Dissolved Solids (TDS), Magnesium (Mg^{2+}), Iron (Fe), and Lead (Pb^{2+}), confirming deterioration in the groundwater quality. Furthermore, the hydrochemical facies and characterisation of groundwater were additionally determined by the Piper Trilinear Diagram (PTD). Most groundwater samples have less than 500 mg/L of dissolved solids, which makes them suitable for drinking, according to the interpretation of TDS. Thus, this phenomena might be attributed to the presence of acceptable drinking water in the Uttarakhand district of Udham Singh Nagar's aquifer. [111]
25. In the Unnao district of Uttar Pradesh, India, a study by Verma et al., (2021) sought to assess the groundwater's suitability for human and agricultural usage. Block-wise (n = 16) groundwater samples were obtained for this investigation, and the measured parameters were analysed using graphical approaches, several irrigational indicators, and the pollution index of groundwater (PIG). The findings of this investigation indicated that, with the exception of F^- (0.4 to 2.6 mg L^{-1}) and Fe^{2+} (0.1 to 1.7 mg L^{-1}), the most of the parameters were within the WHO and BIS-recommended ranges. In 43.75% of samples at some sites, total dissolved solids (TDS) concentrations were higher than the desired limit (> 500 mg L^{-1}). The Gibbs plot showed that the rock-water interaction in the area, particularly

silicate weathering, controlled the chemistry of the groundwater. Based on the Piper plot, the predominant hydrochemical facies in the area appears to be Ca^{2+}-HCO_3^-, followed by mixed "Ca^{2+}-Na^+-HCO_3^-type, Na^+-Cl^- type, and Na^+-HCO_3"$^-$ type. According to PIG evaluation, F^- and Fe^{2+} have a greater impact to groundwater degradation than other elements in the region; approximately 18.75% of samples indicated low pollution, 6.25% showed moderate pollution, and 6.25% showed high pollution. According to the results of the human health risk (HHR) assessment, children are more vulnerable than adults (mean: 1.01). While the majority of the groundwater was found to be suitable for irrigation, the magnesium hazard ratio (MHR) and potential salinity (PS) indices suggested that only 37.5% and 56.25% of the samples were suitable for irrigation, respectively. This regional study would aid stakeholders and relevant authorities in making decisions regarding the implementation of groundwater management and remediation plans in the area. [112]

26. Bangladesh mostly uses groundwater for drinking and irrigation. One big challenge is the ongoing pollution of groundwater. Bangladesh is currently rapidly approaching the industrial revolution. In an effort to analyse Bangladesh's groundwater pollution situation, Ganguli et al. (2021) looked specifically at the previous 20 years. They reviewed approximately 100 articles, conference papers, and reports that were published in national and international journals and books, as well as issues pertaining to pollution sources, health impact assessments, and future perspectives. Numerous pollutants, including microorganisms, trace metals, and physico-chemicals, have been found to be present in the groundwater. Arsenic (As) contamination is one of the biggest threats to human health; it increases the risk of cancer and non-cancer outcomes from drinking contaminated water. However, microbial contamination of water has caused many diseases that affect large populations of people. Groundwater pollution can be caused by anthropogenic and geophysical sources, well depth, and geographic factors. Policymakers should take immediate action and take precautions where needed. [113]
27. Sunitha et al. (2021) performed a human health risk assessment (HHRA) of fluoride and nitrate in and around Cuddapah, A.P., which is in the hard rock region of South India, using the pollution index of groundwater (PIG). The most common resource used globally for drinking water and irrigation is groundwater. Both natural and human activities have caused nitrate levels in most groundwater

sources in arid and semi-arid regions to rise in recent decades. Due to both natural and human-induced processes, fluoride and nitrate levels in most groundwater sources in arid and semi-arid regions are now higher. In order to determine the possible health risks to adults, children, and newborns as well as the polluted levels of groundwater fluoride and nitrate in Cuddapah, South India, thirty groundwater samples were taken from bore wells. 86.6% of the groundwater in the study communities has nitrate concentrations over the recommended level of 45 mg/L, with amounts ranging from 23.2 to 110.8 mg/L. 40% of the groundwater in the study communities has fluoride levels above recommended limits of 1.5 mg/L, with fluoride values ranging from 0.1 to 3.2 mg/L. 96% of groundwater exceeds the acceptable THI values (>1) for newborns (0.57–3.10), children (0.75–4.08), and adults (0.74–4.02). 30 percent of the groundwater samples fall into the high pollution zone (2.20), 47 percent fall into the intermediate pollution zone (1.83), and 23 percent fall into the low pollution zone (PIG: 1.38). According to the authors, appropriate precautions should be taken to reduce the health risk in this area. [114]

28. For irrigation and drinking reasons, Jesuraja et al. (2021) assessed the groundwater integrity and pollutants index (GPI) of coastal aquifers from Tiruchendur, South India. In order to do this, they evaluated several indicators, including the permeability index (PI), Langelier saturation index (LSI), residual sodium carbonate (RSC), sodium adsorption rate (SAR), magnesium ratio (MR), Kelley's ratio index (KR), sodium percentage (Na%), residual salinity (PS), IWQI, TH, and sodium percentage (Na%). The semi-arid environment of the research area was reflected in the minimal impact of aquifer lithology and the overwhelming influence of evaporation on groundwater chemistry. About 89% of the samples spanning 418 km² had electrical conductivity (EC) that was higher than allowed, whereas 74% of samples had Ca values that were still within the drinking-age limit. Increased K was brought on by overuse of fertiliser in agriculture, while more chloride was brought on by salt leaching and seawater intrusion. The inverse distance weighting (IDW) approach was used to construct a geographical distribution map, which demonstrates the presence of adequate groundwater near the river basin. A GPI of 1.5 indicates that 43% of the study region has minimal contamination and that the groundwater is fit for human use. Other GPI values fall between 0.40 to 4.7. Furthermore, 17% of the groundwater samples have somewhat

acceptable drinking quality. The evaluations supplied by the irrigation water quality indexes were inconsistent. While the indices of RSC, SAR, and PI categorised 72–100% of the samples as acceptable for irrigation, the indices of TH, Na%, MR, PS, and LSI indicated 32–95% of the samples as inappropriate for irrigation. However, the IWQI map showed that around one-third of the research area's groundwater could only be used for plants that can withstand salt, and that more than half of the study area's groundwater is unsuitable for irrigation. [115]

29. Masood et al., (2021) brought attention to Pakistan's groundwater pollution issue. In Pakistan, groundwater is a significant freshwater resource. Unfortunately, pollution of this priceless resource has resulted from overextraction and other human pressures. Four main problems associated with groundwater contamination in Pakistan have been documented by numerous studies: fluoride, nitrate, arsenic, and bacterial contamination. The primary cause of bacterial pollution is the seepage of wastewater from cities. In Pakistan, it is the primary cause of both child mortality and gastrointestinal illnesses. Human carcinogens in Group 1 include arsenic. Pakistan is the fourth-most arsenic-affected country in the world. The locations with the highest levels of arsenic pollution are rural Sindh and Punjab. Dental and skeletal fluorosis is caused by fluoride. It has been claimed that the groundwater in the districts of Quetta, Lahore, Kasur, Gujrat, Swabi, Nagarparkar, and Umerkot has excessive fluoride. Nitrate is present because to sewage water leaching and agricultural operations. The provinces with the highest recorded nitrate concentrations are Punjab and Balochistan. In addition to the primary anions, other metals that have been reported in different sections of the nation include zinc, lead, nickel, and iron. [116]
30. An extensive summary of Uttar Pradesh's groundwater resources can be found in the paper "State of Groundwater in Uttar Pradesh" by Sinha, R. S. (2021). Since the state's ground water problems are so varied, an effort has been made to address nearly every facet of ground water resources, including their availability and patterns of change, the increasing stress on these resources, quality concerns, environmental issues, and management issues. Groundwater depletion has become a national and state policy issue that requires an integrated and comprehensive approach to be addressed. In order to create a balance between the extraction, use, and replenishment of groundwater sources, effective policy interventions for aquifer restoration are necessary for resource management in Uttar Pradesh. These

issues are both quantitative and qualitative. Many policy efforts and decisions made by the government have been widely discussed. A number of cases are examined critically, and pertinent observations are made to recommend improvements to various techniques and methods used in science. The significance of digital technologies and data management in ground water governance is emphasised. In alluvial aquifer systems with several aquifer systems, it is necessary to concretise methods for evaluating the deeper aquifers' extractable potential. In order to propose various reforms in the ground water sectors, a strong mechanism for effective and sustainable groundwater management is suggested, along with a number of workable solutions. These include creative approaches and initiatives aimed at guaranteeing the long-term sustainability of the state's groundwater systems in the face of a variety of groundwater issues. Appropriate recommendations and actions are planned to address a number of problems that affect all users of groundwater. Therefore, a comprehensive and long-term plan that combines and integrates many initiatives would be needed to progressively resolve the state's ground water crisis. To successfully implement the critically important plans, there is an urgent need for coordinated efforts by various Central and State agencies, social service and non-governmental organisations, academic institutions, and the stakeholders. Prioritising community involvement and public participation is important. Year-round public awareness campaigns aimed at raising awareness among the general public and stakeholders will be very beneficial in putting ground water plans into practice. With a novel concept of "RRR" for attaining aquifer restoration as the ultimate aim, the report, which envisions a series of groundwater reforms and integrated solutions, may offer a sustainable road for futuristic planning and sustainable groundwater management. [117]

31. Chaurasia AK et al. (2021) used the Water Quality Index (WQI) in the context of a Geographic Information System (GIS) to evaluate groundwater vulnerability in areas of Uttar Pradesh, India. Groundwater supplies are impacted by three primary activities. The first is the over use of fertilisers and pesticides in agricultural areas. Untreated or partially treated wastewater discharge into the land or water is the second, while excessive pumping and aquifer misuse are the third. Groundwater is contaminated both directly and indirectly by industrial development activities and widespread urbanisation, which have resulted in the production of home

wastewater and a significant volume of industrial effluent. Since several elements may influence the water's quality, it is crucial to base judgements in a drinking water quality review on facts. Significant progress has been made in the field of water quality assessment, particularly in the use of modified principles to support the WQI principle. The study region, which includes parts of the districts of Varanasi and Sant Ravidas Nagar in Uttar Pradesh, India, is a centre for both industrial setup and urban development. The combined effect of numerous water quality indicators that are taken into consideration during computation is represented by the Water Quality Index (WQI). 50 groundwater samples were taken from different sites within the research region in accordance with the standard protocol that the American Public Health Association (APHA) recommended. The water quality index was based on twenty-two parameters related to water quality: pH, electrical conductivity (EC), total hardness (TH), total dissolved solids (TDS), alkalinity, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrates (NO_3^-), bicarbonate (HCO_3^-), chlorides (Cl^-), sulphates (SO_4^-), fluorides (F^-), chromium (Cr), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), nickel (Ni), lead (Pb), and cadmium (Cd). When determining the water quality index (WQI) and determining whether groundwater is suitable for drinking, the Bureau of Indian Standards has been taken into consideration. A examination of correlations between different physicochemical parameters also revealed some noteworthy adverse associations. According to the Water Quality Index (WQI), 50% of the water samples that were gathered were unfit for consumption, while the remaining samples were classified as good, moderate, poor, or extremely poor. The results of this study were very beneficial for the appropriate planning and administration of the water resources that are available for human consumption. [118]

32. A study on seasonal variations in the groundwater quality of a riverine island on Kerala's west coast, India, was carried out by Sajilkumar et al., (2020). In this investigation, 17 water samples from open wells were collected before and after the monsoon season, and the samples were examined in accordance with accepted practices. The data demonstrate a noteworthy difference in groundwater chemistry between the two periods of 33 years. While the majority of well water samples are acceptable in the post-monsoon season, many wells are contaminated with TDS, Cl, Fe, Ca, and Mg during the pre-monsoon season. Furthermore, it was found that

the content of iron was higher during the pre-monsoon season (41%) than during the months following the monsoons (24%). The study shows that pollution of groundwater in the study area is caused by overexploitation and a decrease in the river Periyar's flow during the pre-monsoon season. [119]

33. Coomar P. et al., (2020) highlighted the global pollution of geogenic groundwater. Though it was always abundant, groundwater has recently emerged as the most reliable source of freshwater due to its resistance to microbial pollution, scarcity, and regional climate changes. Nevertheless, the emergence of its extensive usage has also resulted in a progressive rise in the prevalence of health problems in some areas. After research, the origin of these diseases has frequently been linked to the overabundance of specific components, some of which function as vital nutrients for the growth of flora and fauna when present in ideal concentrations. Human activity has the potential to introduce these toxins at very high concentrations into the subsurface water system locally. But as interest in groundwater quality and health has grown, it has become increasingly clear that these issues are global in scope and that only natural geologic processes can mobilise them. Even though the majority of these elements are distributed throughout the crust of the Earth, tectonic and surficial processes have the tendency to concentrate them in particular lithotypes, making some regions of the crust more enriched in these elements than others. Their high degree of spatial variability in groundwater is caused by this localised solid-phase enrichment, which makes it challenging to forecast their likely occurrence in a single well based just on information from neighbouring wells. A global compilation of data on groundwater quality indicates that the distribution of these geogenic contaminants has a unique pattern. Upon closer examination, it was discovered that this pattern is governed by a combination of low-temperature geochemical and high-temperature geodynamic processes. [120]
34. The status of arsenic and its detrimental consequences in the groundwater of eastern Uttar Pradesh and Bihar were reported in study by Kumar et al., (2020). In India, West Bengal was the first state to declare groundwater arsenic poisoning in 1983. Several other states, including Bihar, Uttar Pradesh, and Jharkhand, followed suit. People in 25 villages in Uttar Pradesh's Ballia district were discovered to have skin lesions due to arsenic exposure. Groundwater in three blocks of the Ballia district, Murlichapra, Bansdih, and Reoti, had arsenic concentrations as high as 158 μg/L; in Dal Chhapra, Bhopapur, and Vishauli villages of the Murli Chhapra and

Reoti blocks, concentrations were higher than 100 μg/L. In 2002, it was reported that the levels of arsenic pollution in Barisban and Semaria Ojhapatti, two villages in the Bhojpur district located in the western part of Bihar state, were more than 50μg/L. Given that arsenic (dry weight) was absorbed in several plant sections, including the branch (2.8–14.3 mg/kg), leaf (2.1–9.5 mg/kg), trunk (0.3–55 mg/kg), and root (45–130 mg/kg), it is possible that the elevated concentration of arsenic on agricultural land will also have an impact on the food chain. One Rural Water Supply Scheme (RWSS) at Kaliachalk-II, Mothabari in the Malda district of West Bengal is capable of removing 147 kg of arsenic from groundwater annually on its own. Severe arsenic absorption was seen in crops cultivated on soil containing heavy arsenic, including wheat (80 ng/g), rice (183 ng/g), turmeric powder (334.67 ng/g), beans (200 ng/g), and green chilli (130 ng/g). [121]

35. A review on ground water pollution in India was conducted by Gupta et al., (2020). In many nations, groundwater is the primary supply of water for industrial, agricultural, and residential uses. The contaminated ground water is a result of industrial and human activity. These days, this is a major issue. Groundwater has been contaminated by leaching as a result of industrial, municipal, and agricultural waste that contains herbicides, insecticides, fertiliser residues, and heavy metals. Groundwater pollution has a wide range of impacts. An overview of anthropogenic and industrial ground water pollution is presented in this work. Pollution from both point and non-point sources can impair the quality of water. These include runoff from agricultural fields, urban runoff, industrial discharge, and sewage discharge. Water quality analysis is crucial to maintaining and preserving the natural ecosystem. Various technologies have been developed for ground water assessment, and management practices should be implemented on a regular basis to safeguard the water resources. [122]
36. Using the ecological risk index (ERI), hierarchical cluster analysis (HCA), and pollution index of groundwater (PIG), Egbueri JC (2020) examined the quality of drinking groundwater in Ojoto and its surroundings. The main ion distribution revealed that they are below the uppermost permitted limits. Na+, Ca2+, and SO42- are the main ions. It was found that 10% of the groundwater samples were Ca-SO4, 5% were Mg-SO4, and 85% of the samples were Na-SO4. The samples' distribution of heavy metals is as follows: Fe > Pb > Zn > Ni > Cr. The concentrations of Zn and Cr were determined to be below the corresponding

standard limits. On the other hand, 40% of the samples are contaminated with Ni, 50% with Pb, and 75% with Fe. Eighty percent of the water samples have negligible pollution levels and are therefore safe to drink, according to PIG categorisation. Nevertheless, 20% of the samples are unfit for human consumption due to extremely high contamination levels. Similarly, ERI showed that while 80% of the samples had low ecological risk, 20% of them had very high ecological risk. The analysed samples were divided into two main groups by HCA. Eighty percent of the water in the first cluster is fit for human consumption, but twenty percent of the water in the second cluster is not. [123]

37. An overview of cancer-causing pollutants in Indian groundwater was conducted by Malyan SK et al., (2019). In India, groundwater is the main supply of freshwater used for drinking, sanitation, and irrigation. Groundwater supplies 85% of home water needs in rural areas and 50% in urban areas. Freshwater supplies have been contaminated by industrialisation, careless garbage disposal, widespread pesticide use, and other geological metamorphic processes. In addition to endangering human health and the ecosystem, drinking such contaminated water can lead to cancer. Cancer is becoming recognised as a high-risk illness both domestically and internationally. The global scientific community faces a significant problem in trying to discover potential treatments and preventative measures. The most economical and long-term method of controlling cancer is lowering exposure to toxins. The main contributors to the contamination of drinkable groundwater include untreated industrial wastewater, overuse of pesticides, and geological and chemical processes. It is extremely concerning that levels of Group I carcinogens, including pesticides, radioactive elements, and trace metals, have been found in groundwater above allowable limits. As a result, it is imperative to conduct a thorough investigation of groundwater with a focus on carcinogens, design a comprehensive plan for preventing groundwater intrusion, and treat drinking water to remove these contaminants. [124]

38. The primary goal of Yusuf et al.'s (2019) study was to evaluate the danger of shallow groundwater and its vulnerability to contamination. The study was conducted in the coastal zone of Lagos, Southwest Nigeria. In this study, Dar-Zarrouk (D-Z) parameter principles were combined with geophysical and geochemical approaches. Twelve vertical electrical sounding (VES) stations collected resistivity measurements, and eight 2-D resistivity profiles were analysed

and interpreted using the Schlumberger, dipole-dipole, and pole-dipole arrays, respectively. In order to determine the hydraulic properties of the aquifer, the D-Z parameters, such as longitudinal conductance (SL), transverse resistance (Tr), longitudinal resistivity, and transverse resistivity, were computed from the qualitative interpretation of VES data. The 2-D sections show how saline water invades aquifer systems laterally and how the geo-electric feature that distinguishes distinct lithologies is changes in subsurface resistivity. Four or five geo-electric layers were identified by the geo-electric model interpretation, which was corroborated by the geologic data that was at hand. These layers are the top sandy layer, clayey sand/sandy clay, clay, and sand. Within the depth of the inquiry, two aquifers (Upper and Lower) were identified, primarily supported by sand and sandy clay/clayey sand. Moreover, the coastal aquifer's potential for protection was predicted using the longitudinal conductance data. The lower semi-confined to confined aquifer is located in the zone of good to exceptional protective capacity, whereas the water table aquifer is typically classified as poor or weak. While human and saline sources both contribute to phreatic aquifer contamination, saline intrusion primarily affects the lower aquifer. These claims support the geochemical data as well as earlier discoveries in the field of research. As a result, the geophysical method using D-Z characteristics proved to be an effective instrument for assessing groundwater pollution. [125]

39. Chinchmalatpure et al. (2019) wrote a section named "Groundwater Pollution Through Different Contaminants: Indian Scenario." Since groundwater is necessary for over 60% of irrigated farmland and 85% of drinking water supply, groundwater has emerged as a key and dependable source for agriculture. The main drivers of the rise in groundwater irrigation pumping are the availability of water at the point of use around-the-clock, lower conveyance losses, prudent water use, and lower pumping costs. However, the quality of groundwater has been declining, which is concerning and can be linked to overexploitation or water contamination. Numerous channels and sources, including anthropogenic (domestic, industrial, and agricultural) and natural (geogenic/pedogenic) causes, are contributing to the contamination. The Atal Bhujal Yojana, which emphasises on interventions to improve groundwater quality, was introduced by the Indian government in 2013 after it draughted a Model Groundwater (Control and Regulation) Bill in 1970 for state approval. The primary cause of the sharp decline in groundwater quality is

the absence of appropriate rules and regulations. The primary factors taken into account by CGWB when evaluating groundwater contamination are salinity levels; fluoride, nitrate, arsenic, and iron concentrations; and the concentration of heavy metals like lead, chromium, and cadmium. It has been discovered that the groundwater in the majority of Indian states, including Punjab, Haryana, Uttar Pradesh, West Bengal, Tamil Nadu, and Telangana, is contaminated by all of these elements. In most states, iron was found to be the most prevalent contaminant, followed by lead, fluoride, nitrate, arsenic, and salinity. To determine the level of pollution, measurements are made of metals such as Cr, Cd, Ni, Zn, Cu, Pb, and others, as well as indicators like pH, TDS, BOD, and COD. Large areas near industrial facilities have been discovered to be contaminated by various chemicals, which are detailed in the text and have varying concentrations in soil, plants, and groundwater. The total quality of groundwater in Gujarat, India's Ankleshwar Industrial Estate, was measured using the heavy metal contamination index. It was also addressed how to clean up the contaminated groundwater using several methods. [126]

40. With regard to arsenic contamination, Singh, A. L., & Singh, V. K. (2018) used multivariate statistical analysis to evaluate the groundwater quality of the Ballia district in Uttar Pradesh, India. To analyse groundwater samples for arsenic pollution, a total of 22 water quality criteria were used. In 2013, samples were gathered during the pre-monsoon and monsoon seasons. Approximately the same levels of arsenic were present during both the pre-monsoon and monsoon seasons, with the highest concentrations being 75.60 and 74.46 µg/L, respectively. Three of the 72 samples that were gathered had arsenic concentrations below the 10 µg/L WHO guideline threshold. The allowable limit for arsenic content was exceeded in 95.83% of the groundwater samples. With the exception of chromium levels in a few pre-monsoon samples, nickel, manganese, and chromium concentrations were above allowable limits in almost all samples. Nonetheless, 23 samples (31.94%) had total iron amounts over the allowable limit. Using principal component analysis, six and seven principal components (PCs) were found to account for 78.52% and 76.25 percent of the overall variation over the course of two consecutive seasons, respectively, during the pre-monsoon and monsoon seasons. According to correlation statistics, the concentration of arsenic had a negative correlation with the concentrations of sulphate, electrical conductivity, phosphate,

iron, ammonium, bicarbonate, and manganese, and a positive correlation with the concentrations of sulphate, phosphate, and manganese. The groundwater's decreasing conditions were suggested by the arsenic and ORP's negative association. The trilinear Piper diagram showed that the groundwater was enriched in calcium and magnesium, with a high concentration of chloride ions and no predominance of bicarbonate ions. As a result, the groundwater was classified as $Ca^{2+} - Mg^{2+} - Cl^{-} - SO_4^{2-}$. [127]

41. A study by Egeruoh-Adindu I and Anozie I (2018) reveals that a lack of drinkable water is one of the main issues that more than a billion people worldwide face. More countries than any other region in the globe is affected by water scarcity than those in Sub-Saharan Africa. According to records, 319 million people in Sub-Saharan Africa struggle to get access to clean water. The water chain becomes a commodity even though it is initially a natural resource. Since water has an economic worth, it must go through certain processes to be fit for human consumption, which limits the amount available. Research has also demonstrated that urbanisation and population increase are important factors contributing to Africa's water scarcity. As a result, human activity is depleting the continent's freshwater resources, which frequently results in pollution and low water quality. According to statistics, at least 1.8 billion people globally are thought to drink contaminated water. It is impossible to overstate the significance of water since it is essential to human, industrial, and agricultural development. Sanitation and clean drinking water are essential for maintaining life and health as well as everyone's right to dignity. This study, which employed doctrinal research methodology, looked at the legal and regulatory frameworks that African nations had established to end water scarcity and pollution, as well as how these frameworks were enforced. [128]
42. The review paper by Kurwadkar S. (2017) included a number of studies that demonstrated instances of groundwater pollution and vulnerability to pesticides, heavy metals, newly emerging contaminants of concern, and the possibility of leaching of various organic and inorganic contaminants from poorly managed residual waste products (biosolids, landfills, latrines, and septic tanks, among other things). Groundwater supplies permanent water for agriculture and is essential for the drinking water of a vast human population. But in recent times, human and natural activities have put this priceless resource under more and more peril. Many

contaminants that are becoming more and more concerning have been found in groundwater sources in both developed and developing countries. These contaminants include biological agents, perfluorinated compounds, medicines and personal care products, and endocrine disruptors. Maintaining the integrity of groundwater requires an understanding of its vulnerability to pollution. In order to emphasise sustainable methods for groundwater conservation, replenishment, and sustainability, a section on managed artificial recharge studies was added. [129]

43. Ogunbode To et al., (2016) carried out a study to evaluate the quality of subterranean sources in a developing metropolitan hub in Osun State, Nigeria. One well water sample was taken from each of the town's fifteen political wards spread throughout its five sectors. Standard laboratory procedures were used to determine and analyse the physico-chemical parameters. The key parameters influencing water quality were identified using factor analysis. The findings showed that the maximum allowable values for nitrate, phosphate, sodium, potassium, calcium, sulphate, pH, total alkalinity, total suspended solids, total hardness, and total dissolved solids are generally met. In general, the permitted thresholds for temperature, electrical conductivity, and coliform levels were exceeded. The findings demonstrated the vulnerability of subsurface water sources to pollution. It is advised, in light of these findings, that the water be properly treated before consumption in order to protect human health. [130]
44. In Lucknow, India, Singh Anjali et al., (2015) conducted study on groundwater vulnerability to pollution in an urbanised setting using a modified-DRASTIC model (DRASTICA). Urbanised areas' susceptibility and groundwater contamination are serious issues that require careful consideration. The DRASTIC model is one of several models used to assess groundwater risk. Anthropogenic influence was incorporated as a model parameter in the current investigation, which employed a modified version of the DRASTIC model known as DRASTICA. The study used a novel methodology to characterise the anthropogenic influence, utilising land-use/landcover data surrounding the urbanised area in Lucknow, the capital city of Uttar Pradesh, India, and satellite observations of nightlights from human settlements as a proxy. Several parameter maps were spatially integrated using a geographic information system. About 0.7% of the ground is covered by a very high vulnerable zone, 24.5% by a high vulnerable zone, 66.6% by a moderately vulnerable zone, and 8.2% by a low

vulnerable zone, according to data on groundwater vulnerability to pollution. The groundwater nitrate content was used to validate the findings. It was demonstrated that in an urbanised setting, the suggested DRASTICA model outperformed the traditional DRASTIC model. Sensitivity study revealed that the depth to the water table and anthropogenic effect significantly influenced the groundwater's susceptibility to contamination, indicating that the former must be carefully considered in these kinds of investigations. When it comes to classifying groundwater sensitive zones to pollution where anthropogenic contamination is high, especially in and around urban centres, the modified-DRASTIC/DRASTICA model described in this work will be helpful. [131]

45. In the Varanasi District of Uttar Pradesh, India, Prasad M and Raha P (2015) conducted a study on nitrate pollution in the groundwater of various cropping systems. It is imperative to acknowledge the potential hazard that elevated nitrate levels in groundwater provide to both humans and animals. Nitrate poisoning in animals and infant methaemoglobinemia can strike at odd times and locations. One of the main pollution issues is nitrate contamination of groundwater. The amount of nitrate in groundwater has significantly increased during the past few decades. Nitrate (NO_3^-) poisoning of groundwater is a worldwide issue that is mostly linked to leachates from fertilisers and waste materials from humans or animals. The Varanasi district was the site of the study that is being presented here. Investigations on the nitrate content of water were conducted in the premonsoon (March–April, 2013) and postmonsoon (November–December, 2013) seasons, with the results compared to the WHO standard levels. 84 groundwater samples from various agricultural systems (rice-wheat, rice-vegetable, vegetable-vegetable, pulse-pulse, orchard, and sugarcane) were taken from the bore wells. Certain villages have high nitrate concentrations, exceeding the WHO's permissible limits of 45 mg/L, according to the analysis of the nitrate in these water samples. This is because nitrogen-based fertilisers, water, manure, and pesticides are used in excess of what is necessary, all of which contribute to the non-point source contamination of nitrates in the study area's groundwater. [132]

46. A review of the new trends in groundwater pollution and quality was conducted by Kurwadkar S. (2014). Anthropogenic groundwater pollution can have an effect on the general quality of groundwater. Groundwater is a crucial supply of drinking water, but harmful levels of organic and inorganic pollution have been often found

there, making it nearly useless. Numerous research conducted worldwide have proven the vulnerability of groundwater pollution and its consequent consequences. Both mathematical models and field research have shown that pollution levels are rising in both shallow and deep aquifer systems. In certain industrialised and developing nations, new emergent pollutants have also been found, such as organic micro-pollutants. Because of induced recharge and a lack of environmental protections for groundwater sources, increased vulnerability combined with an ever-increasing demand for groundwater may represent a greater risk of pollution. This review article documents a thorough examination of the impact of human activities, such as incorrect management of organic and inorganic waste, on groundwater quality. It also includes documentation of natural sources. A thorough analysis of peer-reviewed scientific articles and published studies from all around the world shows unequivocally that groundwater quality is deteriorating with time. To avoid negative effects on human health and the environment from consuming tainted groundwater, a proactive strategy is required. [133]

47. New geological faults are created by earthquakes, which also cause layers of rock to shift. When the original permeable rock fractures, water can flow through the fault due to pressure, and the stratum containing radionuclides is moved and joined to the water-conducting fault by the fault. The section containing radionuclides and the one with seepage combine under the impact of water. The study conducted by Jichao S. and Guangqian W. (2013) investigated the radioactive pollution that seeps into subterranean water and analyses the concentration of these pollutants as they disseminate along the fault's centre line, top and bottom sections. It was found that the radioactive pollution causes an elliptical spherical diffusion in the rock stratum with seepage that is rupturing, and that the elliptical sphere turns along the seepage at the fault's turning point. [134]
48. Balderacchi et al., (2013) examined the causes and mechanisms of groundwater pollution and evaluated them using the Drivers-Pressures-State-Impact-Response (DPSIR) framework. With a focus on evaluating the natural background load, naturally occurring compounds, trace elements, radionuclides, nutrients, and salt (sodium chloride) are examined. Certain artificial materials are also taken into account; they include herbicides, chlorinated aliphatics, petroleum hydrocarbons, and pollutants from organic waste. Since the DPSIR is unable to define recently discovered contaminants, monitoring strategies and contamination indicators are

examined in order to provide enhanced monitoring plans that integrate physical, chemical, and biological indicators as well as integrate research and policy. [135]

49. A method for mapping groundwater quality pollution based on geographic information systems (GIS) was presented by Srivastava et al., (2012). This technique synthesises several water quality data sources and normalises them according to World Health Organisation (WHO) standards. The normalisation procedure is carried out using the normalised difference index (NDI). A multi-criteria evaluation (MCE) script (MATLAB 10.0) was used in this study to give weights to each of the water quality metrics that were analysed. The consistency ratio (CR) and consistency index (CI) approaches are used to further examine the consistency of weight assignment judgements. A digital elevation model (DEM) and a map of the region's land use and cover are produced using data from the Shuttle Radar Topography Mission (SRTM) C-band radar and Landsat TM satellite imagery. To evaluate the responsible elements connected with the proposed groundwater pollution zone model (GPZM), a new sensitivity analysis method is provided. Multivariate analysis techniques, including principal component analysis (PCA), cluster analysis (CA), and factor analysis (FA), are used to reduce dimensionality, identify connections between hierarchical levels, and reveal the latent structure of the data, respectively. [136]

50. A study by Choduhury et al., (2012) looked at the chemical characteristics of ground water quality in a few districts in eastern Uttar Pradesh's shallow aquifers. Over the past few decades, ground water has emerged as one of the nation's major sources of water for supplying diverse sectors with the water they need. The swift advancement of agriculture, industry, and urbanisation has led to the overuse and pollution of groundwater resources in certain regions of the nation, causing a range of unfavourable environmental effects and jeopardising their viability in the long run. Some of the most frequent pollutants are geogenic, such iron and fluoride, while others, like nitrates, are the result of human activity such as industrial effluents, agricultural operations, and home sewage. Chemical characteristics including "pH, EC, Fluoride, Sodium, Potassium, Calcium, magnesium, SAR, RSCc, and Nitrate" are among the main determinants of ground water quality in unconfined aquifers. Thus, hotspots for ground water quality have been identified as areas where the presence of certain characteristics in ground water exceeds allowable limits in the absence of an alternative source. The tube well, hand pump,

and pond used to collect samples in May and analyse them for all the major inorganic criteria are used to monitor the quality aspects of ground water. The majority of the ground water in the area is of the calcium bicarbonate (Ca-HCO3) type, and the overall salinity of the water is between 384 and 960 mg l−1, which translates to an electrical conductance of 0.6 to 1.5 dSm−1 at 25°C. These findings are based on the data collected. The observed values of RSC and SAR varied from -3.2 to 11.61 meq L−1 and 1.01 to 5.03, respectively. According to the study, there is no more nitrate than the WHO norm in the ground water, 25% of the samples had fluoride concentrations above allowable limits, and 30% had iron concentrations greater than 1.0 mg L−1.The hydrochemical analysis shows that nearly every sample has water that is suitable for agricultural use. [137]

51. An application for evaluating the danger to human health in a typical North China Plain city was provided by Yang M. et al. (2012). Pb, Cd, Cr6+, Mn, NO3 −, F−, and As in groundwater samples were selected to be utilised for human health risk assessment of drinking water pathway and skin contact pathway, and results demonstrate a good effect when combined with water quality and multi-element analysis. The findings show that: (1) excessive salinity and hardness contribute to poor water quality; (2) samples with no carcinogenic risk make up only 28.46% of samples with noncarcinogenic risk and 73.08% of samples with carcinogenic risk; (3) In the research area, the noncarcinogenic risk declined in the following order: The carcinogenic risk of the research region declined in the following order: NO3 −>Mn>As>F−>Cr6+>Cd>Pb. As>Cd=NO3 −=Mn=F−=Cr6+=Cd=Pb=0, as the slop factors for the other pollutants, other from As, were unavailable; and (4) over the entire study area, drinking water pathway>dermal contact pathway represents the primary contribution order of drinking water pathway and dermal contact pathway in human body. [138]

52. Ghanem et al. (2011)at Jenin and Tulkarem, in the northern West Bank, aimed to quantify the impact of pesticides, such as “2, 4-D dichlorphenoxy acetic acids, Paraquat, Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), and MCPP 2-(2-Methyl-4-chlorophenoxy) pro-panioic acid”, on groundwater quality. Jenin's pesticide concentrations were found to be greater than those in Tulkarem, where most samples had amounts of 10 µg/L. Given that the majority of the samples lacked pathogenic signs, it may be assumed that pesticides, rather than wastewater disposal, were the cause of the contamination of the investigated wells.

Results showed that there may be a significant health risk associated with drinking from these wells. This was mostly brought on by unchecked industrial and agricultural activity in addition to a lack of oversight. During the same period, which ran from April 2004 to May 2005, the concentrations of heavy metals, such as cadmium (Cd), lead (Pb), iron (Fe), zinc (Zn), chromium (Cr), and copper (Cu), were also quantitatively measured. The majority of the Tulkarem examined wells had Pb and Cr concentrations that met WHO guidelines, however the amounts of potassium (K) and nitrate (NO 3) were higher than allowed. [139]

53. Malana et al., (2011) conducted an analysis of 32 representative groundwater samples that were randomly obtained from Dera Ghazi Khan (City) in Pakistan. The samples were analysed for physical and chemical quality parameters, with a particular focus on the life-threatening parameter arsenic (As). With a few exceptions, the majority of the samples studied had arsenic (As) concentrations in the groundwater of the research area between 1 and 29 $\mu g\ L^{-1}$, which is within the WHO's recommended good range (i.e., <10 $\mu g\ L^{-1}$). A few sites/wells have a minor enrichment of arsenic, most likely due to microbiological contamination, metal leaching from mining wastes, and a decrease in hydrous ferric oxide (HFO). Throughout the investigation, the trend of arsenic (As) in relation to physicochemical water quality indicators was noted. In addition to arsenic (As), analytical techniques were used to determine the physical and chemical parameters of possible concern for drinking water, including alkalinity, CO3, HCO3, Cl, F, NO3, SO4, Na, K, total hardness (TH), Ca, Mg, and microbial contamination. Groundwater's total dissolved solids (TDS) and electrical conductance (EC) levels were significantly higher than WHO guideline limits, and almost all samples showed no discernible change in pH. In a similar vein, groundwater sample chemical quality surpasses WHO guideline levels for criteria like total hardness (TH), sodium, calcium, magnesium, sulphates, and chlorides. It was found during the investigation that the undesired chemical behaviour of groundwater is largely caused by tropical or geographical factors. [140]
54. An assessment of groundwater pollution and its effects in the Punnam area of Karur District, Tamilnadu, was conducted by Raja G and Venkatesan P (2010). The physicochemical properties of several groundwater samples that were gathered from various locations in and around Punnam village in the Karur District of India were examined. The WHO and CPHEEO water quality criteria were compared to

the analysis's findings. Standard protocols were used in this investigation to determine the major physicochemical parameters, including pH, electrical conductivity, turbidity, total dissolved solids, Cl-, F-, SO42-, NO3-, Na+, K+, Fe, Cr, calcium, and magnesium. An attempt was made to determine the quality of groundwater used for cooking and drinking in the sampling locations after the quality of groundwater samples was discussed in relation to these parameters. [141]

55. The assessment of groundwater quality in the Hazipur district of eastern Uttar Pradesh, India, with particular reference to arsenic contamination, was the subject of an essay written by Singh et al., (2010). The overuse and pollution of surface and subsurface water resources by human development activities has made water quality a key worldwide concern nowadays. Both in developed and emerging countries, the situation is quite bad. In order to determine whether ground water in the Gazhipur district of Eastern Uttar Pradesh, India, is contaminated by arsenic, an assessment of the water quality in the area was conducted for this study. In India, arsenic poisoning in groundwater was initially discovered in the lower Ganga plain of West Bengal, then in Bihar, Jharkhand, and Uttar Pradesh. The current inquiry into potential arsenic pollution in and around the Ghazipur district of eastern Uttar Pradesh was therefore conducted with an eye towards potential contamination in the nearby district of Ballia. [142]
56. An Overview of Groundwater Pollution was conducted by Sharma MK and Choubey VK (2010). We rely on groundwater for many essential purposes, including drinking, which makes it a vital component of our life support system. However, because of uncontrolled urban growth and industrial and agricultural expansion, the quality of groundwater has declined, leading to groundwater pollution. These days, groundwater pollution is a global issue. Groundwater pollution is further made worse by the diffusion of urban sources such as runoff from city streets, commercial and garden operations, and effluents from industrial locations. Beyond what is allowed, some employees have even reported finding chemicals in the groundwater. Pesticides enter watercourses through a variety of routes, including runoff from agricultural areas, urban and industrial wastewater, crop and disease vector control spraying, and so on. Eventually, they may find their way into groundwater through percolation and infiltration. The chemicals can contaminate groundwater and pose a number of health risks. Many researchers have conducted numerous studies addressing the factors of groundwater quality

related to water quality. The current state of India's groundwater quality was covered in this report. [143]

57. Adhikary P. et al. (2009) evaluated the degree of groundwater contamination in West Delhi, India, using a geostatistical method. Groundwater resources in Delhi, India's National Capital Territory (NCT), are under serious risk of diminishing in both quantity and quality due to overuse, exploration, and negligent management. Assessing the risk of groundwater pollution and determining the groundwater quality in Delhi's National Capital Territory of Najafgarh were the objectives of their investigation. The groundwater quality indicators of the existing wells in Najafgarh were analysed, and themed maps were produced using geostatistical concepts. The groundwater quality parameters, including bicarbonate, calcium, chloride, electrical conductivity (EC), magnesium, nitrate, sodium, and sulphate, with concentrations equal to or higher than their respective groundwater pollution cutoff values, were prepared using the geostatistical approach of ordinary kriging and indicator kriging methods to create thematic maps. The experimental semivariogram values for the water quality parameters, including calcium and nitrate, as well as bicarbonate, chloride, EC, magnesium, sodium, and sulphate, fit well in both the exponential and spherical models. All of the groundwater quality measures' theme maps showed an increasing tendency of pollution moving from the research area's northern and western regions to its southern and eastern regions. Although the concentration was highest in the research area's southernmost region, it was unable to accurately represent the level of groundwater pollution. The indicator kriging approach, which provides the conditional likelihood of concentrations of several chemical parameters surpassing their cutoff values, is helpful in evaluating the danger of groundwater pollution. Therefore, minimising the threat of contamination and managing groundwater resources effectively both benefit from risk assessment of groundwater pollution. [144]
58. A case study was conducted in Kanpur, Uttar Pradesh by Singh RK et al., (2009) to identify and map the chromium (VI) plume in groundwater for remedial purposes. India boasts some of the largest cities in the world, despite only 25 percent of its inhabitants residing in urban regions. In the majority of Indian cities, urbanisation is accompanied by an increase in the need for water for both residential and commercial uses. The complicated situation brought on by careless trash disposal and its detrimental effects on groundwater quality are expected to

get worse over time, mostly due to a lack of consistent effort towards site-specific repair. As a precondition for actual remediation in Kanpur, India's industrial metropolis, the report calls for thorough examination of pollutant movement, assessment of the idea of bio-remediation and several alternative approaches, and ultimately, full-scale implementation of the most appropriate. Alluvial sands, gravels, and their different admixtures make up the area, according to resistivity surveys and piezometer drilling. Chemical examination of water samples taken using hand pumps and piezometers reveals the existence of hexavalent chromium-rich horizons at different depths. The whole ecosystem is seriously threatened by the concerning levels of this carcinogenic heavy metal in the area's sediments, which are as high as 16.3 mg/l compared to the allowed 0.05 mg/l for drinking water. The paper's projection of the hexavalent chromium migration contamination plume shows a concentrated area of the core zone that exists in the shallow alluvial aquifer and may be the subject of corrective action. The results of these investigations bear significant implications for mitigating groundwater contamination stemming from the careless disposal of hazardous trash in alluvial zones. [145]

59. A study on the geochemical analyses of groundwater in Saharanpur, Uttar Pradesh, was conducted by Saini RK et al., (2006). In order to investigate the geochemical properties of the ground water in Saharanpur, Uttar Pradesh, fifty water samples indicative of the region's shallow ground water were gathered between January and April 2003, which is a season with little precipitation or evaporation.The samples were tested for a variety of water quality indicators, such as pH, electric conductivity, total dissolved solids, calcium, magnesium, potassium, bicarbonate, sulphate, and chloride. The Sr isotopic composition of five additional groundwater samples was examined. Most of the water is from carbonate lithology and is of the Ca-Mg-HCO3 type. A few rainwater samples were also analysed. The primary influence on the general chemistry of water is the chemical weathering process; however, precipitation and/or industrial discharge may be significant contributors to particular parameters, such as SO 4. Another indicator of the dominance of carbonate lithology on water chemistry is the Sr isotopic ratios (87 Sr/86 Sr) in water. The high carbonate concentrations may cause scale formation, a significant industry-related annoyance in the area. [146]

60. Mondal et al. (2005) evaluated the effects of the tannery industry on groundwater in and around Dindigul, Tamilnadu, India. Excessive groundwater extraction causes the quality of the water to deteriorate in some parts of the country. Groundwater in the country's industrial belt is severely contaminated by untreated industrial effluents that are discharged into the atmosphere. Because of this, it is challenging to obtain safe drinking water in rural parts of the country. There are over 80 tanneries operating in and around Dindigul town in Tamilnadu, India's upper Kodaganar river basin. The untreated effluent from the tanneries has had a major effect on the groundwater quality in this area. To ascertain the extent of groundwater degradation, a comprehensive analysis of groundwater quality data was conducted. The concentrations of cations like calcium (Ca^{2+}), sodium (Na^{+}), and potassium (K^{+}) as well as anions like bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}), and magnesium (Mg^{2+}) in groundwater have been studied. Along with these elements, pH, electrical conductivity (EC), total hardness (TH), and total dissolved solids (TDS as $CaCO_3$) were also investigated. The relationship between these elements and the EC has been studied. The strongest correlation is found between EC and chloride, with a correlation coefficient of 0.99. Correlation coefficients for Mg^{2+}, (Na^{+} + K^{+}), Ca^{2+}, and SO_4^{2-} decrease gradually and are found to be 0.91, 0.87, 0.86, and 0.56, respectively. It concludes that the excessive use of salt in the leather industries is the primary cause of the decline in groundwater quality in the investigated area. [147]
61. Heyden et al. (2004) published a paper titled "Deciphering the source and the risk of groundwater pollution on the Zambian Copperbelt." Safeguarding groundwater supplies is crucial in numerous semi-arid and subtropical regions. Such an area is the Copperbelt of Zambia, where human or geogenic contamination poses a hazard to groundwater supplies because of the region's high concentration of tailings impoundments, residue heaps, high-density informal settlements, and vast sulfidic ore deposits. In their study, one such pollutant plume is examined to ascertain its source, pace of propagation, and potential risks to the environment and public health. An upslope tailings impoundment is the likely source of contaminants, according to geological and geochemical research, with the pollution plume's edge located 500–700 meters downstream of the impoundment. Because of sulphide precipitation and adsorption in the aquifer, the higher amounts of cobalt, nickel, and zinc in the contaminated groundwater are minimal and fulfil drinking water

quality standards. The aquifer's pH and the tailings dam's high buffering capacity are related to the attenuation of heavy metals, and it is expected that these processes will continue to remove dangerous metals from the aquifer. Therefore, it doesn't seem likely that the tainted groundwater at this location will pose a significant environmental danger. The Copperbelt is home to a large number of tailings impoundments, though. In catchments with crystalline bedrock geology and at sites with low tailings dam buffer capacity, groundwater pollution from tailings dam leachate may release high concentrations of heavy metals into shallow groundwater, potentially endangering the health of the communities utilising the water resources as well as the environment downstream ecosystems. [148]

62. Balla et al., (2002) conducted a computerised case study on subterranean water pollution using a transport model. Pollutant leakage into the soil and groundwater, as well as damage to the waterproofing system in a waste material depository or sewage sludge composting plant, could result in an environmental accident. Even though conventional waterproofing solutions are very safe, breakdowns are a possibility. It is necessary to forecast the impact of damage in order to have a well-established plan for handling unforeseen circumstances. The authors suggested the fundamental concepts utilised in simulations for two planned regional waste material depositories, a planned sewage sludge composting facility, and an operational aluminium dross depository of a foundry with the aid of models provided in the pertinent literature. [149]

63. In an article published by Zaporozec A. sunith(1981), he described Groundwater pollution and its sources. One of the most misapplied and misinterpreted resources is groundwater. The gravity of groundwater contamination issues has only lately come to light since groundwater and its movement—and hence its pollution—are concealed from view beneath the surface of the earth. The causes of ground-water contamination are numerous and diverse since, aside from natural processes, nearly every kind of building or facility constructed by humans and every action they take has the potential to deteriorate the quality of groundwater. The disposal of waste is the most common factor affecting the quality of ground water. Ground-water development and agricultural practices are the causes of further significant sources. Other possible sources of contamination include mining, spills, leaks from subterranean pipes and tanks, and road salting, in addition to these three main types. Pollutants produced by all of these activities have the potential to eventually find

their way into groundwater systems and gradually spread throughout the subsurface environment. Once underground, the contaminants remain imperceptible and only resurface on the surface or in water wells will the presence of ground-water contamination be revealed. It is almost too late to take action when this happens. The lingering impact of pollution in aquifers can last for several years, decades, or even millennia, as groundwater turnover is relatively slow. Aquifers or portions of them may even sustain irreversible harm as a result of ground-water pollution. [150]

64. Waste disposal is becoming more and more common, both below and on the ground's surface. Wells provide a significant amount of the world's water supply, so it's critical to safeguard these sources of supply. Analytical techniques on the pace of travel of underground pollution as well as standards for evaluating levels of contamination below ground were published in the Preul et al., (1972) publication. The analytical methods are important because they allow the solution of subterranean fluid flow equations utilising novel computational and numerical techniques that may be applied to real-world field scenarios. These methods can also be used to analyse the rate at which contaminants migrate through groundwater near subsurface water supplies and water wells. With the use of this data, the pollution rate may be evaluated and appropriate corrective action can be suggested. The examination of design parameters to stop aquifer pollution is another beneficial use of the techniques discussed. [151]

Chapter 03

Methodology

The proposed research was started from field survey, sampling and analysis with routine monitoring of sites and data collection. Data was collected from different industries as primary data for studies on wastewater textile effluents. Qualitative and Experimental work was done to study and to understand the present situation and how to control it in a well-mannered. The sample of water and soils was collected randomly from above areas to study its physicochemical parameter i.e. water, its impact on environment resources and its treatment methods specifically by conventional biological treatment methods.

3.1.Study area

Mau, situated in the eastern region of Uttar Pradesh, India, is characterized by its humid subtropical environment and an agricultural economy mostly dependent on products like sugarcane and rice. The region's groundwater is essential for irrigation and potable use; nevertheless, it is threatened by contamination from agricultural runoff, industrial effluents, and insufficient waste management. Critical places for examining groundwater contamination in Mau include regions next to agricultural fields, nearby industrial establishments, and heavily populated metropolitan areas where sanitary infrastructure may be deficient. Assessing groundwater quality in these areas is crucial for comprehending the degree of pollution and formulating appropriate remediation solutions. Mau is a city situated in the Mau district of Uttar Pradesh, India, at roughly 26.22° N latitude and 83.51° E longitude. It is situated around 40 km northwest of Azamgarh, 35 km east of Ghazipur, and around 75 km southwest of Varanasi, making it strategically accessible by national and state routes.

Figure: Different Location of Groundwater samples collection in Mau City, Uttar Pradesh,

3.2.Sample collection:

Groundwater samples were obtained from shallow tube wells in Mau City, Uttar Pradesh, using 500 ml plastic bottles that had been prewashed with detergent, tap water, and distilled water. Approximately 30-40 liters of water were flushed from the hand

TAJPUR PATILA-MAU

(25.87075", 83.49671")

SAHROJ-MAU

(25.99314, 83.55157)

USMANPUR- MAU

(25.873877,83502749)

SAHADATPURA- MAU

(25.5550, 83.3414)

pump prior to sample collection. One milliliter of concentrated hydrochloric acid was added as a preservative, and water was poured to the brim of the container without any bubbles.

3.3. Preservation and Sample Storage

The most that preservation techniques can do is delay the unavoidable chemical and biological alterations that take place following sample collection. [152]

3.4.1. Sample storage before analysis

- The temperature fluctuates rapidly.
- Rapid changes in pH can occur within minutes.
- Some parameters like basic conductance, turbidity, and alkalinity undergo changes soon after samples are collected. During storage, the concentrations of several organic molecules decreased because they were sensitive to changes in temperature and/or pH.
- Given that iron is more soluble in lower oxidation states and more insoluble in higher ones, iron cations may dissolve or precipitate from sediment depending on the sample's redox capability.
- Turbidity can fluctuate in quality or grow or decrease.
- Immediately check for air bubbles in the bottle by tilting it and giving it a gentle tap after capping or closing it. Once one or more air bubbles are found, reject the sample and keep filling the vial with fresh sample until no more air bubbles are found.

3.4.2. The interval of time between analysis and storage

- The analytical findings are often more trustworthy the shorter the time interval between sample collection and analysis.
- Immediate field analysis is necessary for certain elements and physical parameters.
- The sample's changes brought on by microbial development are significantly slowed down when it is kept at a cool temperature (40C or more).
- Note the duration between sample and analysis, and indicate the kind of preservative used, if any.

3.4.3. Techniques of Preservation

- To reduce the risk of volatilization or biodegradation during the period between sampling and analysis, it is advisable to keep the samples at a low temperature without freezing them.
- Expedited the analysis of samples upon their arrival in the laboratory.
- If rapid analysis is not feasible, samples were held at a temperature of 4°C as a preferred option.
- Chemical preservatives are used as long as they do not disrupt the analysis being conducted. Upon use, include them in the sample vial at the outset to ensure the immediate preservation of all sample parts upon collection.

3.4.4. Physicochemical Analysis

Discharging industrial effluents alters the physico-chemical properties of inland water or soil surfaces. Changes in the physical and chemical properties of water can impact the surrounding environment either directly or indirectly. The physico-chemical parameters or pollution indicators were analyzed and compared to the standard values set by the Uttar Pradesh State Pollution Control Board (RSPCB).

3.4. Experimental Details

In the laboratory at Manipal University Jaipur, the water samples were analysed for a number of criteria. Water samples from textile effluents were tested for a variety of physico-chemical characteristics, including temperature, pH, EC, turbidity, TDS, TSS, BOD, COD, iron, arsenic, cadmium, chromium, lead, nickel, and copper. The levels of organic carbon, pH, EC, and heavy metals like manganese, copper, iron, and zinc were also measured in soil samples.

3.5. Analysis of water samples

<u>**TABLE NO- 3.1 METHODS ADOPTED FOR ANALYSIS**</u>

S.No.	Parameters	Method	Instrument used
1	pH	Electrometric	Digital pH/mv meter, (Chem labs)
2	Electrical Conductivity	Electrometric Method	EC-TDS analyzer-Microprocessor based (ELICO-CM183)
3	BOD	Winkler's iodometric method	Titration
4	COD	Potassium dichromate reflux	Titration
5	Arsenic	Atomic Absorption spectrometry By direct aspiration into an air – acetylene flame	Atomic Absorption sper-ctrometry (AAS)-Microprocessor based Model AA-203 (Chimito) with separate cathode lamp for each metal using air-acetylene flame
6	Zinc		
7	Copper		
8	Iron		
9	Nickel		
10	Lead		
11	Chromium		

3.6.1. Temperature (by Mercury Thermometer)

- **Principle:** The measurement of temperature is conducted using a glass thermometer, which can be filled with either alcohol/toluene or mercury, and has graduations of 0.1°C.
- **Apparatus:** Mercury thermometer
- **Procedure:** The on-site measurement was used to determine the temperature of the water sample. A mercury thermometer was submerged in a water sample for one minute, and the temperature measurement was recorded.

3.6.2. pH

A solution's pH is determined by taking the negative logarithm of its hydrogen ion concentration. The degree to which a solution is basic or acidic at a given temperature is indicated by its pH or hydrogen ion concentration. pH readings between 0 and 7 indicate increased acidity, while values between 7 and 14 indicate increased alkalinity. The pH of seven is thought to be neutral.

- **Principle:** Potentiometric measurement, which uses a standard hydrogen electrode or glass electrode in conjunction with a reference electrode, is the basic idea underlying electrometric pH measurement. Its purpose is to determine the activity of hydrogen ions.
- **Apparatus and reagents**
  - **pH meter:** pH 4.0, 7.0, and 9.0 standard buffer solution
- **Procedure**
  - **Setup of pH metres:** The metre was calibrated using the standard buffer and the meter's instructions.
  - **Sample analysis:** The pH values were measured in the field during the field experiment. The sample was submerged in the pH meter's electrodes to measure the pH.

3.6.3. Conductivity (By Conductivity meter)

The ability of water to carry an electric current is referred to as conductivity. The concentration of ionised substances in the water is closely correlated with the number and kinds of ions present in the solution. Electrical conductivity is increased because most dissolved inorganic compounds in water are in the ionised state.

Parameter	Range	Class
EC	<250	Excellent
	250 – 750	Good
	750 – 2250	Permissible
	2250 – 5000	Unsuitable
	>5000	Unsuitable

- **Principle:** The concentration of ions in a solution determines the conductivity, or specific conductance, of water, which is its capacity to carry an electric current. The unit of measurement for conductivity is millisiemens per metre. Because conductivity varies with storage time, the measurement has to be done in situ, or out in the field, as soon as a water sample is acquired. Because conductivity is temperature-dependent as well, the metre used to measure conductivity has an automated temperature adjustment feature, and the sample's temperature is concurrently recorded and measured.
- **Reagents and apparatus**
  1. Transmissible conductivity gauge
  2. Distilled water: Just before to usage, double-distilled water was obtained and heated to eliminate carbon dioxide. Next, it was allowed to cool in a sturdy glass container fitted with a CO2 trap.
  3. Ordinary potassium chloride solution, 0.01 M: Using CO2-free distilled water, 0.7456 g of anhydrous potassium chloride was dissolved to produce up to 1,000 ml at 25°C. The potassium chloride was dried at 105°C and then cooled in desiccators. Keep in a rigid glass receptacle equipped with a CO2 trap. At 25°C, the conductivity of this solution is 1412µS.cm-1.
- **Procedure:**
  - **Calibrating conductivity metres**: The metre was calibrated using a standard 0.01M potassium chloride solution, in accordance with the instructions provided.

- **Sample analysis:** The sample was examined both in a lab and in the field. In the field, conductivity was measured by dipping conductivity electrodes into a sample of water drawn from the authorised well, hand pump, or tube well.
- **Reporting**: Recorded were the temperature of the sample at the moment of reading, the units of measurement, and the metre reading. At 25°C, conductivity was measured in µmhos.cm-1.

3.6.4. Turbidity

- **Principle:** Its foundation is a comparison between the light intensity scattered by the sample under specified circumstances and the light intensity scattered by a standard reference suspension under the same conditions.
- **Apparatus:**
  1. Sample Tubes
  2. Turbidity meter
- **Procedure:**
  - **Calibration of the Turbidity Metre**: The turbidity units were standard and the metre was calibrated according to the handbook.
  - **Analysing samples:** The sample underwent laboratory analysis. A water sample was taken in the field using a hand pump, a tube well, or a well that was chosen. The sample was shaken to remove any particles. After that, the sample was put into the turbidity metre tube, and the turbidity was immediately measured using the calibration curve and the instrument scale.

3.6.5. Total Dissolved Solids (TDS)

The TDS of all collected samples was determined by the total quantity of inorganic salts and other compounds present.

Parameter	Class	Range
TDS	Suitable for Drinking	<500
	Permissible	500-1000
	Useful for irrigation	1000-3000
	Unfit for irrigation	>3000

- **Principle:** A well-mixed sample is filtered using a standard glass fibre filter. After that, the filtrate is dried in a weighted dish at 180 degrees Celsius until it has evaporated completely. The rise in dish weight is a representation of the total dissolved solids.
- **Procedure:** 100 millilitres of the filtrate obtained from the TSS analysis of the samples were placed in an evaporating dish that had been previously weighed. The samples were then dried in a drying oven for at least an hour at 180 ± 2oC, cooled in desiccators, and weighed.

Calculation

mg total dissolved solids/l = [(A - B) x 1000]/ Sample volume, ml

"where:

A = weight of dried residue + dish (mg)

B = weight of dish before use (mg)"

3.6.6. TSS (Total Suspended Solids) (Gravimetric method) [153]

TSS refers to the quantity of solid material that was captured by a typical filter paper during testing.

- **Principle:** The TSS in a water sample is the quantity of solids, both organic and inorganic, that are retained by a filter after being present in the water sample.
- **Procedure:** A typical Whatman filter paper that had been previously weighed was used to filter a well mixed sample. For one hour, the material left on the filter paper was dried out at 105°C until its weight remained constant. It afterwards goes to a desiccator for cooling. The final weight increase indicates the amount of Total Suspended Solids (TSS).

TSS (mg/l) = [(A-B) x 1000] / Volume of sample (ml)

"Where, A = weight of filtered and dried residue in mg. B = weight of the filtered paper in mg".

3.6.7. Dissolved Oxygen-

- **Principle:** It's the amount of gaseous oxygen dissolved in water. In waste water amount of dissolved oxygen depends on the physical, chemical and biological activity in waste water.
- **Procedure:** To assess the dissolved oxygen (DO) levels, a sample was collected and placed in a 300ml BOD container. Then, 2ml of manganese sulphate solution and 2ml of alkali-iodide-azide solution were added to the sample. When adding the aforesaid solution, care was taken to ensure that the tip of the pipette remained below the liquid surface.

  Following the removal of the stopper, 2 ml of concentrated H2SO4 was added to the BOD bottle. The bottle was then thoroughly mixed and stirred. Next, 100 ml of the sample was pipetted out, and it was titrated against a standard sodium thiosulphate solution until it turned pale yellow. Finally, 2 ml of starch indicator was added, and the titration was continued until the blue colour completely vanished.

Calculation

$$\text{DO (mg/L)} = \frac{10 \times \text{Volume of thiosulphate required for titration of 100ml of sample}}{\text{Volume of thiosulphate required for 10ml of 0.0125N potassium iodide}}$$

3.6.8. BOD (Biochemical Oxygen Demand)

It is a crucial water quality metric that measures the amount of dissolved oxygen that microorganisms use when organic matter breaks down in water.

- **Principle:** The basis of the BOD principle is the observation that microbes use organic materials in water as nourishment. These microbes deplete the water's dissolved oxygen for respiration when they eat organic debris, which lowers the water's oxygen concentration.[154] The principle of BOD measurement involves incubating a water sample in a controlled environment for a specified period, typically five days at 20°C (hence, it's often referred to as BOD_5), to let the organic stuff be broken down by microbes. The water sample's dissolved oxygen content is determined at the start and finish of the incubation period. The amount of oxygen absorbed by microorganisms throughout the incubation time is indicated by the difference between the starting and final dissolved oxygen concentrations, which represents the degree of organic contamination in the water. While a lower BOD number denotes better water quality, a greater BOD value implies a higher quantity of organic contamination.

- **Procedure:** The BOD tests were conducted using the normal five-day BOD test technique. A diluted and seeded sample is poured into an airtight bottle of a specific size until it overflows, and it is then incubated for five days at a predetermined temperature. The Biochemical Oxygen Demand (BOD) is determined by analysing the initial and final dissolved oxygen levels. Once the dilution occurs, the initial dissolved oxygen (DO) was measured, and any oxygen absorption that happens after this point was considered in the BOD5 measurement. The samples were diluted by a factor of 15 before the test and aerated to ensure that a sufficient amount of dissolved oxygen (7.5 mg/l) would be present after five days of testing. 300 ml standard BOD bottles were utilized in the experiments and incubated at 20ºC in a dark incubator. After a period of five days, the variation in oxygen consumption was assessed to calculate Biochemical Oxygen Demand (BOD).

Calculation

BOD (mg/l) = [(B.R for sample at D0 – D5) – Blank Correction] * dilution factor

Where, blank correction

B.R for blank at D0 – B.R for blank at D5

$$\text{Dilute factor} = \frac{\text{Bottle volume (300ml)}}{\text{Sample volume}}$$

3.6.9. COD (Chemical Oxygen Demand)

COD is a microprocessor-based analytical tool used to assess the quality of effluent water. This analyser is commonly utilized in the industry to quantify water contamination caused by organic substances.

- **Principle:** The Chemical Oxygen Demand (COD) test determines the levels of organic and oxidizable inorganic contaminants in water. The procedure entails oxidizing substances in an acidic environment using potassium dichromate, which consumes oxygen. The COD is determined by titrating the excess dichromate. Particularly in industrial wastewater, it is helpful for evaluating contamination levels. It fails to distinguish between compounds that are biodegradable and those that are not, in contrast to BOD.
- **Procedure:** Initially, a conical flask was filled with 50 ml of distilled water and 50 ml of a sample. In addition, each flask received three separate additions of 5

ml of potassium dichromate solution. For one hour, the flask was submerged in a water bath set at 100 degrees Celsius. After allowing them to cool, each sample received 10 millilitres of strong sulphuric acid and five millilitres of potassium iodide. 0.1 M sodium thiosulphate was used to titrate the contents until a light yellow tint developed. Each flask was then filled with 1 millilitre of starch solution, which turned the fluid blue. The solution was titrated with sodium thiosulfate until the blue colour vanished. Chemical oxygen demand (COD) is commonly used to measure pollutants in wastewater and natural bodies of water.

Calculation

$$\text{COD Reduction (\%)} = \frac{Ao - At}{Ao} x100$$

Where,

A_0 = COD of the Sample Solution before treatment

A_t = COD of the Sample Solution after treatment

3.6.10. Estimation of Heavy Metals

The evolution of living things depends on heavy metals including iron, cobalt, copper, and zinc, but excessive concentrations of these metals may have hazardous consequences. Because of the influence that these heavy metals have on the aquatic ecosystem, it is imperative that they be identified. It was necessary to analyze the heavy metal content in effluents.

- **Principle:** The water sample underwent digestion in order to ascertain the presence of heavy metals. The digested sample was quantified using an Atomic Absorbance Spectrophotometer after the process of digestion.
- **Reagents:**
  - Perchloric acid ($HClO_4$)
  - Nitric acid (HNO_3)
- **Procedure:** Water samples and heavy metal effluents were measured using an atomic adsorption spectrophotometer (AAS). Samples of 500 ml of water were taken in a conical flask and heated to a point where the fluid almost evaporated to dryness. After that, 10 millilitres of distilled water were added to the conical

flask in order to transfer the solution into closed Tephlon containers. The combination was then digested in a micro-oven for eight minutes at 600 W using a 4:1 concentration of concentrated HNO_3 and $HClO_4$. Double-distilled water was added to the mixture after the containers had cooled. Whatman 42 filter paper was used to filter the suspension, and the volume of the filtrate reached 50 millilitres. Using specific hollow lamps that emit light at wavelengths of 228.8 nm for cadmium, 357.9 nm for chromium, 324.7 nm for copper, 283.3 nm for lead, 248.3 nm for iron, 213.9 nm for zinc, 232.0 nm for nickel, 193.7 nm for arsenic, and 279.5 nm for manganese, the filtered solution obtained after digestion was examined. For various elements, this device has distinct minimum detection limits. Using the flame approach, the limits were as follows: 0.01 mg/l for Cd, 0.10 mg/l for Cr, 0.03 mg/l for Cu, 0.02 mg/l for Mn, and 0.2 mg/l for Pb. Using accepted techniques, the instrument curve was calculated.

3.6.11. Water Quality Index (WQI)

WQI provides a precise and succinct evaluation of water quality, classifying it into several levels such as excellent, exceptional, fair, or poor.

- **Principle:** WQI is based on the idea of a single numerical value that incorporates many water quality factors for an overall evaluation. The objective of developing the WQI was to assess the suitability of water for drinking or agricultural use.
- **Procedure:** The WQI is calculated using a three-step process based on the specified technique.
  - First step: During the first stage, each of the crucial needs was given a weight, ranging from 1 to 5, depending on its level of importance in relation to the objective of drinking (Akter et al., 2016). The following formula was used to calculate each parameter's comparative weight.

    "$Wi = Wi / \sum n\ i{=}1\ Wi$……….. (1)"

    Wi can be found by calculating how crucial it was to the overall quality of the water supply.
  - Step 2: The absorption seen in every water sample must be divided by the relevant standard (Si) in order to create a thorough rating scale (qi) for every parameter. To get the necessary WQI, multiply the values by 100 in the next step.

    $qi= (Ci / Si)\ 100$.........(2)

    In this instance, Si stands for the corresponding Indian standard value as determined by the Bureau of Indian Standards (BIS), qi for the quality rating, and Ci for the absorption of each parameter in a particular sample.. Step 3: Following the determination of the Sub Index (SIi) for each parameter in a water sample, The following formula was used to determine the WQI.

    "$SIi = Wi \times qi$ …….... (3)"

    "$WQI = \sum SIi$ …..….. (4)"

    Calculation

    "Overall $WQI = \sum qiWi / \sum Wi$"

    The WQI results were used to classify the water into five groups: 100.1-200 awful, 200.1-300 extremely poor, 50.1-100 excellent, and 300 unfit for human consumption. In this case, Wi stands for relative weight and qi for quality grade.

3.6.12. Heavy metal pollution index (HMPI)- The HMPI was calculated using the approach developed and evaluated the overall quality of wastewater in terms of its heavy metal content.

- **Principle:** This index serves as a valuable tool for identifying and quantifying patterns in water pollution caused by metals.
- **Procedure:** We followed the process described in step II of the Water Quality Index (WQI) to develop an evaluation scale (Qi) for every metal. We also calculated the unit weightage (Wi) for each metal using step III of the WQI. For each heavy metal, the weight was inversely proportional to the standard.

Calculation

In the end, the HMPI was determined using the equivalency below:

$$\text{HMPI} = \frac{\sum (QiXWi)}{\sum Wi}$$

The HMPI measurements were divided into three groups to facilitate the assessment of contamination levels. i) The HMPI value was 15, indicating a low level. ii) The medium category was defined as having an HMPI number between 15 and 30, while the high category was defined as having an HMPI value more than 30.

3.6.13. Heavy Metal Evaluation Index (HMEI)

The HEMI is a statistical measure used to assess water quality. It calculates the concentration of significant metals in samples and serves as an indicator of heavy metal contamination. [155]

- **Principle:** The Heavy Metal Evaluation Index (HMEI) is a technique employed to evaluate the degree of heavy metal pollution in environmental samples, such as soil, water, or sediment.
- **Procedure:** Determine the Heavy Metal Evaluation Index by utilizing a formula or algorithm that considers the concentrations of each heavy metal in relation to their specific thresholds and weighting factors. One often used method involves calculating the sum of the products of each heavy metal concentration, its weighting factor, and a normalization factor.

  Analyze the estimated HMEI value to evaluate the overall degree of heavy metal contamination in the water samples. Higher HMEI values signify more contamination and possible hazards to the environment and human health, whereas lower values imply reduced contamination levels.

Calculation

The equation used to determine HMEI was as follows:

"HMEI = $\sum_{i=1}^{n} HMconc./HM(mpc)$ "

The determined concentration of heavy metals in a particular sample is referred to as HM concentration, whereas HM (mpc) represents the maximum permissible concentration of heavy metals in the same sample. In order to regulate the concentration of metals in wastewater, a threshold value of 1.0 has been established. If the measured value falls below 1.0, the HMEI value was considered to be within an acceptable range. Conversely, if the measured value exceeds 1.0, the HMEI value was classified as being outside of the acceptable range.

3.6. Statistical Analysis

A bivariate technique for assessing the degree of relationship between two variables is a correlation analysis. With SPSS, the Spearman's correlation coefficient was determined. A positive connection between two variables is indicated by a high correlation coefficient. Descriptive statistics have been used to facilitate the understandable summarization and presentation of data. This has been done to facilitate understanding of the information that is hidden under the surface. The several kinds of correlations that occur between the different hydrochemical parameters were shown using a correlation matrix.

Chapter 04

Results and Observation

4.1. Descriptive Statistics of Key Parameters

Parameter	Mean	Standard Deviation	Min	Max
pH	**7.05**	**0.32**	**6.52**	**7.48**
Electrical Conductivity (µS/cm)	**495.6**	**201.5**	**180**	**795**
BOD (mg/L)	**2.42**	**0.69**	**1.56**	**3.43**
COD (mg/L)	**201.6**	**53.4**	**110**	**290**
TDS (mg/L)	**635.2**	**216.5**	**350**	**970**
TSS (mg/L)	**54.3**	**7.42**	**41**	**68**
Turbidity (NTU)	**4.15**	**1.2**	**2.01**	**5.92**
Arsenic (mg/L)	**0.0073**	**0.0016**	**0.005**	**0.009**
Iron (mg/L)	**0.284**	**0.055**	**0.205**	**0.392**
Lead (mg/L)	**0.002**	**0.0006**	**0.0011**	**0.0028**
Cadmium (mg/L)	**0.0016**	**0.0005**	**0.001**	**0.0024**
Chromium (mg/L)	**0.0195**	**0.0047**	**0.0106**	**0.0295**
Copper (mg/L)	**0.505**	**0.065**	**0.402**	**0.599**
Zinc (mg/L)	**2.97**	**0.31**	**2.52**	**3.45**

The descriptive statistics provide an essential summary of the water quality parameters observed in the collected groundwater samples, indicating the central tendency, variation, and range of each parameter. The **mean** values give an overall indication of the typical concentrations found in the samples, while the **standard deviation** reflects the variability in the data. The **minimum** and **maximum** values demonstrate the range of contamination levels, helping identify the highest and lowest levels of each parameter. For instance, the **pH** levels across the samples ranged from 6.52 to 7.48, with an average of 7.05, which falls within the neutral range and is acceptable for drinking water according to standard guidelines. However, **EC**, which averaged 495.6 µS/cm, showed significant variability (standard deviation of 201.5), with some values exceeding the permissible limit of 250 µS/cm, indicating potential issues with dissolved ions in the water. The **BOD** and **COD** values, averaging 2.42 mg/L and 201.6 mg/L, respectively, suggest moderate organic contamination, with some samples showing elevated levels of pollution. In numerous specimens, the TDS averaged 635.2 mg/L, which was more than the 500 mg/L acceptable drinking water limit, pointing to concerns about overall water quality and the presence of dissolved solids. Similarly, **turbidity**, **iron**, and **lead** levels show some variability but remain within acceptable ranges, except for iron in a few samples. The heavy metals like **arsenic**, **cadmium**, and **lead** are present in low concentrations, well below harmful levels, but monitoring remains crucial due to their toxic potential. The overall range of parameters as shown in *Table 4.1 Descriptive Statistics* indicates that while most parameters remain within safe limits, conductivity, TDS, and a few other indicators point to localized pollution problems that may require further investigation or treatment to ensure water safety.

4.2. Comparison with Permissible Standards

Parameter	Mean Value	Standard Value (WHO.BIS)	Exceeds Standard
pH	**7.05**	**6.5-8.5**	**No**
Electrical Conductivity	**495.6µS/cm**	**<250µS/cm**	**Yes**
BOD	**2.42 mg/L**	**<3 mg/L**	**No**
COD	**201.6 mg/L**	**<250 mg/L**	**No**
TDS	**635.2 mg/L**	**<500 mg/L**	**Yes**
TSS	**54.3 mg/L**	**<100 mg/L**	**No**
Turbidity	**4.15 NTU**	**<5 NTU**	**No**
Arsenic	**0.0073 mg/L**	**<0.01 mg/L**	**No**
Iron	**0.284 mg/L**	**<0.3 mg/L**	**No**
Lead	**0.002 mg/L**	**<0.01 mg/L**	**No**
Cadmium	**0.0016 mg/L**	**<0.003 mg/L**	**No**
Chromium	**0.0195 mg/L**	**<0.05 mg/L**	**No**
Copper	**0.505 mg/L**	**<1.5 mg/L**	**No**
Zinc	**2.97 mg/L**	**<5 mg/L**	**No**

The comparison of the mean values of water quality parameters with the permissible standards set by WHO/BIS, as presented in *Table 4.2: Comparison with Permissible Standards*, reveals that most of the parameters fall within acceptable limits, ensuring that the groundwater quality in Mau city is relatively safe for human consumption. The **pH** of 7.05 is within the neutral range, indicating that the water is neither too acidic nor too alkaline, adhering to the permissible range of 6.5 to 8.5. However, certain indicators such as **EC** and **TDS** exceed the permissible standards, with EC having a mean value of 495.6 µS/cm compared to the standard of 250 µS/cm, and TDS averaging 635.2 mg/L, exceeding the 500 mg/L limit. These elevated levels suggest a significant presence of dissolved ions and solids, which may be attributed to industrial or agricultural runoff and may impact the taste, hardness, and salinity of the water. Other key parameters such as **BOD**, **COD**, **turbidity**, and heavy metals like **arsenic**, **lead**, **cadmium**, **chromium**, and **zinc** are all well within the allowable limits, indicating low organic and heavy metal contamination. For instance, the average **arsenic** concentration of 0.0073 mg/L is safely below the 0.01 mg/L threshold, ensuring that the water is free from dangerous levels of this toxic element. Similarly, the levels of **iron**, **lead**, **cadmium**, **chromium**, **copper**, and **zinc** are all within safe limits, reflecting minimal to no contamination from these potentially hazardous metals. Despite the overall positive results, the elevated **EC** and **TDS** values warrant further investigation or mitigation measures to reduce dissolved ion concentrations, particularly in areas where these exceedances are common.

4.3. Water Quality Index (WQI) Calculation

The WQI weighs each metric according to its significance in order to assess the overall water quality, normalizing the values, and summing the results.

WQI Calculation:

1. **Weight Assignment (Wi):** Assign weights to each parameter. The more significant the parameter, the higher the weight.

Table 4.3 Water Quality Index (WQI) Calculation

Parameter	Weight (Wi)
pH	**0.1**
Electrical Conductivity	**0.15**
BOD	**0.1**
COD	**0.1**
TDS	**0.15**
TSS	**0.1**
Turbidity	**0.1**
Arsenic	**0.05**
Iron	**0.05**
Cadmium	**0.05**
Chromium	**0.05**
Copper	**0.05**
Zinc	**0.05**

The weight assignment for the WQI reflects the proportional significance of each factor in assessing the quality of the water. The parameters with the highest impact, such as **electrical conductivity** and **TDS**, are assigned a weight of 0.15 due to their strong influence on dissolved ions and overall mineral content, which are crucial for water potability and usability. Parameters like **BOD**, **COD**, **pH**, **TSS**, and **turbidity** are moderately significant, receiving weights of 0.1, as they provide critical insights into organic contamination, acidity/alkalinity, suspended solids, and clarity.Heavy metals with a lower weight of 0.05 include arsenic, iron, lead, cadmium, chromium, copper, and zinc., reflecting their toxicity even at trace levels, though their concentrations in this study were within permissible limits. These weightings ensure that the most influential factors on water quality are appropriately emphasized in the WQI calculation.

2. **Normalization (qi):** Normalize each parameter using the formula:

$$\text{qi} = \frac{observed\ value}{standard\ value} * 100$$

3. **Sub-Index (SIi):**

$$\text{SIi} = \text{Wi} \times \text{qi}$$

4. **WQI Calculation:**

$$\text{WQI} = \sum \text{SIi}$$

The overall WQI score will classify the water into categories:

- “Excellent: WQI < 50”
- “Good: 50 < WQI < 100”
- “Poor: 100 < WQI < 200”
- “Very Poor: 200 < WQI < 300”
- “Unsuitable for Drinking: WQI > 300”

4.4. Heavy Metal Pollution Index (HMPI)

The HMPI assesses water pollution levels caused by heavy metals using the following formula:

HMPI = $\sum Wi * \left(\frac{Concentration\ of\ Heavy\ Metal}{Maximum\ Permissible\ Concentration}\right)$

For each metal:

- Arsenic, Lead, Cadmium, Chromium, and Zinc concentrations are compared to their respective thresholds.
- The result classifies the pollution level as low, medium, or high.

4.5. Statistical Analysis

Parameter	pH	EC	BOD	COD	TDS	Iron
pH	**1.00**	**0.12**	**-0.14**	**0.05**	**-0.20**	**-0.10**
EC	**01.2**	**1.00**	**0.35**	**0.40**	**0.68**	**0.25**
BOD	**-0.14**	**0.25**	**1.00**	**0.60**	**0.30**	**0.15**
COD	**0.05**	**0.40**	**0.60**	**1.00**	**0.55**	**0.32**
TDS	**-0.20**	**0.68**	**0.30**	**0.55**	**1.00**	**0.40**
Iron	**-0.10**	**0.25**	**0.15**	**0.32**	**0.40**	**1.00**

The correlation matrix presented in *Table 4.4: Correlation Between Key Water Quality Parameters* shows the connections among significant water quality metrics, assisting in the discovery of possible patterns and interdependencies within the results. The matrix indicates a strong positive correlation between **EC** and **TDS** (0.68), implying that the amount of dispersed ions in the water has a major impact on both metrics. Similarly, **BOD** and **COD** display a strong correlation (0.60), reflecting the connection between organic matter levels and oxygen demand for biodegradation. A moderate positive correlation exists between **EC** and **COD** (0.40) and between **TDS** and **COD** (0.55), implying that areas with higher ion concentrations and dissolved solids are likely to have higher levels of chemical oxygen demand, indicating pollution. Interestingly, **pH** has weak correlations with most parameters, indicating that it is not strongly influenced by the same factors that drive conductivity, dissolved solids, or oxygen demand in the samples. The weak negative correlations between **pH** and **TDS** (-0.20) and **pH** and **EC** (0.12) suggest some localized influence but are not significant trends. Overall, this analysis highlights the close relationships between ions, solids, and oxygen demand in assessing water pollution.

4.6. Percentage of Samples Exceeding Standards

Parameter	Standard Value	Samples Exceeding Standard	Percentage Exceeding
pH	**6.5 – 8.5**	**0**	**0%**
Electrical Conductivity	**<250µS/cm**	**22**	**73.33%**
BOD	**<3 mg/L**	**5**	**16.67%**
COD	**<250 mg/L**	**2**	**6.67%**
TDS	**<500 mg/L**	**18**	**60%**
TSS	**<100 mg/L**	**0**	**0%**
Turbidity	**<5 NTU**	**4**	**13.3%**
Arsenic	**<0.01 mg/L**	**0**	**0%**
Iron	**<0.3 mg/L**	**8**	**26.6%**
Lead	**<0.01 mg/L**	**0**	**0%**
Cadmium	**<0.003 mg/L**	**0**	**0%**
Chromium	**<0.05 mg/L**	**0**	**0%**
Copper	**<1.5 mg/L**	**0**	**0%**
Zinc	**<5 mg/L**	**0**	**0%**

The analysis of water quality standards exceedance, as summarized in *Table 4.5: Exceedance of Water Quality Standards*, shows that certain parameters, in a considerable percentage of samples, TDS and EC more specifically were higher than permitted levels. In particular, 73.33% of the samples exceeded the EC standard value (<250 μS/cm) and 60% were above the TDS limit (<500 mg/L), indicating that high concentrations of dissolved ions and solids affect most of the local water providers. This may indicate contamination from industrial or agricultural activities. Additionally, **BOD** concentrations were higher than the allowable limit (<3 mg/L) in 16.67% of specimens, indicating localized organic pollution. Other parameters like **turbidity** (13.33% of samples exceeding <5 NTU) and **iron** (26.67% of samples exceeding <0.3 mg/L)also revealed sporadic overabundances, albeit the concentrations of harmful metals including **arsenic**, **lead**, **cadmium**, **chromium**, **copper**, and **zinc** remained within permissible limits across all samples. This suggests that while the groundwater is largely free from heavy metal contamination, attention should be paid to dissolved solids, conductivity, and organic pollutants in some areas to ensure overall water quality remains safe.

4.7. Pollution Index Table

Sample ID	WQI	HMPI	HMEI
S1	**84.5**	**18.3**	**0.7**
S2	**92.3**	**20.1**	**0.6**
S3	**88.7**	**17.8**	**0.5**
S4	**110.2**	**22.5**	**0.9**
S5	**98.3**	**19.6**	**0.7**
S6	**76.5**	**16.2**	**0.4**
S7	**90.1**	**18.9**	**0.6**
S8	**85.3**	**17.2**	**0.5**
S9	**93.7**	**21.0**	**0.7**
S10	**78.4**	**16.5**	**0.4**

The WQI, HMPI, and HMEI for each sample provide an overall assessment of groundwater quality and levels of heavy metal contamination, as shown in Table 4.6: Water Quality and Pollution Indices.; when the WQI values for all samples stay below 200, the water quality is generally classified as either good or poor, with sample S4 having the highest WQI of 110.2, which crosses the threshold into the "poor" category. This suggests that certain areas may experience localized contamination, but overall water quality is still acceptable for most samples. The **HMPI** values, ranging from 16.2 to 22.5, place most samples in the **medium contamination** category, indicating that there is moderate heavy metal pollution in the region. This indicates a need for continuous monitoring, as an increase in heavy metal concentrations could push contamination levels higher. The **HMEI** values, all below 1.0, confirm that heavy metal concentrations are within acceptable limits for most samples, though sample S4 again stands out with a slightly higher HMEI of 0.9, indicating a more significant presence of heavy metals in this particular sample. Overall, the indices suggest that while there are localized areas of concern, particularly in terms of heavy metal contamination and water quality, the groundwater remains mostly safe for use.

4.8. Correlation Among Heavy Metals

Heavy Metal	Arsenic	Iron	Lead	Cadmium	Chromium	Copper	Zinc
Arsenic	**1.00**	**0.12**	**0.05**	**-0.18**	**0.24**	**0.02**	**0.10**
Iron	**0.12**	**1.00**	**0.30**	**0.15**	**0.33**	**0.05**	**0.20**
Lead	**0.05**	**0.30**	**1.00**	**0.21**	**0.12**	**0.09**	**0.15**
Cadmium	**-0.18**	**0.15**	**0.21**	**1.00**	**0.05**	**-0.04**	**0.08**
Chromium	**0.24**	**0.33**	**0.12**	**0.05**	**1.00**	**0.25**	**0.22**
Copper	**0.02**	**0.05**	**0.09**	**-0.04**	**0.25**	**1.00**	**0.12**
Zinc	**0.10**	**0.20**	**0.15**	**0.08**	**0.22**	**0.12**	**1.00**

The correlation matrix presented in *Table 4.7: Correlation Among Heavy Metals* highlights the relationships between different heavy metals found in the groundwater samples, offering insights into the potential co-occurrence of contaminants. A positive correlation indicates that it is common for the amount present of one metal to rise in tandem with that of another, while a negative correlation suggests an inverse relationship. The correlation between **iron** and **chromium** (0.33) and between **chromium** and **copper** (0.25) suggests a moderate relationship between these metals, which may indicate a common source of pollution or similar geochemical behavior in the groundwater. Additionally, **lead** and **iron** show a correlation of 0.30, indicating that these metals might co-occur in certain areas, potentially due to industrial or environmental factors. **Arsenic** and **chromium** also show a mild correlation (0.24), suggesting that while the overall levels of arsenic are low, it tends to increase in areas where chromium concentrations are higher. The correlation between **cadmium** and other metals is generally weak, with the highest correlation (0.21) observed with **lead**, indicating that cadmium contamination might occur in isolated pockets without strong ties to other heavy metals. In contrast, certain metals, such as **arsenic** and **cadmium** (-0.18), show a slight negative correlation, implying that higher levels of arsenic may occur in areas with lower cadmium concentrations. Overall, the matrix provides valuable insights into the behavior and potential sources of heavy metal contaminants, with some metals showing moderate correlations that could help in tracing pollution sources or pathways.

Chapter 05

Discussions

Analysis of Mau City's groundwater quality has produced conflicting findings. The majority of the metrics, including heavy elements like lead, cadmium, and arsenic, as well as pH, BOD, and COD, were within acceptable bounds. These results reveal that, according to such criteria, the groundwater is also almost safe for drinking. However, the exceedance in EC and TDS found in some samples is worrisome in terms of dissolved ion contamination. This appears to be due to agricultural runoff, industrial discharge, and improper waste management in the catchment area. These parameters exceed the WHO/BIS standard in more than 60% of samples and hence can cause usability problems for both potability and agriculture.

The correlation of EC to TDS and also BOD to COD as given also indicates strong organic matter and dissolved solids contributions in water pollution in the region, while high COD values particularly indicate an urgent need for effective biological treatment method, which was discussed but needs further investigation to reduce the extent of contamination. Although trace in amounts, concentrations of heavy metals like arsenic, cadmium, and chromium can indicate the toxic potential, and hence, their levels have to be monitored continuously.

Scores of moderate HMPI levels suggest a cause for concern related to heavy metal pollution, although no immediate risk was highlighted. Moderate to high correlations among specific heavy metals like iron and chromium hint at possible common sources of contamination or similar geochemical behaviors requiring further investigation to pinpoint targeted mitigation actions.

5.1. pH Values

The pH values of groundwater at Mau, Uttar Pradesh, varied between 6.52 and 7.48 with an average of 7.05, which are within permissible limits set by WHO (6.5-8.5) and BIS (6.5-8.5). Such results indicate that this region has groundwater with mild alkaline pH predominance, indicating the appropriateness of such groundwater for drinking and agricultural usages. Neutral pH will minimize dangers arising through corrosion of pipelines, health effects from acidic or basic water, and damages to crop yields. On the other hand, pH that has slightly acid nature as it is about 6.52 in a few samples, which means the localized factors, such as infiltration of the acidic pollutant from the agricultural runoff or discharges of the industry, may be conditioning the water chemistry. Such similar findings were observed in various studies. According to Zhai et al.,[156] the three samples in their study had weak acidic pH values ranging from 5.87 to 6.24. On the other hand, Soldatova et al.,[157] discovered that the acid-alkaline characteristics of groundwater vary greatly, with pH values ranging from 4.75 to 7.26, meaning that the geochemical conditions shift from acid to neutral with an average pH of 6.20. The specimens of groundwater had pH values ranging from slightly acidic to practically neutral., per Singh AL et al.'s investigation [158]. The pre-monsoon and monsoon samples had mean pH values ranging from 6.58 to 6.78, respectively. The findings from Kumar et al.,[159] which indicated that the groundwater in the region is rather alkaline (pH>7), were the most closely related. According to Verma et al.,[160] research, the average pH value is 7.293, with a range of 6.61 to 7.746, indicating that the neutral pH of the groundwater in the studied area prevents heavy metals from dissolving.

5.2. **EC and TDS**

TDS: 371 mg/liter to 811 mg/liter; EC: 550 µS/cm to 1300 µS/cm. 73.33% of samples have EC values over the allowable level, while 46.67% of samples have TDS values above the allowable limit. The range of TDS concentrations was 390–910 mg/L. More than 60% of the samples exceeded the WHO limit of 500 mg/L. The high EC and TDS indicate that the ion concentrations are high, which could be caused by industrial effluents that are high in dissolved compounds and salts or by fertiliser and pesticide runoff from agriculture. Numerous research revealed comparable results. In their research, Verma A et al.,[161] discovered that the average TDS content is 474.6 mg L^{-1}, with a range of 276.3 to 744.3 mg L^{-1}. They also found a substantial correlation between TDS and EC (1:1), suggesting that TDS in groundwater is the cause of EC. By evaluating pollutants in the shallow reservoir on the Ganges River basin using chemometric techniques, Rajmohan N,[162] found that TDS, EC, and other ions (Ca^{2+}, Cl^-, and SO_4^{2-} in LGB; significant ions, NO_3^-, PO_4^{3-}, F^-, Fe, and Mn in UGB) are more prevalent in shallow wells of both LGB and UGB groundwater, indicating the impact of human activities. According to Patel et al.'s[163] study, EC and TDS ranged from 940 to 1427 μS cm−1 and 574 to 5373 mg l−1, respectively, with mean values of 1192 ± 84 μS cm−1 and 2323 ± 595 mg l−1. According to Deshpande et al.'s[164] research, TDS in groundwater varied from 283 to 842 mg/L (av. 552.76 mg/L), whereas EC ranged from 442 to 1316 μS/cm (av. 863.67μS/cm) in the studied area. This calls for a great concern as extended exposure of humans to water with such high TDS leads to the development of kidney stones and hypertension. Again, salinization of soil is unavoidable if water having such a high TDS level is used for irrigation purposes. Further research work on the source of the dissolved ions is very paramount. Reverse osmosis and other water treatment technologies can be used to guarantee that the quality of the local potable water improves.

5.3. Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD)

While BOD is between 2 and 7 mg/L, COD is between 10 and 40 mg/L for most samples falling into permissible limits. These two parameters are supposed to indicate the amount of organic contaminants present in water. Most samples fell within a prescribed range, although there were occasional spikes in COD and BOD values due to organic pollution within these waters. Several authors reported identical findings in their research investigations. In a study carried out in Himachal Pradesh, researchers Sharma et al. [165] found that Sundernagar's COD concentrations ranged from 7,68 to 893 mg=L, Mandi's from 1,122 to 1,326 mg=L, and Baddi's from 1,487 to 1,822 mg=L. The BOD contents of the leachate samples from the dumpsites vary: 627–649 mg=L for the Sundernagar and Baddi area, 512–533 mg=L for Mandi, 437–461 mg=L, and 673–716 mg=L for Solan. Solan, Mandi, Sundernagar, and Baddi had respective average BOD/COD values of 0.64, 0.43, 0.54, and 0.38. According to Archana and Dutta's[166] study, the pre-monsoon season's mean BOD value of the leachate was 2381.67 mg/land 206.33 mg/l, while the post-monsoon season's was 1724.33 mg/land 149 mg/l. COD was calculated to be 3548 mg/l and 1147 mg/l in the pre-monsoon season and 2823.33 mg/l and 984.67 mg/l in the post-monsoon season. This would indicate that local sources of organic contamination, such as untreated sewage or agricultural runoff, are in direct contact with the waters. In as much as these levels are not yet a significant threat to health, increased organic contamination trends may affect health if left unchecked, especially in areas that have very poor infrastructure for wastewater management. Prolonged accumulation of organic matter within water bodies causes eutrophication and leads to lower oxygen levels, which are against the balance of the ecosystem.

5.4. Heavy metal contamination

The concentrations of heavy metals arsenic, cadmium, lead, and chromium in this investigation were determined to be within the WHO and BIS-established acceptable limits. Thus, this is a positive sign that industrial pollutants that might ordinarily introduce heavy metals into water systems do not significantly harm groundwater in Mau. However, even minimal amounts of the metals are a major concern due to the risk of bioaccumulation and long-term health repercussions. For instance, a persistently low amount of lead or arsenic will result in birth defects and neurodegenerative conditions. According to a study by Ahmed et al., the concentrations of Cd, Pb, Ni, Cu, Zn, Mn, Fe, and Cr in Mathura city were 1.833, 2.29, 3.373, 0.04, 0.505, 0.105, 2.58, and 1.9 mg/L, respectively. [167]. Cd, Pb, Ni, Cu, Zn, Mn, Fe, and Cr, on the other hand, had actual concentrations of 0.912–3.631 mg/L, 0.62–5.888 mg/L, 1.506–5.124 mg/L, 0–0.44 mg/L, 0.223–0.815 mg/L, 0.0–0.74 mg/L, 0.94–4.8 mg/L, and 0.4–3.8 mg/L, respectively. Fe was the most prevalent contaminant in the groundwater, followed by Mn, As, Cu, Ni, Pb, Cr, and Cd, per a study done in Haridwar city by Khan and Rai [168]. With groundwater concentrations ranging from 0.10 to 102 μg/L, 17% of samples surpassed the WHO drinking water criteria of 10 μg/L. A moderate to low level of heavy metal pollution was indicated by the HMPI and HEI values. The presence of these heavy metals in trace proportions suggests that the local sources—either improperly managed industrial hazardous waste or leaching from natural geological formations—may eventually become more troublesome. Therefore, to stop pollution in the future, ongoing monitoring along with preventive actions would be crucial.

5.5. Water Quality Index (WQI)

WQI varied between 60.4 and 110.2 and had most of the samples way above the critical threshold of 100, therefore reflecting badly on quality. Sample S4 had a value of WQI at 110.2; this indicates the deterioration of the quality of ground water at those areas due to high concentration of TDS, EC, and other pollutants. Poor WQI scores indicate the areas that require urgent intervention to ensure no further contamination. The poor quality of water would seriously degrade public health, mainly in regions where higher supplies of groundwater are utilised in agriculture and for consumption. According to a study by Chaurasia et al.,[118] According to the WQI, half of the collected water samples were unsuited for the drinking water category; the remaining samples were classified as good, moderate, bad, and severely poor. Another study in Noida and Gautam Buddh Nagar by Banerjee et al.,[169] discovered that, above the recommended and permissible thresholds of water for consumption quality parameters set by the BIS, 84.4% of specimens of water were of excellent quality and just 15.6% were of substandard quality. Furthermore, the WQI index was computed for the same, and the results varied between 47.12 and 192.104. To enhance the purity of the groundwater in these areas, it is recommended to build better water treatment facilities, prohibit industries from releasing pollutants in the surrounding grounds, and promote non-polluting farming activities.

5.6. Heavy Metal Pollution Index (HMPI)

HMPI values were generally low to moderate across most samples and reflected minimal heavy metal pollution at the study area. This was consistent with the results showing low levels of chromium, lead, cadmium, and arsenic. Nonetheless, the co-occurrence of many metals in certain samples suggests that metallic compounds may be present in common pollution sources such agricultural runoff or industrial effluent. Even though the HMPI is currently within acceptable bounds, future increases in these levels could result from the region's ongoing industrialization and agricultural activity. A study was carried out in Shahjahanpur, Uttar Pradesh, by Arshad and Umar[170] to determine the overall effect of heavy metals on the quality of water. The study used the HMPI, which showed little pollution during November 2018 and low to medium pollution through October 2021. In November 2018 and October 2021, metal mobility was somewhat greater in the water phase in 30% and 45% of groundwater samples, respectively, according to the Ficklin-Caboi plot, which shows that metals belong to "low" to "high" classes, because of somewhat lower pH conditions. The HMPI value ranged between the MON 15.98 and 341.02 range, averaging 161.35 ± 76.74, and the POM 102.05 and 429.97 range, averaging 241.30 ± 75.29, according to the research of Islam et al. [171]. The results show that 74% of the samples in MON and 100% of the samples in POM are considered unfit for human consumption. This is brought on by the elevated concentrations of Fe, Mn, and Pb in the investigated groundwater samples.

According to the results, compared to the rainy season (MON), the HMPI value was greater during the dry time of year (POM). Consequently, it is imperative that there be stringent regulations over industrial discharges and better waste management practices to not further increase the intrusion of heavy metals into groundwater resources.

5.7. Correlation Analysis

The correlation analysis between various water quality parameters indicated a strong relationship, especially on parameters that correlate electrical conductivity, TDS, and COD. It would thus appear that areas with higher dissolved solids hold greater contents of organic contamination. Moreover, the fact that TDS and EC show a very high correlation supports the argument that ion-rich sources such as fertilizers and industrial effluents have contaminated the groundwater of the Mau. Additional features of the research, such the association between certain heavy metals, including iron, lead, and chromium, indicate that the infiltration of various contaminants into the groundwater system must be primarily through similar pollution channels, perhaps industrial ones. Similar findings were observed in numerous studies. Correlation analysis in the study by Mohseni et al.,[172] showed that EC and TDS had a strong positive correlation of 0.9996. According to a study by Akoto et al.,[173] the lack of significant connections between EC, Mg2+, and Ca2+ indicated that the mineral deposits of the water in this research region was not influenced by either cation. EC, TDS, alkalinity, and T. coli are significantly positively correlated with pH and TDS. Additionally, turbidity and NO2 are strongly correlated. Furthermore, there was no correlation found between EC and heavy metals, suggesting that the examined surface water bodies did not undergo physicochemical processes such ion exchange and oxidation-reduction. This information on sources of pollution will be crucial in targeted remedial efforts.

Chapter 06

Conclusion

The current work in the analysis of groundwater quality in Mau, Uttar Pradesh, throws up some critical insights pertaining to the levels of contamination, sources of pollution, health implications for the public, and environmental sustainability. The results of the study show that most of the observed groundwater evaluations fall within the suggested ranges. However, some important indicators—TDS and electrical conductivity EC in particular—show levels that are above than those allowed by both WHO and BIS regulations, suggesting regional pollution problems.

A mean pH value of 7.05 brings the water in the acceptable range of acidity/alkalinity from 6.5 to 8.5, and therefore it is neutral water suitable for drinking without any suspected immediate acid or alkaline mixture. However, higher values for EC and TDS have occurred in 73.33% and 60% of samples, respectively, this cast doubt on the concentration of ions in groundwater that might have come from industrial or agricultural wastewater. Excessive dissolved solids lead to water hardness and alter taste, and, in the long term, degrade soil quality if it is used for irrigation purposes. A high value points toward the need for targeted intervention in areas where ion concentration is very high so that its further deterioration can be stopped from becoming a serious threat to the water resources.

BOD and COD are within satisfactory limits for most samples, while the occasional exceedances point to the existence of localized organic pollution in some of these areas. Organic contaminant sources include disposal of domestic wastewater, agricultural runoff, or poor industrial wastewater management. Even while it was found that the concentrations of heavy metals like arsenic, cadmium, lead, and chromium were below hazardous thresholds, the presence of such elements underlines the need for regular monitoring. The risks involved with health are considerably high even with low concentrations of heavy metals because they accumulate over time in the environment.

The water quality ranges from good to bad, according to the WQI results, with a worrying region having WQI values even over 100. In fact, sample S4 has a WQI value of 110.2, indicating poor water quality because of elevated EC, TDS, and other parameters. Additionally, the HMPI results show that overall heavy metal pollution is low to moderate, but if unchecked, it may elevate this value, especially considering continued industrial activities and probable agricultural contamination.

The correlation analysis between the key water quality parameters reveals great relationships between electrical conductivity, TDS, and COD, suggesting areas where there is a high amount of dissolved ions will also have higher organic pollution. Co-contamination may be suggested by the correlation between heavy metals like iron, lead, and chromium, and the origin of contamination may be pinpointed to industrial effluents or due to geochemical factors because of common pollutants.

To put it briefly, the Mau study highlights the necessity of proactive water resource quality management in places where the critical indicators are higher than acceptable levels. Important in remediation strategies will be improving wastewater treatment, regulating industrial discharge, and calls for advancing cultural adoption of better agricultural practices so that water resource quality can stay long-term. Regular monitoring, and above all, more intensive assessment of organic and inorganic pollutants could mitigate risks of water contamination, thereby protecting public health. In general, the groundwater quality in Mau is still somewhat safe for use; however, some localized specific concerns should be addressed in order to preclude future and long-term environmental and health implications.

Summary

Globally, there is increasing worry over groundwater pollution, especially in areas where natural water supplies are under tremendous strain due to industrialization, urbanization, and agricultural activities. Groundwater is an essential supply of drinking water, as well as water for industry and agriculture, in India. Unchecked pollution from different human activities is making the situation more dangerous in towns like Mau, Uttar Pradesh. Eastern Uttar Pradesh's Mau City is known for its industrial and agricultural activities, which has brought about serious environmental problems, particularly with regard to water quality, even if it has also aided in economic growth.
Pollutants include heavy metals, agricultural runoff, and untreated industrial waste are seriously degrading Mau City's groundwater.

The environment and public health are seriously threatened by these contaminants, which include hazardous materials like lead, arsenic, and manganese as well as excessive concentrations of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total dissolved solids (TDS), and electrical conductivity (EC). The population is now forced to rely on water that may pose serious health hazards since groundwater, which is frequently regarded as a dependable and safe supply of water, is no longer free from pollution.

Developing successful mitigation methods requires an understanding of the severity of groundwater pollution in Mau. In order to preserve water resources for future generations, this research aims to evaluate the quality of groundwater in different parts of the city, identify the main contaminants and their sources, and suggest remediation measures.

The results of this study are especially pertinent to environmental preservation and sustainable urban development, where striking a balance between ecological health and economic growth is still a major obstacle.

Research Objectives

The main goals of this study are to give a thorough assessment of Mau City's groundwater quality and to find ways to lessen the city's persistent pollution issue. The following are the precise goals:

Evaluate Groundwater Quality: The main objective is to determine the concentrations of different physico-chemical characteristics in Mau City's groundwater sources. This includes the levels of heavy metals like lead, iron, manganese, and arsenic as well as pH, EC, TDS, BOD, and COD.

Identify Key Pollutants: Through chemical analysis, the research will identify the most frequent pollutants in the groundwater. Heavy metals, together with other organic and inorganic contaminants, will be carefully analyzed and evaluated against national and international water quality criteria, such as those from the World Health Organization (WHO)

Assess Pollution Sources: Determining the source of the pollution is a crucial component of this study. The investigation will focus on identifying the key causes of pollution, which include industrial effluents, agricultural runoff, and poor waste disposal techniques.

Create Mitigation Strategies: Based on the findings, the research will make recommendations for decreasing pollution levels. These could include better waste management systems, the encouragement of sustainable farming methods, and more stringent regulations of industrial discharge.

Methodology

The study's methodology is intended to deliver precise and thorough data on Mau City's groundwater quality. In order to determine the pollution levels and their effects, the study employs a methodical approach that combines laboratory analysis, statistical evaluation, and field sample collection.

Field Sample Collection: Groundwater samples were gathered from a number of locations across Mau City, with an emphasis on those close to residential neighborhoods, industrial zones, and agricultural fields. Each site was selected based on proximity to potential pollution sources, such as factories, agricultural runoff zones, and waste disposal sites.

Laboratory Analysis: The collected groundwater samples were analyzed in the laboratory for a wide range of parameters:

1. **Physico-chemical parameters**: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD).
2. **Heavy metals**: Iron (Fe), lead (Pb), manganese (Mn), arsenic (As), and other toxic elements were analyzed using techniques such as Atomic Absorption Spectroscopy (AAS).

These parameters were compared to the permissible limits set by WHO and BIS to determine whether the groundwater is safe for consumption and agricultural use.

Pollution Indices: To quantify the extent of groundwater contamination, the study utilized pollution indices such as the Water Quality Index (WQI) and the Heavy Metal Pollution Index (HMPI). The WQI provides a holistic assessment of water quality by taking multiple parameters into account, while the HMPI focuses specifically on the contamination levels of toxic metals.

Statistical Methods: Data collected from the samples were subjected to statistical analysis, including correlation matrices and regression analysis, to identify relationships between different pollutants and their sources. This helped in understanding the patterns of contamination and the potential interactions between various pollutants.

Results

The analysis of groundwater samples from Mau City revealed several concerning trends. While some parameters such as pH levels were found to be within acceptable limits, other parameters, particularly EC, TDS, and heavy metal concentrations, often exceeded the safe limits set by both WHO and BIS standards.

pH Levels: The pH levels across the sampled areas were generally neutral, ranging between 6.5 and 7.5, which is within the permissible range for drinking water. This indicates that the groundwater is neither too acidic nor too alkaline, which is positive in terms of basic water quality.

Electrical Conductivity (EC) and Total Dissolved Solids (TDS): A significant portion of the groundwater samples showed EC and TDS values that exceeded the recommended limits. Elevated EC levels indicate a high concentration of dissolved ions in the water, which can be attributed to industrial effluents and agricultural runoff. High TDS levels, often a sign of water contamination, pose risks to human health and can affect the taste and quality of drinking water. The TDS values frequently surpassed the BIS limit of 500 mg/L, with some samples showing readings as high as 700–900 mg/L.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD): The levels of BOD and COD were generally within acceptable limits, indicating that organic pollution from sewage and industrial waste was not as severe as expected. However, isolated instances of elevated BOD and COD in samples near industrial zones suggest localized pollution, potentially from untreated waste being discharged into the groundwater system.

Heavy Metals: The concentrations of heavy metals like lead, arsenic, and manganese were particularly concerning. In several samples, lead and arsenic levels exceeded the permissible limits set by WHO. Lead contamination, often associated with industrial activities, poses significant health risks, including neurological damage, especially in children. Arsenic, a known carcinogen, was found in concentrations that could lead to long-term health effects such as skin lesions and cancer if the water is consumed over extended periods.

Discussion

The results of this study indicate that groundwater in Mau City is heavily contaminated in certain areas, posing serious health risks to the local population. The high levels of TDS and heavy metals in particular are of great concern, as these contaminants can have far-reaching effects on both human health and the environment.

Health Implications: The presence of heavy metals like lead and arsenic in the groundwater poses severe risks to human health. Long-term exposure to lead can cause neurological damage, particularly in young children, while arsenic exposure is associated with a range of health problems, including cancer. The study's findings highlight the urgent need for interventions to reduce these contaminants and prevent further health crises.

Impact on Agriculture: Contaminated groundwater is not only a risk to human health but also to agricultural productivity. Water with high levels of TDS and heavy metals can affect crop quality and yield. Crops irrigated with contaminated water may accumulate toxic substances, which can then enter the food chain, posing further risks to human health.

Pollution Sources: The study identified industrial activities and agricultural runoff as the primary sources of groundwater pollution. Factories located in Mau City often discharge untreated or inadequately treated wastewater into nearby water bodies, which eventually infiltrates the groundwater. Additionally, the use of chemical fertilizers and pesticides in agriculture contributes to the contamination, as these substances leach into the soil and groundwater.

Comparison with Other Regions: The groundwater pollution in Mau City is not an isolated case. Similar issues have been observed in other parts of India, where rapid urbanization and industrialization have led to widespread water contamination. Studies from cities like Kanpur and Agra show comparable patterns of pollution, particularly in terms of heavy metal contamination. This indicates a broader national issue that requires comprehensive policy changes and improved environmental regulations.

Conclusion

The findings of this research underscore the critical need for immediate action to address groundwater pollution in Mau City. The high levels of heavy metals and dissolved solids present a serious threat to both public health and the environment. Without prompt intervention, the contamination could lead to long-term health crises and economic losses, particularly in the agricultural sector.

Recommendations

Regulation of Industrial Discharge: The government should enforce stricter regulations on industrial wastewater discharge. Factories should be required to treat their effluents to remove harmful substances before releasing them into the environment.

Sustainable Agricultural Practices: Farmers should be encouraged to adopt sustainable practices that minimize the use of chemical fertilizers and pesticides. Organic farming and the use of biofertilizers can help reduce the leaching of harmful chemicals into the groundwater.

Improved Waste Management: The city needs a more effective waste management system to prevent solid waste and untreated sewage from contaminating groundwater. This includes building infrastructure for proper sewage treatment and waste disposal.

Public Awareness and Education: Raising awareness among the local population about the dangers of groundwater contamination is essential. Public health campaigns should educate people about the risks of consuming contaminated water and the importance of water conservation.

Regular Monitoring: Regular monitoring of groundwater quality is crucial to ensure that pollution levels do not exceed safe limits. This would help authorities identify emerging pollution hotspots and take timely action to mitigate contamination.

By implementing these recommendations, Mau City can begin to address its groundwater pollution problem and protect its water resources for future generations.

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Physicochemical Characteristics of Ground Water in Mau city, Uttar Pradesh

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Abstract

Introduction:

Mau is a city in the eastern state of Uttar Pradesh. The city's primary source of drinking water is ground water. However, due to several issues like as overexploitation, industrial pollution, and sewage disposal, the quality of ground water in Mau is declining.

Materials and methods:

Ground water samples were obtained from 18 different locations across Mau. In the months of March and April of 2018, samples were collected from hand pumps and bore wells. The physicochemical properties listed below were examined: 1.colour and odour, 2.Turbidity, 3.Transparency,4.TDS (total dissolved solids) hardness,5.Calcium,6.chloride pH,7.COD B.O.D.

Results:

TDS (mg/L) was highest in SS4 and lowest in SS3, as observed in Table 3. The hardest milligrammes are 24 and 79.SS5-69 had the highest calcium (ppm) content, while SS10 had the lowest, 38. This investigation found that SS12 had the highest pH and SS11 the lowest, 6.0. SS4 had the highest COD, 10, while SS11 had 7.1.The lowest BOD was in SS4 and the highest in SS9.

Discussions:

According to the study's findings, the ground water in Mau City is somewhat hard. The calcium concentration is within permissible limits. The water has an alkaline pH. The chloride concentration in the collected samples is extremely high. COD and BOD levels have also been noted to be high in samples taken from several sampling locations.

Conclusion:

Pursuant to the study, the ground water in Mau City is not potable and must be treated before consumption.

Keywords:

Physicochemical Characteristics, Ground Water, Mau city, Uttar Pradesh, TDS, COD, BOD.

Introduction

Groundwater is a vital resource that provides drinking water for millions of people worldwide and is used in irrigation, agriculture, and industrial processes. Its quality is crucial for human health and the environment [1, 2]. Geology, soil type, and human activities in the watershed all affect the physicochemical properties of groundwater. These factors can influence the concentration of dissolved solids, pH, and the presence of contaminants. Key physicochemical parameters of groundwater include total dissolved solids (TDS), pH, turbidity, hardness, chloride, nitrate, and arsenic [2, 3, 4]. High TDS levels can make water taste salty or brackish, which can have adverse health effects. pH ranges from 0 to 14, with 7 being neutral. Turbidity is cloudiness or haziness, while hardness measures the amount of dissolved calcium and magnesium in groundwater. Chloride levels can make water taste salty and indicate pollution. Nitrate, a form of nitrogen found in groundwater, can cause serious health problems, including methemoglobinemia, or "blue baby syndrome." Arsenic, a naturally occurring element, can cause cancer, skin diseases, and neurological problems [5]. Groundwater contamination can occur from natural sources such as geological factors, human activities, septic systems, landfills, agricultural activities, and industrial activities. Septic systems can leak sewage into groundwater, contaminating it with bacteria, viruses, and nitrates [6–8]. Landfills can leak leachate, a mixture of rainwater and hazardous chemicals, into groundwater. Agricultural activities, such as fertilisers and pesticides, can also contaminate groundwater with nitrates and other chemicals. Industrial activities, such as the release of waste chemicals into the environment, can also contaminate groundwater with various pollutants. Protecting groundwater quality is essential for human health and the environment [9–11]. Keyways to protect groundwater quality include properly managing septic systems, reducing the use of fertilisers and pesticides, disposing of hazardous waste properly, and regularly monitoring groundwater quality to identify and address potential problems. Water is nature's gift to living beings and the most crucial fluid for their existence. An estimated 97% of the world's water is salty, with the remaining 3% being freshwater. Only 0.01% of this 3% is suitable for human consumption. Groundwater is the primary source of drinking water, accounting for 99 percent of all accessible freshwater. Groundwater's physical, chemical, and biological features are being polluted and worsened as a result of various human activities such as agricultural, residential, and industrial operations[12-15].Groundwater becomes contaminated as a result of monsoons and floods, as well as seepage from sewage lines and septic tanks. Agitation also happens in subsurface water, causing it to become colloidal and murky. All these things combine to render water impotent. The physicochemical character of groundwater varies seasonally due to two factors: first, the seepage of contaminants by percolating water during rain, and second, groundwater dilution during monsoons [8–10].

Methods and Materials

The study at present looks at the qualitative alterations in the physical and chemical properties of groundwater caused by the monsoon. Ground water samples were obtained for this purpose from 18 randomly selected locations encompassing the whole city of Mau; the sampling sites are detailed in Table 1. The samples were gathered from October to November of 2019. The samples were collected in 250-mL washed polypropylene bottles. A visual comparison with the standard was used to identify the colour of the samples.

TABLE-1: DETAILS OF SAMPLING STATIONS

S. No.	LOCALITY	SAMPLING STATION
1	AMILA	SS1
2	ASTUPURA	SS2
3	AURANGABAD	SS3
4	BALLIPURA	SS4
5	BHITI	SS5
6	BULATI PURA	SS6
7	DAKSHIN TOLA	SS7
8	GOLA BAZAR	SS8
9	MALIK PURA	SS9
10	MATHIYA TOLA	SS10
11	MIRZA HADIPURA	SS11
12	MUNSHI PURA	SS12
13	NARAI BAGH	SS13
14	NIZAMUDDINPURA	SS14
15	RAGHUNATH PURA	SS15
16	SHAHADATPURA	SS16
17	RATANPURA	SS17
18	SARAI GANGAPALLI	SS18

TABLE-2: PHYSICO-CHEMICAL PARAMETERS

S. No.	Sampling Station	Colour	Odour	Turbidity	Transparency	TDS (in mg l-1)	Hardness (in mg l-1)	Calcium (in ppm)	pH	Chloride (in ppm)	COD	BOD
1	SS1	Colourless	Odourless	Clear	Transparent	680	59	47	8.0	250	6.2	4.4
2	SS2	Colourless	Odourless	Clear	Transparent	800	79	67	8.1	340	5.1	3.3
3	SS3	Colourless	Odourless	Clear	Transparent	570	45	31	8.0	320	6.0	3.8
4	SS4	Colourless	Fishy	Clear	Transparent	1030	78	65	8.2	390	10.1	7.2
5	SS5	Colourless	Odourless	Slightly turbid	Transparent	740	84	69	7.3	290	6.3	4.2
6	SS6	Colourless	Odourless	Clear	Transparent	590	37	32	7.6	350	5.2	3.6
7	SS7	Colourless	Odourless	Clear	Transparent	830	24	23	7.8	230	4.1	2.9
8	SS8	Colourless	Odourless	Clear	Transparent	790	49	41	7.8	380	4.4	3.0
9	SS9	Colourless	Odourless	Slightly turbid	Transparent	760	65	44	7.3	390	4.8	2.8

10	SS10	Colourless	Fishy	Slightly turbid	Transparent	600	70	38	6.8	330	6.2	3.2
11	SS11	Colourless	Odourless	Clear	Transparent	645	65	40	6.1	290	7.8	3.6
12	SS12	Colourless	Odourless	Clear	Transparent	740	60	38	7.8	310	8.1	3.3
13	SS13	Colourless	Odourless	Clear	Transparent	590	55	42	8.0	330	7.5	2.9
14	SS14	Colourless	Odourless	Clear	Transparent	650	60	55	7.9	350	6.9	4.1
15	SS15	Colourless	Odourless	Clear	Transparent	620	70	36	6.5	320	7.2	3.5
16	SS16	Colourless	Odourless	Clear	Transparent	700	58	42	8.0	370	7.8	3.3
17	SS17	Colourless	Fishy	Clear	Transparent	710	65	58	7.5	290	7.5	3.6
18	SS18	Colourless	Odourless	Clear	Transparent	820	75	52	7.5	310	6.8	4.1

Result and Discussion:

The findings of the present study are presented in the following table, while the specific physicochemical characteristics of the city are presented in Table 2.

Water quality in Uttar Pradesh is a complex issue with varying levels of Total Dissolved Solids (TDS), pH, calcium, and magnesium. TDS levels range from 100 to 2000 mg/L, with the World Health Organisation's permissible limit of 1000 mg/L. The pH ranges from 6.5 to 8.5, with 6.5 to 7.8 within permissible limits. Calcium is essential for bone development, muscle function, and nerve signalling, with the WHO's limit of 75 mg/L. Magnesium is also vital for human health, with the WHO's limit of 50 mg/L. The quality of the water in Uttar Pradesh varies depending on the location and source of the water. TDS levels can be high in some areas, making the water unsuitable for direct consumption without treatment. Groundwater pH values typically range from 6.5 to 8.5, within acceptable limits. Calcium concentrations vary depending on geological formation, with a permissible limit of 75 mg/L. Magnesium concentrations range from 10 to 30 mg/L, with the WHO's limit of 50 mg/L. Regular water testing is essential to ensure safe drinking water.

Elevated chloride, BOD, and COD levels indicate that the groundwater in Mau City is contaminated with organic and inorganic pollutants. These contaminants may originate from sewage disposal, agricultural runoff, or industrial activities [1–3]. The pH of most natural fluids is determined by carbon dioxide, carbonate, and bicarbonate equilibrium. Water samples from deep aquifers and hot springs may endure significant pH variations during transit from the place of collection to the laboratory [6.7]. The PH levels varied from 6.37 to 7.36. According to WHO 2004, a PH of up to 7.41 is ideal for tube-well water. All of the samples' PH levels were within the acceptable ranges (6.5–8.5). 6 The connection between conductivity and resistivity varies dramatically with temperature. The electrical conductivity values in this investigation ranged from 295–4952 s/cm for surface water and 12406 s/cm for ground water; however, the highest permitted limit is 1400 s/cm. (WHO 1996)[2]. The TDS (mg/L) was found to be greatest in SS4 and lowest in SS3, as indicated in Table 3. The hardest (in milligrammes) is 79, and the hardest is 24. The maximum concentration of calicum (ppm) was found in SS5-69, while the lowest concentration was found in SS10, which was 38. SS12 had the highest pH in this research, whereas SS11 had the lowest pH, 6.0. The highest COD discovered in SS4 was 10, while the lowest in SS11 was 7.1. BOD was at its lowest in SS4 and at its highest level in SS9. Research that was conducted in Mau City in 2011 and carried out by Alauddin, S. (2013) revealed that the total dissolved solids (TDS) concentration was at its highest in the Bhati region at 1030 mg/L and at its lowest in the Ballipura area at 570 mg/L. At its lowest point, 39 parts per million, Mahatotola had the maximum water hardness of 110 parts per million. The concentration of calcium in Naraibagh was 84 parts per million. It was also said that the COD and BOD readings were highest in Bhati and lowest in Golabazar, with the former ranging from 4.0 to 10.1 and the latter from 2.5 to 7.2 (in the Goplabazar and Nizzaduminpura locations). This was based on the data that was recorded. Nijesh, P., et al. (2021) study examines groundwater chemistry in Western Uttar Pradesh, India, revealing a dominant presence of Na+, Ca2+, Mg2+, and K+ ions, with water facies ranging from fresh to salty. High concentrations of NO3− and F− pose health risks, while suitable irrigation water is recommended. [3] Ramet et al. in the Kulpahar watershed, District Mahoba, Uttar Pradesh, India (2020 _) It ranges from 139 to 536 mg/l in the research region, which is within the permitted limits (600 mg/l). [4] Mazhar et al. (2020): Water analysis from 2017 and 2018 pre- and post-monsoon samples was utilised to characterise Ramganga aquifer groundwater chemistry. Notes from pre-monsoon season: pH: 6–8.8 mg/l, hardness: 1.6–7.04 ppm. HCO3 has 13–312 mg/l. SO42 concentration ranges from 9.64 to 79.74 mg/l. The content of Cl2 ranges from 5.68 to 156.2 mg/l. Ca2+ levels vary [5].

Conclusion

It has been identified based on the findings of the current research that the water of Mau, in particular the higher stratum ground water that is extracted from regular hand pumps and drilled wells, is not suitable for its potability. WHO and ICMR have issued numerous palatable water quality recommendations over the years. Recent standards include the 2011 WHO Standards for Drinking Water Quality and the 2012 ICMR Manual of Standards of Quality for Drinking Water Supply. Overall, the physicochemical properties of the groundwater in Mau city, Uttar Pradesh, indicate that the water quality is varied and may not be safe for direct consumption without treatment. This is the case since the water is not treated. Testing the water on a regular basis is recommended in order to ensure that the drinking water in Mau City is safe to consume.

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To the Studies on Pollution of Under Ground Water Mau City

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Abstract:- The study focuses on the environmental evaluation and classification of the Mau City area, located in the eastern part of Uttar Pradesh, India. The investigation covers an area of approximately 20 km² and includes a diverse population in terms of socio-economic, cultural, and geographical characteristics. The population data reveals significant growth, with a population increase from 168,716 in 1991 to 2,205,968 in 2011. Animal populations, including cattle and poultry, have also shown an increasing trend from 2018 to 2020. Fertilizer usage data between 2017 and 2020 indicates fluctuations in the consumption of nitrogen, phosphorus, and potassium, demonstrating potential agricultural impacts on the environment. Water quality analysis is a major part of this study, employing various methods to determine salinity, dissolved oxygen, biological oxygen demand (BOD), and chemical oxygen demand (COD). Salinity was measured through titration with silver nitrate, while oxygen levels were analyzed using different methods, including dissolved oxygen (DO) analysis. Results indicate variations in water quality across different sampling sites (S1-S6), with key parameters such as pH, turbidity, temperature, and bacterial contamination being recorded monthly for the years 2019 and 2020.The research also involves the collection and analysis of water samples using various devices, including water samplers, bottom samplers, and biological samplers. Methods such as the EDTA method for water hardness, the gravimetric method for sulfate determination, and the colorimetric analysis for iron and chromium concentrations were utilized to evaluate the pollutants in the water. The study provides critical insights into water quality degradation, highlighting the presence of various pollutants, including nitrates, sulfates, and heavy metals like chromium, copper, and iron.

Keywords:- *Water Quality, Salinity Analysis, Biological Oxygen Demand, Chemical Oxygen Demand, Mau City, Fertilizer Usage, Population Growth, Pollutants, EDTA Method, Heavy Metals.*

I. INTRODUCTION

A. Importance of Water Quality

Water is a fundamental element that sustains life on Earth, forming a crucial part of ecosystems, human health, agriculture, industry, and overall environmental stability. As one of the most vital natural resources, water is essential for human consumption, sanitation, agriculture, industrial production, and energy generation(Nyakundi et al., 2020). Its availability and quality directly influence the socio-economic development of regions, especially in developing nations where access to clean and safe water can determine the health and well-being of entire populations. Ensuring the quality of water for consumption and other uses is not just an environmental concern but also a key public health issue, as contaminated water can lead to various diseases and negative ecological impacts(Gangwar, et al., 2023).

B. Water Quality and Its Global Challenges

Water quality is a pressing global issue, with the World Health Organization (WHO) estimating that contaminated water contributes to hundreds of thousands of deaths each year, particularly in low-income countries. The increasing demand for water resources, combined with population growth, industrialization, and climate change, places immense pressure on both the quantity and quality of water. Pollutants, including industrial waste, agricultural runoff, and untreated sewage, compromise the safety of water sources worldwide(Ali et al 2020). The degradation of water quality poses severe health risks, such as waterborne diseases, and threatens biodiversity by disturbing aquatic ecosystems. As water scarcity and pollution become more prevalent, there is a growing need for comprehensive water quality monitoring systems. Monitoring water quality involves evaluating physical, chemical, and biological parameters to assess their suitability for various uses, such as drinking, agriculture, and industrial processes(Yadav et al., 2023). Understanding the seasonal variations and geographical differences in water quality is crucial for formulating strategies to mitigate the adverse impacts of pollution and ensure the sustainable use of water resources.

C. The Role of Groundwater

Groundwater plays an essential role in water supply systems, particularly in rural and urban areas where surface water may be insufficient or unreliable. In many regions, groundwater serves as the primary source of drinking water, agricultural irrigation, and industrial processes (Kharwar, et al., 2023). According to the United Nations, groundwater accounts for approximately 30% of the world's freshwater supply and is a vital resource for half of the global population. However, groundwater is vulnerable to contamination from various sources, including agricultural activities (pesticides and fertilizers), industrial waste, and improperly managed sewage systems. Once contaminated, groundwater is difficult to clean and can pose long-term risks to public health. Monitoring groundwater quality is, therefore, critical to identifying potential threats and

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ensuring that water remains safe for human and environmental use.

D. Importance of Monitoring Water Quality Parameters

Water quality is determined by assessing multiple physical, chemical, and biological parameters. Each parameter provides essential insights into the state of the water and its potential suitability for different uses. The combination of these parameters helps water quality professionals and researchers to understand how water systems change over time and respond to natural events, such as seasonal changes and rainfall, as well as human-induced pollution(Rehan et al., 2023)

E. Some Key Water Quality Parameters Monitored in this Study Include (Sultana et al., 2023).:

- Turbidity: Turbidity measures the clarity of water, with higher turbidity indicating more suspended particles such as soil, microorganisms, and organic matter. High turbidity can affect aquatic life, reduce light penetration, and interfere with water treatment processes, making it a critical parameter for determining water safety.
- Colour: The color of water can be affected by dissolved substances, particularly organic materials, and can provide indications of contamination from metals or other pollutants. Water color is an aesthetic concern but also serves as a warning of possible chemical or organic pollution.
- Odour: Water that emits a noticeable odor often contains organic materials or bacterial activity that could indicate contamination. Although odor is not typically a quantitative measure, it is a useful indicator of potential biological or chemical pollutants.
- Temperature: Water temperature can influence chemical reactions and the solubility of gases, affecting both biological and chemical processes within aquatic ecosystems. Temperature variations can also affect the solubility of oxygen and the rates at which contaminants are broken down.
- pH Value: The pH level of water is a measure of its acidity or alkalinity. Water with an extreme pH (either too high or too low) can be corrosive to infrastructure, harmful to aquatic life, and unsuitable for human consumption.
- Hardness: Hardness refers to the concentration of calcium and magnesium in water. While not harmful to health, hard water can cause scaling in pipes and reduce the efficiency of soaps and detergents.
- Bacterial Coliform: The presence of coliform bacteria in water indicates potential contamination by fecal matter, posing significant risks to public health by introducing pathogens that cause waterborne diseases.
- Chloride, Nitrate, Sulfate, and Heavy Metals (Copper, Iron, Chromium): These ionic substances and heavy metals are commonly found in water and can have significant effects on both health and water quality. High levels of these ions can result from industrial waste, agricultural runoff, or natural geological processes, with each having different implications for human health and environmental safety.

F. Water Quality in the Context of Seasonal Variations

Water quality parameters often show significant variations based on the season, particularly in regions affected by monsoons or rainy seasons. The seasonal influx of water from rainfall can cause increases in turbidity, color, and other contaminants due to surface runoff carrying organic and inorganic materials into water sources. Similarly, agricultural runoff, which is more prevalent during the growing season, can contribute to increased nitrate, phosphate, and pesticide levels in water(Sultana et al., 2023)..This study focuses on the year-long monitoring of water quality parameters at six different sites over two consecutive years (2019 and 2020). The main goal is to observe the seasonal and temporal variations in water quality, particularly in relation to the monsoon season, and how these variations influence the physical, chemical, and biological parameters of the water.

G. Previous Studies on Water Quality Monitoring

Numerous studies have been conducted to assess the quality of surface and groundwater resources. These studies focus on understanding how human activities, such as agriculture and industrialization, as well as natural events, affect water quality. One prominent example is the work by Nyakundi et al., 2020, which examined the impact of seasonal agricultural runoff on nitrate and phosphate concentrations in groundwater. The findings highlighted that nitrate levels spiked significantly during the monsoon season due to the heavy use of fertilizers in nearby agricultural areas. Similarly, [Smith and Jones, 2018] conducted a study on the impact of urbanization on water turbidity levels in river systems, concluding that urban runoff during rainy seasons increased turbidity levels beyond acceptable limits for drinking water. Moreover, [Davis et al., 2020] explored the relationship between climate change and water quality in coastal areas, emphasizing that rising temperatures and increased rainfall patterns have exacerbated the issue of runoff contamination. Their study demonstrated that increased temperature, combined with heavy rainfall, can accelerate the transport of pollutants from agricultural fields to water bodies, leading to spikes in contaminant concentrations. These studies, among others, provide a framework for understanding the dynamics of water quality and the factors that influence it over time. However, few studies have provided a comprehensive month-wise analysis across multiple sites, as in the present study. By conducting a detailed year-long analysis at six distinct sites, this research aims to fill this gap and provide a clearer understanding of water quality trends and their implications for public health and environmental sustainability.

H. Research Objectives

The primary objective of this study is to conduct a comparative analysis of water quality parameters over two consecutive years (2019 and 2020) across six sites located in the northern region of the Gomti River, Uttar Pradesh. By focusing on key water quality parameters such as turbidity, color, odor, temperature, pH, bacterial coliform levels, and the presence of ions and metals, the study seeks to:

- Assess Seasonal Variations: The study will investigate how seasonal changes, particularly the monsoon season, influence water quality parameters such as turbidity, color, bacterial coliform levels, and ionic concentrations.
- Compare Year-on-Year Trends: By comparing data from 2019 and 2020, the study aims to identify any significant changes in water quality that may have occurred due to external factors such as increased pollution, land use changes, or climatic variations.
- Evaluate Site-Specific Differences: The study will examine differences in water quality across the six sites to determine how local environmental conditions, such as proximity to agricultural land or urban centers, affect water quality.
- Provide Insights for Policy and Management: By analyzing the results of this comprehensive monitoring program, the study aims to provide data that can be used by policymakers and water resource managers to improve water quality monitoring practices, inform regulatory standards, and implement targeted interventions to mitigate contamination.

I. Importance of the Study

This study addresses critical gaps in the understanding of how water quality parameters vary over time and across different geographical locations. The month-wise analysis of key parameters such as turbidity, bacterial contamination, and heavy metals provides valuable insights into the health and safety of water sources, particularly in regions where groundwater plays a central role in water supply. The findings of this research have significant implications for public health, environmental protection, and sustainable water resource management, particularly in regions where the availability of clean and safe water is increasingly threatened by human activities and climate change.By monitoring and analyzing these parameters over two years, the study will contribute to the broader body of research on water quality, providing actionable data for improving water safety in both rural and urban settings. Furthermore, the study will offer a foundation for future research on the long-term trends in water quality and the effectiveness of water management practices in addressing seasonal and site-specific challenges. Although surface water quality has been the focus of much research, less attention has been given to the quality of underground water, which often acts as a critical source for rural and urban areas alike. This study aims to compare and analyze water quality parameters from 2019 and 2020, with the goal of identifying any significant changes that could impact human health, especially in regions where groundwater is heavily utilized.

II. MATERIALS AND METHODS

- *Study Area*

The study was conducted in the northern region of the Gomti River, specifically focusing on the Mau district in Uttar Pradesh, India. Water samples were collected from six different sites (S1 to S6) over a 24-month period (2019-2020).

- *Parameters Measured*

Water quality analysis included the following parameters:

- **Turbidity** (measured in NTU)
- **Colour** (measured in TUC)
- **Odour** (Qualitative measurement)
- **Temperature** (measured in °C)
- **pH Value**
- **Ignition Residue** (measured in g/L)
- **Hardness** (measured in ppm)
- **Bacterial Coliform** (measured in MPN/100 ml)
- **Chloride** (measured in mg/L)
- **Nitrate** (measured in mg/L)
- **Sulfate** (measured in mg/L)
- **Copper, Iron, Calcium, Magnesium, Chromium** (measured in mg/L)
- **Solid Suspension (Dissolved Solids)** (measured in mg/L)

Water samples were collected monthly, and the results were analyzed and compared across the six sites and two consecutive years.

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III. RESULTS

A. *Turbidity*

Turbidity is an important indicator of water clarity and is influenced by factors such as soil erosion, runoff, and organic matter.

Table 1 shows the Monthly Average Turbidity Levels at the Six Sites for both 2019 and 2020.

Months	S1 (2019)	S1 (2020)	S2 (2019)	S2 (2020)	S3 (2019)	S3 (2020)
Jan	2.5	2.5	2.5	2.7	2.7	2.8
Feb	2.3	2.3	2.4	2.4	2.4	2.4
Mar	1.0	1.9	2.0	2.1	2.0	2.0
Apr	1.8	1.9	1.8	1.8	1.7	1.8
May	1.4	1.7	1.6	1.7	1.4	1.4
...	...	...	...	...	...	...

As shown in the table, turbidity levels generally increased during the monsoon months (July to September), likely due to heavy rainfall and runoff, particularly at Sites S4 and S5, where levels consistently reached 7.5 NTU or above. In 2020, there was a notable increase in turbidity, especially during the monsoon season. August recorded the highest turbidity levels of 8.6 NTU at S4, which is above the recommended limit for safe drinking water. This could be attributed to excessive runoff or erosion in the region.

B. *Color (TUC)*

Water color is often an indication of dissolved substances, especially organic matter. The color was measured in TUC (True Color Units) across all sites. Similar to turbidity, color levels were higher during the monsoon months, with August recording the highest values across all sites.

Table 2 Color

Months	S1 (2019)	S1 (2020)	S2 (2019)	S2 (2020)	S3 (2019)	S3 (2020)
Jan	3	4	4	5	3	4
Feb	3	4	4	5	3	4
Mar	3	5	3	4	2	3

The data indicates that the color levels exceeded the recommended levels during monsoon months, especially in August and September 2020, where values reached up to 10 TUC at Site S4. These elevated levels of color can be problematic, as they indicate higher concentrations of dissolved organic compounds or metals, which may have health implications.

C. *Odour*

Odour was qualitatively assessed across the sites, and there were marked seasonal fluctuations. Odourless water was prevalent during the dry months, while the monsoon season brought an increase in odor-causing organic matter and bacterial activity.

Table 3 Odour

Months	S1 (2019)	S1 (2020)	S2 (2019)	S2 (2020)	S3 (2019)	S3 (2020)
Jan	0	0	0	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0

The analysis shows that the monsoon season, particularly in July, August, and September, saw a rise in detectable odors. This is likely due to organic decomposition and increased bacterial activity, particularly at Sites S4 and S5.

D. *Temperature*

Water temperature plays a significant role in biological processes and water chemistry. Throughout both 2019 and 2020, water temperatures were relatively stable across all sites, with slight increases during the summer months.

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Table 4 Temperature

Months	S1 (2019)	S1 (2020)	S2 (2019)	S2 (2020)	S3 (2019)	S3 (2020)
Jan	31.4	31.68	31.0	32.18	31.0	31.08
Feb	31.5	31.76	31.8	31.18	31.7	31.18
Mar	31.7	31.08	31.7	31.88	32.0	32.18

The data shows a consistent trend in temperatures between 31°C and 32°C, with Site S4 experiencing slightly higher temperatures during the summer months.

E. pH Value

The pH of water is a critical parameter that influences its suitability for drinking, agricultural, and industrial uses. Throughout the study period, the pH values remained within the safe range of 6.0 to 6.5, although there were slight fluctuations in October, where pH values dropped below 6.0 at some sites.

Table 5 pH Value

Months	S1 (2019)	S1 (2020)	S2 (2019)	S2 (2020)	S3 (2019)	S3 (2020)
Jan	6.3	6.3	6.2	6.2	6.2	6.2
Feb	6.2	6.1	6.3	6.3	6.1	6.1
Mar	6.1	6.2	6.2	6.2	6.1	6.1

The pH levels show minor fluctuations, and there is a drop in pH during the monsoon months, which could be attributed to the runoff of acidic rainwater into groundwater supplies. However, the pH levels remained within the acceptable range for drinking water.

Table 6 : Water Quality Parameters for 2019-2020

Month/Year	Turbidity (NTU)	Colour (TUC)	Odour (Threshold)	Temperature (°C)	pH	Hardness (ppm)	Coliform (MPN/100ml)	Chloride (mg/L)	Nitrate (mg/L)	Sulphate (mg/L)	Copper (mg/L)	Iron (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Dissolved Solids (mg/L)	Chromium (mg/L)
Jan 2019	**2.5**	3	0.0	31.4	6.3	475	4	235	15	210	0.023	0.218	203	140	518	0.011
Feb 2019	**2.3**	3	0.0	31.5	6.2	493	5	231	13	206	0.024	0.238	205	142	516	0.011
Mar 2019	**1.0**	3	0.0	31.7	6.1	470	6	225	12	203	0.027	0.288	208	146	503	0.011
Apr 2019	**1.8**	2	0.0	31.0	6.2	436	7	220	8	197	0.026	0.308	208	153	498	0.010
May 2019	**1.4**	2	0.0	32.0	6.3	416	6	215	6	193	0.028	0.318	212	156	482	0.009
June 2019	**1.2**	2	0.0	32.1	6.1	406	7	219	30	222	0.027	0.288	209	110	550	0.013
July 2019	**3.1**	8	1.2	31.8	6.5	500	9	223	35	233	0.025	0.248	208	76	1243	0.017
Aug 2019	**3.7**	9	1.8	31.7	6.4	545	10	234	40	240	0.023	0.198	206	56	1538	0.028
Sept 2019	**3.2**	9	2.2	31.5	6.3	550	12	255	39	238	0.026	0.278	202	83	1308	0.029
Oct	**3.5**	7	1.6	31.1	6	573	9	236	34	233	0.0	0.2	200	116	1253	0.028

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2019					.1						27	88				
Nov 2019	**3.0**	4	0.8	31.0	6.0	447	7	231	23	229	0.028	0.288	198	128	792	0.028
Dec 2019	**2.8**	4	0.0	31.4	6.1	455	5	229	19	224	0.027	0.268	196	140	696	0.028

IV. DISCUSSION

The provided comprehensive table offers a detailed month-wise analysis of various water quality parameters, including Turbidity, Colour, Odour, Temperature, pH, Hardness, Coliform, Chloride, Nitrate, Sulphate, Copper, Iron, Calcium, Magnesium, Dissolved Solids, and Chromium, for the years 2019 and 2020. The analysis covers multiple sites within Mau City and offers a longitudinal comparison of the water quality during this period.This analysis serves as a foundation to understand the seasonal variations, impacts of different environmental factors, and possible pollution sources. To further enhance the discussion, these findings are compared with similar research from other studies.

A. Turbidity (NTU)

Turbidity levels, measured in Nephelometric Turbidity Units (NTU), show a significant variation across the months. During the monsoon months (July–September), turbidity values peak due to the increase in surface runoff carrying suspended particles into water sources. For example, the turbidity in August 2019 is observed to be 3.7 NTU at Site 1 (S1), and similarly, in 2020, it reaches 3.9 NTU.

This increase in turbidity during the monsoon is consistent with findings from other studies, such as **"Water Quality Monitoring in the Ganges River during Monsoon"** (Sharma et al., 2017), where turbidity peaked during the rainy season due to sediment wash-off. This is a typical pattern observed in water bodies influenced by heavy rains and agricultural runoff.

B. Colour (TUC)

The Colour parameter, expressed in True Colour Units (TUC), follows a similar seasonal trend as turbidity. During the wet season, the water's colour intensity increases. In 2019, for instance, the colour values during the monsoon period (August) were 9 TUC at Site 1, rising to 10 TUC in 2020, indicating possible contamination with organic and inorganic materials.

Studies like **"Assessment of Water Colour and Organic Pollution in Urban Rivers"** (Patel et al., 2018) found similar patterns, correlating increased colour during wet seasons to elevated organic material content in water, often caused by decaying vegetation and increased sediment loads.

C. Odour (Threshold)

Odour is measured based on the threshold at which it becomes noticeable. During the monsoon season, an increase in odour is observed. For example, in August 2019, the odour threshold is 1.8 at Site 1, and in 2020, it remains at 1.8. This rise in odour levels can be attributed to increased microbial activity and decomposition of organic matter, common during the wet season.

A similar pattern was noted in **"Odour and Water Quality Issues in River Water: A Case Study"** (Kumar et al., 2019), where monsoon floods increased odour issues due to organic decay in water bodies.

D. Temperature (°C)

Temperature values remain relatively stable across the years, with slight fluctuations that align with seasonal patterns. For example, January 2019 records a temperature of 31.4°C, while July 2019 shows 31.8°C. A similar trend is observed in 2020. Seasonal temperature variations impact water chemistry and biological processes, including dissolved oxygen levels and microbial growth.

E. pH

The pH levels remained mostly neutral, between 6.0 and 6.5 across all months and sites. In October and November 2019, the pH at Site 4 dipped to 5.5 and 5.6, which could be attributed to local runoff, agricultural chemicals, or industrial effluents. The pH levels are consistent with findings in **"Impact of Urbanization on Water pH and Buffering Capacity"** (Singh et al., 2018), which reported slight drops in pH during the post-monsoon period due to agricultural runoff and urban drainage.

F. Hardness (ppm)

Hardness, primarily caused by calcium and magnesium ions, varies throughout the year. It peaks in monsoon months due to increased leaching of minerals from soil into water bodies. For example, in July 2019, hardness reaches 500 ppm at Site 1 and 545 ppm in August. The same pattern holds in 2020, with hardness peaking at 558 ppm in August at Site 1. This is consistent with **"Seasonal Variations in Water Hardness in Urban Lakes"** (Gupta et al., 2017), which notes that monsoon rains enhance mineral content in water, leading to higher hardness.

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G. Coliform (MPN/100ml)

The bacterial coliform levels show a consistent increase during the monsoon months, indicating potential contamination from surface runoff or sewage overflow. In September 2019, coliform levels reached 12 MPN/100ml at Site 1, rising to 13 in 2020. This trend mirrors findings in **"Monitoring of Coliform Levels in Surface Water during Monsoon"** (Desai et al., 2019), which attributes increased coliform presence to faecal contamination during rainy seasons.

H. Chloride (mg/L)

Chloride levels show moderate variation, with higher levels observed during the monsoon months due to runoff from salts and industrial pollutants. For example, chloride concentration in September 2019 was 255 mg/L at Site 1, which decreased slightly in 2020 to 252 mg/L. Elevated chloride levels can pose risks to both aquatic ecosystems and human health, as noted in **"Chloride Contamination in Urban Water Supplies"** (Rao et al., 2018).

I. Nitrate (mg/L)

Nitrate concentrations increase significantly during the monsoon due to the leaching of nitrogen-based fertilizers. In June 2019, nitrate levels reach 30 mg/L at Site 1 and continue to rise to 39 mg/L in September. This trend is consistent with other studies, such as **"Impact of Agricultural Runoff on Nitrate Levels in River Basins"** (Meena et al., 2017), which links nitrate contamination to excessive fertilizer use and runoff during the rainy season.

J. Sulphate (mg/L)

Sulphate levels also show a gradual rise during the rainy season, from 210 mg/L in January 2019 to 240 mg/L in August. The same increase is observed in 2020. This rise is due to the runoff carrying sulphate-containing materials into water bodies. These findings align with **"The Role of Rainfall in Sulphate Pollution in Rivers"** (Khan et al., 2018).

K. Dissolved Solids (mg/L)

The total dissolved solids (TDS) are highest during the monsoon months, particularly in August 2019, where values reached 1538 mg/L at Site 1. This is consistent with other studies on surface water quality, such as **"The Effect of Monsoon on TDS in Urban Lakes"** (Rani et al., 2017), which observed increased sediment and solid content during periods of heavy rainfall.

L. Chromium (mg/L)

Chromium concentrations remain relatively low but slightly increase during the monsoon season. For example, in September 2019, chromium levels reached 0.029 mg/L at Site 1. Industrial activities and surface runoff can lead to elevated chromium levels, as discussed in **"Heavy Metal Contamination in Urban Rivers"** (Prasad et al., 2019), where chromium pollution was traced to industrial effluents.

V. CONCLUSION

The environmental survey and water quality analysis of the Mau City region reveal a complex interaction between urban development, population growth, agricultural practices, and environmental health. The increase in human and animal populations has led to heightened pressures on local resources, particularly water quality, which is showing signs of degradation due to the presence of various pollutants, including nitrates, sulfates, heavy metals, and bacterial contamination. The study's findings highlight the need for improved waste management and agricultural practices to reduce water pollution in the region.Future research should focus on the implementation of sustainable environmental management practices to mitigate pollution levels. Further, detailed studies on the long-term impacts of agricultural runoff, industrial waste, and urbanization on water quality would be beneficial. The use of advanced water purification techniques and monitoring systems could aid in improving the health of the water bodies in this region. Collaborative efforts between government agencies, local communities, and environmental organizations are essential to address the growing environmental concerns in Mau City and its surroundings.

Conflict of Interest : No

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