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INTRODUCTION TO GROUNDWATER HYDROLOGY

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KRISHNA NAGAR, DELHI

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E-mail: info@booksarcade.co.in, booksarcade.pub@gmail.com
Website: www.booksarcade.co.in

Year of Publication 2023

International Standard Book Number-13: 978-81-19199-45-7

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CHAPTER 1

INTRODUCTION TO GROUNDWATER

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The water that exists in the saturated zone below the earth's surface is collectively referred to as groundwater. Humanity's primary supply of freshwater is groundwater. One of today's most urgent challenges is groundwater management [1],[2]. Groundwater is a crucial and dynamic natural fresh water resource that supports the biophysical, ecological, and human health environment, making up around 34% of the yearly water supply. In this study area, groundwater is mostly used for agricultural activities [3],[4]. India will experience water stress by 2025, and if drastic measures are not implemented, India would experience water scarcity by 2050. The topography, geomorphology, buildings, vegetation, and soil qualities of a region largely determine how much groundwater is present there [5],[6]. One of the primary sources of surface feature data for groundwater, such as land uses, land shapes, and drainage density, is remote sensing. To determine the groundwater zones, this data may be quickly entered into a GIS. Groundwater is very important in today's situation with a rising population.

To prove the existence and estimate the substantial amount of groundwater in a region, many traditional approaches, such as geological and geophysical, are applicable. In contrast to these approaches, remote sensing may be utilised as a technique that is much more efficient in that it is a more practical, cost- and time-efficient tool for the reconnaissance survey. New options for hydrogeological investigations are provided by remote sensing and GIS. Recent years have seen the development of remote sensing and GIS as powerful tools for combining all hydro-geological data at hand and defining possible groundwater occurrence zones. These techniques make it feasible to precisely define the prospective groundwater zone. Furthermore, prejudice toward a particular component may be reduced. The exploration, analysis, monitoring, evaluation, and management of groundwater for sustainable groundwater use are all successful.

Earth has 13, 84,12,0000 cubic kilometres of total water, of which 8,00,0042 are groundwater. Additionally, 61,234 cubic kilometres of soil moisture exist. The amount of water below the surface is made up of both groundwater and soil moisture. By soaking into the pores and fissures of permeable rocks, groundwater gets infiltrated into the various strata of the earth. Three sources account for the majority of groundwater. In order, they are as follows: "Meteoric Water," which is the primary source of groundwater and is obtained by precipitation such as rain and snow. The second kind of water is "Connate Water," which is found in the pores and cavities of sedimentary rocks found in oceans and lakes. This water seeps into the ground from the surface via fissures, crevices, and joints of rocks before being stored as groundwater on non-permeable rocks. Sedimentary water is another name for it. Thirdly, "Magmatic Water," which is created when heated rocks are contacted by volcanic activity and turn into water following condensation of vapour.

Most groundwater originates as meteoric water from precipitation in the form of rain or snow. If it is not lost by evaporation, transpiration or to stream runoff, water from these sources may infiltrate into the ground. Initial amounts of water from precipitation onto dry soil are held very tightly as a film on the surfaces and in the micro pores of soil particles in a belt of soil mixture. At intermediate levels, films of water cover the solid particles, but air is still present in the voids of the soil. This region is called unsaturated zone or zone of aeration, and the water present is vadose water. At lower depths and in presence of adequate amounts of water, all voids are filled to produce a zone of saturation, the upper level of which is the water table. Water present in a zone of saturation is called groundwater.

The porosity and structure of the ground determine the type of aquifer and underground circulation. groundwater may circulate and be stored in the entire geological stratum: this is the case in porous soils such as sand, sandstone and alluvium. It may circulate and be stored in fissures or faults in compact rocks that are not themselves permeable, like most of volcanic and metamorphic rocks. Water trickles through the rocks and circulates because of localized and dispersed fissures. Compact rocks of large fissures or caverns are typical of limestone. On the earth, approximately 3% of the total water is fresh water. Of this groundwater comprises 95%, surface water 3.5% and soil moisture 1.5%. Out of all the fresh water on the earth, only 0.36% is readily available to use.

Groundwater is an important source of water supply. 53% of the population of US receives its water supply from groundwater sources. Groundwater is also a major source of industrial and agricultural uses. We are withdrawing water from underground aquifers at a faster rate that it can be replenished. Although immense, world's aquifers are not bottomless and in many areas water levels are sinking fast. The water in some aquifers is millennia old and lies beneath what are now some of the driest regions on Earth. Although people have drown water from from springs and wells since the earliest civilizations, in the past 50 years multiplying populations have needed more food and water and the rate of withdrawal has increased drammatically.

In some coastal areas so much fresh water has been withdrawn from aquifers that saltwater has started to intrude, turning well water brackish and unusable. The subsurface sources account for around 30% of the fresh water on Earth. Only 1% of the remaining 70% may be found in lakes and rivers, while around 69% is encased in ice caps and mountain snow/glaciers. Compared to an average of one third, groundwater supplies up to 100% of the fresh water that humans need in certain areas of the world.

Groundwater is an important natural resource that has a significant impact on the economy. It serves as the main water source for the food and agricultural industries. Generally speaking, groundwater is a steady source of water for agriculture and may be used in a variety of ways: more groundwater can be pulled when it's dry and there is a greater demand, and less groundwater will need to be extracted when the rainfall is enough to meet demands. Agriculture uses more than 70% of the water that is withdrawn globally (both surface and groundwater). Groundwater is believed to make for roughly 43% of all irrigation water used. Keeping the water flowing into rivers, lakes, and wetlands at a constant level is essential for the environment. For the wild animals and plants that live in these habitats, particularly during the dry months when there is no direct recharge from rainfall, it provides the ecosystem with groundwater circulation through the bottom of these water bodies. Groundwater is also necessary to keep inland lakes' navigational systems operating during the dry seasons. By releasing groundwater into the rivers, it aids in maintaining higher water levels there.

Groundwater is present almost everywhere and is often of very high quality. The fact that groundwater is preserved in the layers under the surface, often at significant depths, aids in maintaining its cleanliness and purity. Additionally, since groundwater is a naturally occurring resource that is typically found close to its intended use, it doesn't frequently need the same infrastructure and treatment as surface water. Finding the right balance between using groundwater properly and allowing the aquifer's level to rise again is essential for avoiding misuse and pollution of this priceless resource.

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CHAPTER 2

SOURCES GROUNDWATER

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As it goes down via the pores of permeable rocks after entering the earth's surface from numerous sources, water that was once surface water becomes groundwater.

A meteoric water

The location of the main groundwater supply [1],[2]. These waters are mostly obtained by rain and snow. After it has vaporised, water is replenished by the planet's reservoirs, lakes, rivers, and oceans. It is referred to as "meteoric" or "shooting star water" since it is produced by the melt of rain or snow [3],[4]. Through joints, fractures, and fissures in the rocks, this water is flowing from the surface of the earth into its core. As groundwater, this then compresses at the level of the impermeable rocks.

The liquid that results from precipitation is known as meteoric water (snow and rain). This includes precipitation-indirectly produced water from lakes, rivers, and ice melts. While most precipitation or water that melts from snow and ice travels to the sea through surface flow, a significant amount of meteoric water slowly seeps into the earth [5],[6]. To become a part of the groundwater in aquifers, this infiltrating water continues to descend until it reaches the zone of saturation.

The majority of groundwater comes from meteors. In the hydrologic cycle, other kinds often do not contribute much. Connate water and juvenile (also known as magmatic) water are non-meteoric types of groundwater. When rocks are forming, connate water gets trapped in the rock layers. Connate water is usually salty since the rock it is found in is usually made of sediments from the ocean. When magma intrusion occurs, magmatic water that has a significant impact on mineralogy rises from a vast depth. To put it another way, meteoric water is water that has rained and filled up porous, permeable shallow rocks, or has seeped through them along bedding planes, fractures, and permeable layers.

In this context, the term "meteoric" is used to refer to anything that has a direct atmospheric origin. The name derives from a Greek word that originally applied to debates about astronomy. But with the publication of Aristotle's work Meteorology, which included what are now known as earth sciences, the phrase was ultimately adopted to designate any noticeable changes in the sky (including meteors, originally thought to be weather phenomena).

Connate Water

The phrase "connate water" refers to the liquid that may be discovered in the fissures and fissures of sedimentary rocks found under seas and lakes. It's also referred to as sediment water. The availability of groundwater there ranks second in importance. This is the water that was entrapped at the time of rock deposition in the cracks of volcanic and sedimentary rocks. Connate water has a high mineral content and level of salt, making it difficult to mix with meteoric groundwater. Deep below, in the lowest parts of the zone of saturation, connate water is often discovered.

If rock diagenesis is to be quantified, a comprehensive knowledge of connate water is necessary. Rocks lose some of their permeability and porosity as a result of the solutes present in connate fluids, which often precipitate. The hydrocarbon prospectivity, which is crucial for the durability, resistance to wear, and strength of rocks, is impacted by this.

Aquifer origin and host rock thermal history may both be learned from the chemical composition of connate water. When it comes to the fluid composition and the temperature-pressure conditions that existed during the development of the sediment, connate water often provides clear information. Accurate assessment of connate water saturation is necessary in the majority of situations. Oil reservoirs are a particular example of this. Connate fluid saturation measurement has several uses in oil-producing wells, including in the petrochemical sector.

The pores of sedimentary rock contain connate water. Water is still present in the pore space, but during measurement or analysis, oil is regarded as being in the mobile phase. For more accurate measurement, one should take this idea into account. If the rock's diagenesis is to be estimated, knowledge of the geochemistry of connate fluids is essential. The host rock's porosity and permeability are often reduced by the solutes in connate fluids, which may have a significant impact on the prospectivity of the rock for hydrocarbons. Aquifer origins and the temperature history of the host rock may both be learned from the chemical makeup of the connate fluid. The cementing substance's crystals often include little fluid bubbles. Direct knowledge of the fluid's composition and the pressure-temperature parameters that prevailed throughout the diagenesis of the sediments is provided by these fluid inclusions.

Magmatic Water

Magmatic water, which is sometimes referred to as juvenile water, is an aqueous phase that is in equilibrium with minerals that have been dissolved by magma deep below the Earth's crust and is released to the atmosphere after a volcanic eruption. The rheology and development of magma chambers, as well as the crystallization of igneous rocks, notably silicates, are all important aspects to consider. Magma is made up of various relative abundances of minerals, crystals, and volatiles. Several variables, most notably the existence of water, influence the degree of magmatic differentiation. Viscosity is reduced and halogen-bearing minerals, such as chloride and hydroxide groups, are formed when volatiles, such as oxygen and water, are in plenty in magma chambers. In addition, different basaltic, andesitic, and rhyolitic magma chambers have different relative concentrations of volatiles, which causes certain volcanoes to be far more explosive than others. Although rhyolitic melts have shown to have the greatest solubility, magmatic water is nearly insoluble in silicate melts.

Three different types of magma exist, each with a different composition. An extrusive igneous rock is produced when magma crystallises within the crust. The magma may either produce rhyolite, andesite, or basalt depending on its chemical makeup. Each kind of magma exhibits distinct behaviours as a result of volatiles, especially water and carbon dioxide. The intrinsic viscosity of magma with a high volatile content is decreased by a large temperature drop of up to hundreds of degrees. Variations in the composition of minerals also affect how magma behaves.

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CHAPTER 3

GROUNDWATER CONTROL AND WATER QUALITY

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Due to the fact that subterranean water contamination has become a common problem, the controversy over groundwater quality has spread around the globe. Reports of pollution caused by coal ash, the manufacture of storage containers, saltwater intrusion, arsenic, and farming are a few of the difficulties in this area [1],[2].

The Earth has been referred to as the blue planet because, when seen from space, the cosmos appears as a blue globe covered in water with little and big islands strewn about [3],[4]. With a water bodysurface of over 71% and a volume of almost 1.973 billion cubic metres, the Earth is completely covered in water. Additionally, 97% of the total volume of water in oceans, seas, lakes, rivers, and canals is made up of salt water. Freshwater, which is concentrated in select lakes, rivers, and ponds, makes up the remaining 3% of the total. Furthermore, constituting around 1.6% of the total water capacity, the Arctic's subsurface waters provide for the majority of fresh water that is accessible for human consumption [5],[6].

The next section will discuss the ways that groundwater's nature hampers management and supervision as well as the philosophies for effective groundwater control and supervision. Several of the annotations gathered in this part have become worldwide, despite the fact that different paradigms are received from the United States. The nature of groundwater and complications with control the majority of literary works on the subject of natural pool reserves argue that granting public access might lead to excessive usage of the reserves and the loss of effective facilities. Without the presence of a surface-level authoritarian, individuals often cannot resist using natural pool reserves.

Due to a number of features, including its detracted capability (each consumer has the potential to reduce the well-being of another consumer) and minimal excludability (access control), groundwater may be classified as a natural-pool reserve. Due to their relative economy and steady development at the instantaneous availability of scientific information and power to the potential users, natural aquifers might pose a special risk to groundwater. Due to the natural-pool environment of groundwater, problems related to its quality are very difficult to solve. Once groundwater contamination occurs, it is exceedingly difficult to categorise and remediate.

The researcher identified a collection of characteristics that make groundwater management challenging. Below, a few of these characteristics will be briefly addressed.

Irreversibility: It should be understood that using groundwater might lead to physical changes like ground collapse that permanently harm the aquifer or the topography immediately above.

Furthermore, there are many other ways to address pollution-related injury, none of which can provide results comparable to those of thrust and remediate or surfactant-enriched aquifer treatment.

Time lag: It takes time for the effects of pollution or resource exploitation to become apparent. Time gaps between extraction and the subsequent consequences provide certain difficulties for water control. Groundwater movement and transportation are labor-intensive processes. Pollution may clearly be differentiated after the sources are activated or, in certain situations, after the source ceases to exist.

Indivisibility: Aquifers cannot be contained or even physically protected. However, an aquifer's vulnerability depends on the kind of pollution, the level of contamination, as well as its hydrogeology.

Hydrogeological ambiguity: Because of the enormous differences in hydrogeology, as well as the different ways that groundwater is used, management and control become quite difficult. Such circumstances may be seen in places like California, where the GSA's (Groundwater Sustainability Agency) ambiguous aquifer overlays and peripheries restrict a number of groundwater management issues. Collaborations between surface and groundwater provide challenges for water management due to limited management amongst governmental institutions. Lack of clarity in hydrogeology makes it difficult to determine how much water is stored in each region's transboundary aquifers. We need information. Similar to surface water, groundwater often has unclear characteristics.

Construction of abstraction: There is inadequate monitoring of both the number of groundwater wells that are drilled and the volume of groundwater that each well abstracts. For instance, in order to build the Central Arizona Project, Arizona had to keep track of the groundwater level decline.

Material imbalance: Groundwater data is often withheld and falsely stated, complicating control efforts. This occurs when water users have more information about their historical water use habits than the controlling officials.

Furthermore, the scale also adds complexity to the management and oversight of groundwater. Some aquifers may be hidden by thousands of square kilometres, as the Ogallala Aquifer in central America. However, given the differences in the geology and water-consuming characteristics in different portions of the aquifer, oversight and consequences of groundwater consumption are specific to their environment and, in certain circumstances, location.

Factors Impacting the Quality of Groundwater

The quality of water may be impacted by a variety of environmental and "manmade" factors. Some of the most significant ones include sedimentation, erosion, runoff, dissolving oxygen, pH, temperature, pesticides, and surfactants. Oil/grease, household cleaners, population growth, litter/garbage, and variables impacting groundwater levels.

Below-ground geology

The hydrologic properties of the subsurface material are aquifer (unconfined, confined), and aquiclude.

- The physical characteristics of an aquifer, such as its particular yield, transmissibility, and storage co-efficient.
- Work that involves pumping or extracting groundwater.
- The gradient of groundwater and the topography.
- Subsurface discharge or spring discharge that occurs naturally.
- Distribution and intensity of rainfall patterns.

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CHAPTER 4

WATER-QUALITY FACTORS AFFECTING GROUND-WATER SUSTAINABILITY

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It is impossible to separate the availability of ground water from the acceptability of its quality for various applications [1],[2]. To provide an extreme example, practically anywhere there is fresh ground water, there are salt brines with very high dissolved-solids concentrations [3],[4]. Although brines store enormous amounts of ground water, most inventories of the ground water that is accessible do not include brines due to their intrinsic unsuitability for practically all purposes. Some applications may be viable for ground waters with somewhat lower dissolved-solids concentrations, while others may not be. For instance, some animals can drink water with greater levels of dissolved solids than people.

The susceptibility of a ground-water resource to sources of pollution, which are largely found at and close to the land surface, must be taken into account while managing it [5],[6]. Once pollutants have entered the water table, they travel slowly due to relatively low ground-water velocities to neighboring surface-water discharge sites or deeper sections of the ground-water flow system. For the same reason, even after the initial causes of pollution have stopped, it takes a long time for an aquifer's polluted portions to naturally revert to having higher water quality. Projects to improve the quality of groundwater are often highly costly and only partially effective. In certain situations, ground-water pumping-induced steep slopes may significantly speed up the movement of pollutants into deeper ground water. For these reasons, State and Federal environmental authorities emphasise regulatory measures to stop ground-water pollution in an attempt to safeguard the ground-water resource.

The introduction of pollutants by human activity does not necessarily result in ground water contamination. Arsenic and selenium traces, radionuclides like radon, and high quantities of frequently occurring dissolved components are examples of potential natural pollutants.

The connections between the groundwater and surface water and between the land surface and the water table are two of the most important linkages in hydrology, and they are covered in the first two subsections below. In the third segment, "saltwater intrusion," naturally existing, highly salinized ground water is moved into areas of nearby aquifers with less salinity. This movement is often brought on by pumping of the less salinized (usually drinkable) ground water.

Water-Table/Land-Surface Connection

As long as water and perhaps other fluids travel from the land surface to the water table, almost every human activity that takes place at or close to the land surface might theoretically be a source of contamination to ground water. The use of pesticides, fertilisers, and manures on agricultural areas as well as landfills, industrial discharge lagoons, leaky gasoline storage tanks, cesspools, and septic tanks are all sources of chemicals that enter ground water in this manner. These sources are often divided into "point" and "nonpoint" categories. Point sources include things like landfills, leaky storage tanks, and industrial lagoons. Numerous these sources, together with the related contamination plumes, have undergone thorough analysis, followed by a cleanup effort. Even at extremely low concentrations, many point source pollutants, such as gasoline and other produced organic compounds, make polluted ground water exceedingly unattractive or worthless as a source of home or public supply.

Due to their extensive geographic scope and considerable application rates of potential pollutants (fertilisers and pesticides) to ground water, croplands are a major nonpoint source of pollution. A notable impact of irrigated agriculture is on the quality of surface and ground waters. Higher potential for pollutant transmission from the land surface to ground water occurs from increased areal recharge from excessive irrigation-water applications. Additionally, the transpiration of the applied water by the crops as well as the evaporation of irrigation water during delivery of the applied water to the crops may significantly increase the concentrations of dissolved solids in shallow groundwater and soil water. Numerous point sources, such as animal feedlots, waste lagoons, and storage facilities for agricultural chemicals, are included in agricultural operations in addition to farmland.

Despite the fact that urban land makes up a relatively tiny portion of the country's overall land area, the variety of activities that take place there provide many point sources of pollution that may have an impact on shallow ground water quality. Urban land may be seen as a nonpoint source with a broad variety of water quality from a regional standpoint. From the perspective of water management, these impacts on groundwater quality are especially significant if the water table aquifer under urban area is already being utilised or has the potential to be exploited as a source of water supply.

The U.S. Environmental Protection Agency and the States' wellhead protection programmes are an impressive effort to safeguard the quality of groundwater and the long-term viability of the regional groundwater resource, specifically to safeguard the quality of groundwater pumped from public supply wells. These initiatives use the strategy of estimating water table recharge regions that affect public supplying wells, and then putting ground-water preservation strategies into effect on the land surface above. Implementing ground-water protection practises at the land surface frequently presents significant challenges because many uncertainties exist in estimating areas contributing recharge to pumping wells (particularly for well-screen placements at some distance below the water table). In addition, areas contributing recharge may be located a great distance from the pumped wells.

Surface and Ground Water Connection

This article has previously covered the water flow between surface-water bodies and ground-water systems in both directions. The rushing water carries chemical components in addition to other materials. As a result, toxins in surface water may travel into nearby ground-water systems and contaminants in ground-water can travel into nearby surface-water bodies.

Because ground water often makes up a significant portion of streamflow, the quality of ground water discharge in many hydrologic situations may have an impact on the quality of the receiving stream. Seasonal changes in the impacts of ground-water quality on stream-water quality may arise because the percentage of streamflow that is provided by ground water might vary significantly throughout the year.

Where this discharge considerably lowers the concentration of pollutants supplied to streams from point sources and surface runoff, reductions in the amount of ground water released to a stream as a result of pumping may have major effects. In such cases, streamflow collection by pumping wells may lower the stream's capacity for contamination dilution during times of low flow below the level considered when determining the stream's discharge permits. Surface-water bodies often contribute to wells, and surface water is receiving more attention as a possible source of pollution for wells. The protection of ground water is expanded in numerous ways by the potential for pollution caused by induced infiltration of surface water. These include paying more attention to microbiological contamination and taking the upstream drainage basin into account as part of the well's "contributing area." The sustainable development of ground water near streams or the need for ground water treatment prior to use may be significantly impacted by contaminated surface water. Karst terrains, where aquifers are hydraulically linked by sinkholes or other conduits that may carry river water straight into an aquifer with little or no filtering, are among the environments of most concern for the pollution of ground water by streams.

Saltwater Intrusion

The United States' fresh groundwater supply is bordered laterally and below by salt water. This is particularly true near coastlines where fresh groundwater systems meet the seas, but it is also true in a large portion of the interior of the nation where deep salty water covers freshwater. The presence of saltwater around a fresh groundwater resource is relevant because, in certain cases, the saltwater may flow into the fresh groundwater system and render the water unusable.

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CHAPTER 5

DIFFERENCE BETWEEN SURFACE AND GROUNDWATER

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Surface and groundwater have highly diverse mobility and quality characteristics, which often results in quite different impacts and circumstances [1],[2]. These contrasts account for the extraordinary interest in surface and groundwater interactions and exchanges. Their hydrological and hydrogeological ramifications as well as the potential value of surface and groundwater resources are major drivers of this research [3],[4]. Following are some descriptions of the key distinctions between surface water and groundwater:

1. Snow and ice make up the majority of surface water; other surface waters include runoff from slopes and the water in rivers, springs, and lakes.

2. The gravitational field of the Earth essentially controls how surface water moves [5],[6]. Due to temperature changes or the influence of the wind, there exist fields of motion inside lakes. In a saturated two-phase flow, the gravitational field primarily controls the fields of motion in groundwater (solid–liquid). In unsaturated porous media (when three phases—solid, liquid and gas, and vapor—are present), the effect of molecular forces becomes extremely prominent, and the surface tension forces (thermal and vapour forces) often win over gravitational ones.

3. In very permeable aquifers, groundwater travels at incredibly slow rates. In contrast, surface waters move more quickly in streams and rivers as well as along mountain crests.

4. Surface waters have a free surface where the piezometric line corresponds with the water's level; in artesian aquifers, where groundwater is often retained under pressure, the piezometric line lies above the stratum's level.

5. As a whole, dissolved chemical components in groundwater are higher than in surface water. The concentration of these elements in groundwater rises with the persistence of the water in the soil, the solubility of the rocks the water passes through, and the ambient temperature, pressure, and pH.

Because they circulate through insoluble siliceous rocks during very short time periods, oligo-mineral fluids contain low concentrations of dissolved elements. Therefore, the chemical components that are dissolved in groundwater are of natural origin and are mostly controlled by the rocks through which it flows. The presence of chemical compounds from outside sources may result from pollution brought on by human activity. Due to the little time that surface water spends in touch with hillslope rocks and riverbeds, natural surface water has lower chemical element concentrations.

However, because of human discharge and the hydrodynamic forces that enable it to flow, surface waters have concentrations of contaminants as well as suspended solid debris.

6. As a result, surface water is more susceptible to contamination processes and swiftly disperses the polluting element via dilution or chemical and biological processes, where dissolved oxygen plays a crucial role. The permeability of the geological deposits that divide the aquifer from the surface and the distance between recharge regions determine how sensitive surface waters are, whereas groundwaters are less vulnerable. As a result of their close proximity to surface fluids that seep into the soil and percolate, phreatic strata are more susceptible than artesian aquifers. An aquifer may be contaminated for a very long time without anybody being aware of it. This delay depends on the water's transit duration as well as the solute's diffusion, dispersion, and transportation. Due to the possibility that pollution may have have reached unsafe levels by the time it is identified, these detection issues make the pollution problem worse. Therefore, any remediation procedure takes a long time and requires replacing all of the water in the aquifer when the polluted source is removed.

7. Surface water bodies have a far greater capacity for temperature variation than groundwater. Surface water temperatures vary according to air temperature, which also affects day and nighttime temperatures as well as the seasons. The thermal gradient inside the aquifer affects groundwater temperatures. As a result, changes are gradual; many large aquifers are immune to seasonal changes, and the temperatures within them essentially stay constant. Due to the existence of geothermal flux, the temperature of very deep groundwater rises with depth. These bodies often contain thermo-mineral waters, which are distinguished by high concentrations of dissolved salts and relatively high temperatures.

There are frequent interactions between surface water and groundwater, which alter the fluids' physical, chemical, biological, and energetic characteristics as well as the movement of water masses between the soil and the surface. The nature of the connection depends on the characteristics of the linked bodies of water as well as the regional ground conditions and environmental elements.

In interactions, the compressibility, viscosity, and density of the different water bodies are often taken for granted; nevertheless, on occasion, variations in density become significant due to differing temperatures. Surface water and groundwater often have different chemical and microbiological characteristics. The interactions and exchanges between bodies of surface and groundwater depend on the energy conditions in play and the resulting motional situations. Aquifers and surface waterways may exchange surface water for groundwater if they come into close contact. But more often, the exchange occurs across a wide range of unsaturated soil layers.

While the two water bodies in the second case have separate hydraulic characteristics and motions, they nonetheless share a hydraulic head in the first situation. According to the levels of the concerned strata and the surrounding conditions, the unsaturated level changes. The main source of groundwater supply is atmospheric precipitation. Due to mechanisms of diffuse infiltration, this recharge occurs largely in large permeable regions. Aquifer recharge zones get meteoric influx via river flow from generally wet regions. The Nile, for instance, transports water from a high, lush river basin with equatorial precipitation through arid regions of its journey until it reaches the cultivated fields of its delta on the Mediterranean coast. Part of the rain penetrates the earth as it falls and part of it flows off down the hillslope.

On certain localised depressions in the soil surface, the rain also forms superficial ponded accumulations. The rate of soil infiltration varies according to soil composition and the vertical gradient in ground moisture content. In moderately dry soils, the rate starts off high and then tends to go down, eventually stabilising. There may be the formation of a new "water body" with swamps, ponds, and humid places if the moisture level of the underlying stratum rises as a result of contributions from infiltration and may catch up with and surpass the moisture level on the surface.

When water percolates through unsaturated soil and reaches less porous or impermeable layers, a level of saturated soil is created. A suspended stratum may form when there are localised soil layers that are impermeable, such as alluvial soils. The soluble salts that naturally reside in soil have a tendency to dissolve in the water that percolates through it, transporting them to lower depths. As the temperature rises, these processes become more active and include both naturally occurring salts and those that people have introduced for use in agriculture (fertilizers, pesticides), as well as for more regional industrial and other uses.

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CHAPTER 6

FUTURE OF GROUNDWATER AND CHALLENGES

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Aquifers are a kind of natural infrastructure that perform a variety of functions, including as collecting water from floods and irrigation systems, purifying water to remove numerous toxins and pathogens, and storing water for both short- and long-term periods of time without evaporation losses [1],[2]. Traditional infrastructure projects, such reservoirs or treatment facilities, would be prohibitively expensive to build if aquifer services were to be replaced [3],[4]. Aquifers are a low-cost kind of natural infrastructure that may be utilised to sustainably provide water for many years if they are managed properly [5],[6].

Nevertheless, if not managed properly, this natural infrastructure will degrade and become useless, increasing the costs of and dependence on practically all other components of our water systems. The quantity of water the aquifer can hold in the future may be reduced, for instance, as a consequence of aquifer compaction brought on by groundwater depletion. Pumping for irrigation becomes more expensive as groundwater elevations decline. Groundwater resources in aquifers that are directly polluted or impacted by saltwater intrusion may be completely eliminated, need costly treatment procedures, and take years to recover. As a result, proactive aquifer maintenance and repairing of damaged aquifers are crucial tasks.

According to this definition of sustainability, effective stewardship include conserving resources, making the best use of groundwater, and making sure that future generations will be able to utilise groundwater in the same ways that we do. It's crucial to note that this entails juggling the requirements of quality of life, environmental protection, and economic growth while using groundwater. "If you asked me how my marriage was, and I answered sustainable, that's not fantastic," one participant said of answering the question. A "moonshot objective," like increasing aquifers and a booming economy, may be something we want or need to aspire towards in addition to sustainability. At the national, regional, and even local levels, this objective is important.

Groundwater condition at this time

1. The amount of groundwater kept in aquifers around the country has been steadily decreasing; it is estimated that between 1900 and 2008, 264 Tgal (810 MAF) of groundwater were extracted.
2. This volume, which is almost two times that of Lake Erie, may be responsible for the 2.8 mm of recorded sea level increase.

3. High Plains, Mississippi Embayment, and Central Valley aquifers were the three most depleted aquifers as of 2008. Each of these aquifers is the main source of irrigation in significant agricultural areas, including the High Plains, Central Valley, and rice, which are the country's main producers of grains (Mississippi Embayment). The bulk of agricultural water and about half of the household supply of freshwater were derived from groundwater in 2010, which also produced around 25% of total freshwater withdrawals. Instead of affecting quality, this high usage has mostly impacted quantity (with important geographic exceptions). The majority of the pollution comes from geologic causes, and just 23% of the locations evaluated by the United States Geological Survey (USGS) surpass a human health standard, indicating that groundwater quality is generally excellent throughout the country.

Groundwater challenges

Since groundwater is a resource that cannot be seen, it is difficult to monitor, model, and comprehend it. Over the last several decades, groundwater research has advanced significantly thanks to the development of cutting-edge monitoring equipment and enhanced computational tools that allow complex modelling. Groundwater data from a variety of sources, such as brand-new satellites and low-cost well monitoring, have started to provide fresh insights, but it is still challenging to explain how groundwater functions to the general public and decision-makers. Between the incidence of groundwater damages and their identification, there are sizable geographical and temporal delays, which provide a second problem. We don't completely understand the long-term effects of present groundwater activities or events, and each aquifer's geology and groundwater features determine how depletion and pollution affect it.

For example, it may take over ten years for the effects of groundwater pumping to become apparent and much longer to fix. There are several difficulties in terms of education, finance, and management techniques when managing a resource now for effects that appear decades later. The effects of depletion and pollution may not be immediately apparent since groundwater is out of sight and is seldom monitored.

The third issue is the potential for numerous governance systems for big aquifers as a result of the greater awareness (and litigation) of groundwater effects, which forced governments to develop new regulatory frameworks. Frequently, sub-state entities are used to manage groundwater.

In order to combat groundwater depletion, for instance, capacity use zones were created in the coastal plain region of North Carolina in 2002. The Edwards Aquifer Power was established to save endangered species and handle land subsidence concerns. Texas has 99 groundwater conservation districts with regulatory authority to regulate groundwater.

In order to prevent saltwater invasions, water replenishment districts were developed in California. Diverse regulatory approaches may facilitate focused issue solutions, but they can also sabotage chances for investments in infrastructure and technology since they restrict economies of scale and raise uncertainty over investment return.

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CHAPTER 7

ARTIFICIAL RECHARGE

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In order to enable water to percolate down to a shallow, unconfined aquifer, surface spreading methods retain water at the surface in certain locations [1],[2]. Furrows, trenches, ditches, spreading basins, check dams along stream channels, and other AR examples are typical. Since the suspended sediment in the source water will settle out, block the surface of the recharge area, and decrease the recharge rate, surface spreading areas need recurring maintenance [3],[4]. Clogging is also a result of microbial development in shallow soils. The majority of western states in the United States and several other nations have AR projects that make use of surface spreading methods.

AR is achieved through injection methods using wells. Typically, where surface spreading would typically fail, injection wells inject water straight into a deep, constrained aquifer. To eliminate debris, microbiological growth, and chemical precipitates, injection wells also need care (solid substances). In several nations, injection wells are employed. As an example, since 1956, Israel has used these wells as a crucial component of its water delivery system. The different AR structures are typically seen by society as a more ecologically sound alternative to constructing dams for more surface storage. However, there are still several technological, governmental, and budgetary challenges that must be addressed before AR may be used everywhere [5],[6].

A method for preserving or boosting dependable water supply is artificial recharge. Groundwater has been seriously depleted in certain locations due to agriculture and other usage. In these regions, AR plays a crucial role in maintaining well withdrawals and balancing the supply. An enormous facility in California's Los Angeles County recharges 308 billion litres of water annually on average (80 billion gallons, or 250,000 acre-feet). Groundwater depletion in certain coastal regions may stop groundwater's normal flow toward the ocean and allow saltwater to seep into the aquifer inland. In this instance, AR offers a helpful hydraulic barrier that will probably stop the deterioration of the water quality.

A crucial aspect of AR is site selection. While some aquifers offer little to no promise for effective augmented reality applications, others contain enormous possibilities. An aquifer should ideally be able to transport and keep the required volumes of recharge water while minimising chemical deterioration and migration. Furthermore, surface spreading should not be restricted by the permeability of shallow ground materials. Identifying aquifer characteristics should be done as part of the site research for AR. The modelling of groundwater flow and transport in advanced methodologies would use computer simulations.

The most significant factor in choosing when to start AR is often water availability. When there is a surplus of supply at the source compared to other needs, this happens. However, it may also happen during peak flow events or abnormally rainy years. In the majority of instances, this entails considerable seasonal weather-related factors. Surface water that hasn't been treated serves as the usual source for AR dissemination through methods. According to the needs of the particular location, injection methods have been utilised using untreated water, treated drinking water, or reclaimed water. Recycled wastewater is injected at a steadier rate and is less reliant on seasonal availability.

Rainfall, snowmelt, and to a lesser degree surface water replenish water in a natural way (rivers and lakes). Human endeavours like logging, paving, and other development projects may inadvertently hinder recharge. These operations may lead to topsoil loss, which would limit water infiltration, increase surface runoff, and decrease recharge. It is also possible for the water tables to be lowered by using groundwater, particularly for agriculture. The volume-rate at which an aquifer is drawn upon over the long term should be less than or equal to the volume-rate that is recharged, making groundwater recharge a crucial process for sustainable groundwater management.

Recharge may assist transport surplus salts that build up in the root zone to deeper soil layers or into the groundwater system. Water saturation in the ground is increased by tree roots, which also reduce runoff. Clay soils are temporarily moved downstream by flooding, increasing the permeability of the river bed and the aquifer recharge.

In India, where farmers have over-pumped the country's groundwater supplies to the point of depletion, artificial groundwater recharge is becoming more and more crucial. To support dug-well recharge projects in 100 districts across seven states where water stored in hard-rock aquifers had been over-exploited, the Indian government allocated 1,800 crore (equivalent to 46 billion or US$580 million in 2020) in 2007 based on recommendations from the International Water Management Institute. The discharge of waste via water flux, such as from dairy farms, industries, and urban runoff, is another environmental problem.

When water is available, a well is used to store water in an aquifer, and then later, the water is recovered from the same well. This process is known as aquifer storage and recovery, or ASR. Potable water is involved in a particular kind of AR called ASR. With this method, water may be placed precisely in the aquifer and recovered in practically the same form. The recovered water should ideally not need further treatment and should still be drinkable. Cities often go after ASR.

Saline (salty) or brackish aquifers are both capable of exhibiting ASR. This is feasible if the potable injection water replaces the natural water rather than blending with it. The quality of some of the recovered water is diminished as a result of some mixing that occurs on the edges of the stored water. The chemical alterations connected to any aquifer should be identified via ASR pilot testing.

Today, ASR facilities may be found throughout numerous nations and in a number of US states. The oldest ASR facility in the US is in Wildwood, New Jersey, while the majority of facilities are in Florida, Arizona, and California. The Wildwood neighbourhood started building its current system, which consists of four ASR wells, in 1968. The system stores roughly 380 million litres (99 million gallons) of water annually during off-peak times, and it recovers about 300 million litres (79 million gallons) of water during the summer. There are several places where ASR might be usefully used. ASR is already being used by several towns to deliver water at times of high demand as well as in emergencies. ASR's acceptance as a part of the overall municipal water supply is probably going to grow.

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CHAPTER 8

BASICS OF ARTIFICIAL GROUNDWATER RECHARGE

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Average annual water resources are projected to be 1,869 billion cubic metres (BCM), of which 1,086 BCM are really usable. Out of this, 690 BCM is accessible as surface water, while the remaining 396 BCM is accessible as ground water. Rain or snow is the source of all of this water. Rain and snowmelt water percolates through several layers of soil and rocks, creating the enormous ground water reserve of 396 BCM.

However, the quantity of percolation differs significantly from area to area and within the same region from location to location based on the quantity and structure of rainfall (i.e., number and duration of rainy days, rainfall amount and intensity), characteristics of soils and rocks (i.e., porosity, cracks and loose joints in rocks etc.), the essence of terrain (i.e., hills, plateaus, plains, valleys etc.), as well as other climate extremes like humidity and temperature [1],[2].

Water availability from sub-surface storages as a consequence varies greatly from location to location. Since utilisable surface water is scarce in the majority of the nation's low-rainfall regions, residents must rely heavily on ground water for household and agricultural purposes. Excessive ground water pumping in these regions, particularly in some of the 91 drought-prone districts in 13 states, has led to an alarming decline in ground water levels [3],[4]. Megacities' expansion and widespread urbanisation have made the issue worse by substantially reducing the amount of open space available for natural recharging. Even amongst villages, the supply of ground water varies greatly in hard rock locations [5],[6]. It is essential to artificially replenish the depleted ground water aquifers in order to ameliorate the ground water condition. The procedures that are now accessible are simple, affordable, and long-lasting. With the use of local resources and labour, many of these may be adopted by individuals and village communities.

By altering the way that surface water moves naturally while using appropriate civil building methods, artificial recharge to ground water attempts to increase ground water storage. Artificial recharge approaches often solve the following problems: -

- To increase the sustainable yield in regions where excessive development has drained the aquifer.
- Surface water conservation and storage for future needs, since needs often alter over the course of a season or time.
- Dilution is used to enhance the quality of current ground water.

- To purge bacterial and other contaminants from sewage and waste water so that it is safe for reuse.

The primary goal of artificial groundwater recharge is to replenish supplies from aquifers depleted as a result of excessive groundwater development.

Reducing overdraft, preserving surface runoff, and increasing the amount of ground water supplies are all benefits of the planned augmentation of water storage in the ground water reservoirs using appropriate recharge procedures.The method of artificial recharge involves artificially boosting the groundwater reservoir. In many places of the globe, the groundwater recharge has been significantly diminished by the fast urbanisation and deforestation. The groundwater table has been reduced in many places of the globe as a result of decreased groundwater recharge and excessive groundwater use as a result of rising demands. For instance, in certain areas of Delhi, the groundwater table has decreased by 20 to 30 metres over the course of 60 years. The situation is the same in other significant cities in India and throughout the globe. As a result, it is necessary to use artificial techniques to promote groundwater recharge.

Artificial recharge techniques may be divided into two categories: direct approaches and indirect ones.

i. Direct method: groundwater may be artificially recharged by rerouting water over the land surface via canals, infiltration basins, or ponds; installing irrigation furrows or sprinkler systems; or just pumping water directly into the subsurface through injection wells.

ii. Indirect method: Here, in indirect borewell recharge, the water runs through the earth, enters the pipe, and then seeps in via nylon mesh.

Borewells in good working order that haven't dried up yet respond well to indirect recharge. In the event of dry seasons of the year, this will guarantee that surface water is continuously available. Both naturally occurring and man-made processes refresh the groundwater. Natural recharge takes place when water infiltrates into the aquifer's bed via the process of infiltration.

But because of recent fast development and phenomenal population expansion, there are now fewer places for natural infiltration, which means there are less opportunities for groundwater to be naturally recharged. Artificial recharge is the use of water to artificially refill the water supply in an aquifer, as opposed to natural recharge (which happens from natural sources). The rate of recharge is one of the most challenging parameters to determine accurately when evaluating groundwater resources. Large uncertainty as well as regional and temporal variability often surround recharge estimates. The use of artificial recharge to supplement ground water sources has become more popular due to the rising demand for water.

Simply put, artificial recharge is the act of directing extra surface water into the earth to refill an aquifer. This may be done by distributing the water on the surface, utilising recharge wells, or changing the environment to encourage penetration. It refers to the transportation of water via artificial systems from the earth's surface to water-bearing layers under the ground, where it may be stored for later use. In order to fulfil demand in times of water scarcity, artificial recharge, also known as planned recharge, involves storing water underground. Wastewater treatment, secondary oil recovery, land subsidence avoidance, freshwater storage in salty aquifers, agricultural improvement, and streamflow enhancement are a few areas where artificial recharge is used.

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CHAPTER 9

STRATEGIES FOR RECHARGING GROUNDWATER

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Both recharge that occurs naturally as part of the hydrologic cycle and recharge that is caused by humans, whether directly via spreading basins or injection wells or as a result of human activities like irrigation and waste disposal, are included in ground water recharge [1],[2]. The hydrologic cycle is growing more and more dependent on artificial recharge using surplus surface water or recycled wastewater.

There may be a limited or widespread natural recharge of the water table. Diffuse recharging is the extensive transfer of water from the land's surface to its water table as a consequence of precipitation that falls over a significant region and percolates through the unsaturated zone. Diffuse recharge is more evenly distributed over space, while localised recharge refers to the transport of water from surface water bodies to the ground water system. The majority of ground water systems get both diffuse and localised recharge [3],[4]. Diffuse recharging loses significance as a place becomes drier, on average.

Direct method and indirect method are the two categories into which artificial approaches for groundwater recharge may be categorised.

Additionally, there are two subgroups for the direct method:

a) Surface methods

b) Sub-surface methods.

The primary goal of the surface approach is to increase groundwater penetration via longer residence times made possible by structural and nonstructural techniques. Contour bunding, percolation tanks, check dams, etc. are a few examples of structural measures.

Direct Methods

Surface Method

1. Percolation trough

To store an acceptable amount of surface water, a succession of earthen dams are built using this technique on suitable locations. It is important to choose a tank location such that a sizable volume of water may percolate through the tank bed and into the groundwater table. Both alluvial regions and locations with hard rock respond well to this technique. In order to continuously recharge after the monsoon, this strategy is quite helpful [5],[6].

2. Flooding

This approach works well in areas with a flat terrain where a thin coating of water may be applied. An infrastructure is used to deliver water around the area. In a place with little plant cover or sand soil cover, this approach may increase the rate of infiltration.

3. Recharge

Amplification of streams by building a series of check dams across the river or stream, this approach artificially increases seepage from a natural stream or river. When check dams are built, water is distributed over a broader region, ultimately increasing groundwater recharge. It is important to choose the locations for the check dams such that there is a thick enough permeable or weathered substrate to quickly recharge the water that has been stored.

4. The ditch-and-furrow method

For uneven terrain, utilise this technique. This method involves transporting the water from the source through a network of sparsely spaced flat bottom ditches or furrows. More opportunities for water to seep into the earth are provided by this arrangement. Based on the soil's permeability, the ditch's spacing is determined. A ditch or furrow should be built that is more sparsely spaced for less permeable soil.

5. Convex bund to hold surface runoff for a longer period of time in a hilly area, a contour bund is a tiny embankment built following the contour. In low-rainfall areas with adequate internal subsurface drainage, this plan is used.

Subsurface method

1. Get plenty of rest

Water is immediately refilled into the aquifer via recharge wells. Similar to pumping wells are recharge wells. Whether there are one or several wells, this approach may be used to recharge them. Given that wells must be drilled, this approach is more expensive than the alternative. The aquifer may sometimes be recharged with water via abandoned tube wells, however.

2. Dug a well

Furthermore, artificial groundwater recharge may be accomplished using dug wells. Wells that have been dug often lose water during the time when there are no monsoons. In non-monsoon seasons, the excavated wells may even dry up. You may recharge groundwater using these drilled wells. Using a distribution system, water may be gathered from numerous sources and released at the wells that have been drilled. 3. a shaft or pit Water is refilled into an unconfined aquifer using a recharge hole with varying diameters. Typically, a layer of less permeable soil occurs, particularly in agricultural fields. Surface flooding techniques of recharging do not operate well since there are less permeable strata present. Recharge pits may be dug for these kinds of situations that are deep enough to reach the less permeable layers. Although the cross sectional dimension of the recharge shaft is much less than that of the recharge pits, they are identical to one another. The same way that recharge pits are used, recharge shafts are also used to replenish water in unconfined aquifers with water tables that are located far below the surface of the ground and strata that are weakly impermeable to water at the top of the strata.

Indirect method

Induced recharge

It consists of a covert artificial recharging technique. In this technique, surface water sources including streams, rivers, and lakes are hydraulically linked to the aquifer, which is pumped with water. The aquifer is refilled because of pumping, which creates a reverse gradient that allows water from the surface water source to enter the aquifer. This technique works well, particularly when the surface water quality is low. Surface water is cleaned of pollutants by being filtered via soil layers. As a result, the quality of the water that is received in the wells is substantially higher than that of the surface water.

In addition to the buildings mentioned above, it is common to see ground water dams, subsurface dykes, or what is known locally as Bandharas to stop subsurface flows. Similar rock fracturing methods have been used in hard rock regions to interconnect cracks and boost recharge, including sectional blasting of boreholes using the appropriate methods. To preserve subsurface flow and increase bore well output, cement sealing of fractures has been used in Maharashtra using specially built bore wells.

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CHAPTER 10

ARTIFICIAL RECHARGE STRUCTURES

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Using the Ditch and Furrow Method

The greatest water contact area is provided by shallow ditches or furrows with flat bottoms and close spacing when recharging water from source streams or canals in places with varied topography [1],[2]. This approach requires less soil preparation and is less prone to silting than recharge basins.

Lateral Ditch Pattern

The stream's water is diverted into the feeder canal or ditch, where it forms smaller, oblique ditches [3],[4]. Gate valves control how rapidly water enters these ditches from the feeder canal. The furrow depth is controlled in line with the terrain in order to maintain equal velocity and the largest quantity of wetted surface. Extra water and lingering silt are transferred to the main stream via a return canal.

Dendritic Pattern

To divert stream water away from the main canal, a series of smaller ditches placed in a dendritic pattern may be employed. Until virtually all of the water has permeated the earth, the ditch division process continues [5],[6].

Contour Pattern

The excavation of the ditches follows the area's ground surface contour. As it gets closer to the stream, a switchback is made in the ditch, allowing it to meander back and forth, crossing the spread several times. At its lowest point, the ditch joins the main stream, returning any additional water there.

Recommendations for Site Features and Design

The water contact area seldom surpasses 10% of the total recharge area, despite the fact that this approach may be applied to uneven terrain.

- To maintain flow velocity and deposit silt as little as possible, ditches should be sloping.
- Dikes must be shallow, flat-bottomed, and widely spaced in order to be effective.
- Greatest surface area with water.
- A typical width is between 0.3 and 1.8 metres.
- A collecting ditch should be included to move any surplus water back to the main stream channel.

Spreading Basin and Percolation Tanks

To refill the subsurface water reservoir in both alluvial and hard rock formations, these structures are most often employed in India. When the rocks are severely shattered and worn, these structures are more efficient and practical in hard rock formations. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka, and Gujarat, basaltic lava flows and crystalline rocks have been the sites of several percolation tanks construction.

The percolation

However, tanks are also useful on talus and scree-covered mountain fronts. They are found to be quite helpful in the Satpura Mountain front area of Maharashtra. Percolation tanks may also be constructed in the Bhabar zone. ponds for percolation with wells and shafts Percolation tanks are also constructed to recharge deeper aquifers in cases when shallow or superficial rocks are very clayey or impermeable. The water is preserved in the Gujarati towns of MotiRanjan and Bhujpur in the Percolation Tanks, where recharge wells with filters are constructed.

Key Percolation Tank Characteristics

a. An extensive analysis of the rainfall pattern, the number of rainy days, dry intervals, and evaporation rate is needed to pinpoint prospective percolation tank placements.

b. Since the following evaporation losses would be severe in Peninsular India's semi-arid environment, the percolation tank's storage capacity should be built such that the water percolates to the groundwater reservoir by January.

c. Because of the limited catchment area, percolation tanks are often constructed on second- to third-order streams.

d. The submergence region should be as far away from habitation as is practical.

e. The percolation tank should be placed on severely fractured and worn rock for speedy recharging. When working with alluvium, the boundary structures are ideal for positioning percolation tanks.

F. The permeable vadose zone in the aquifer has to be thick enough to recharge to allow for recharge.

g. Enough wells and agricultural land should be available nearby to use the recharge water.

h. To estimate runoff, detailed hydrological studies should be carried out, and the design capacity should normally not exceed 50% of the catchment's annual total rainfall.

i. The waste weir or spillway must be built adequately to allow the flow of surplus water based on the single-day maximum rainfall after the rank has been filled to its maximum capacity.

j. To reduce seepage losses both below and above the nalla bed, a cut-off trench should be constructed.

k. Use monitoring techniques that include observing in the catchment area and those who have benefitted to minimise embankment erosion brought on by ripple action.

Well and staff gauges should be accessible to assess the percolation tank's impacts and benefits.

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CHAPTER 11

MONITORING MECHANISM FOR ARTIFICIAL RECHARGE PROJECTS

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In any plan for artificially recharging groundwater, the monitoring of water quality and level is of utmost significance [1],[2]. The monitoring data attests to the effectiveness of the artificial recharge structures built, and it considerably aids in the adoption of scientifically sound ground water management techniques.

Water Levels Monitoring

Identification of the artificial recharge technique during the feasibility study stage is substantially aided by the monitoring of surface and ground water levels [3],[4]. In order to analyse the potentiometric head variations over time in the aquifer and the pattern of ground water flow, a network of observation wells is employed. The primary objectives of the observation well network during the feasibility stage are to define the boundary zonation of the aquifer to be recharged and to know the hydraulic characteristics of the natural ground water system [5],[6]. The observation well network is typically low in well density but spread over a large area. The observation well network is redistributed in a smaller region with a higher well density once the viability of the groundwater structure has been determined.

Studying how artificial recharge affects the ground water system naturally is the goal of the monitoring system. It is necessary to build the observation well network based on the artificial recharge technique and the local hydrogeology. In the region of the artificial recharge scheme, the monitoring system of the observation well network should be specifically created to track the effects of single structures. It may then be expanded to track the effects of groups of such structures. The network must include observation wells

The network must include observation wells

(1) Near the recharge facility's center.

(2) Far enough out to monitor composite impacts.

(3) Close to the limit of hydrological boundaries.

Piezometers should be put to monitor the water levels of the overlying and underlying aquifers, which assists in the investigation of leakages, etc., if the refilled aquifer is overlain by a confining/semi-confining layer. It is important to keep track of the water level profiles of both surface water and ground water if the surface water bodies are hydraulically coupled to the ground water aquifer that is being refilled.

For defining the zone of benefit, use the tracer technique

Tritium, Rodhomine B, fluorescent dye, and other environmental isotopes are highly helpful in determining the degree of recharge and effectiveness of recharge structures. Tracers are valuable in identifying the region that benefits from artificial recharge.

Inspection of Water Quality

To maintain the quality criteria for the designated uses of the augmented resource, water quality monitoring is necessary while artificial recharge systems are being implemented. To minimise blockage of the well and aquifer owing to excessive salt precipitation, it is crucial in the case of injection wells to understand the composition of native water in the aquifer and refilled water. Regular sampling from observation well network should be used to get information on the chemical composition of native water and the changes that result from artificial recharge schemes. A network of monitoring wells must be carefully inspected whenever treated wastewater is utilised as recharge in order to identify and eliminate any chance of contamination. Thus, the sort of water quality monitoring programme relies on the particular issue being researched, such as changes in ground water quality, the impact of soil salinization, and the prevention of any pollution, among other things. In general, the samples that need to be gathered may be divided into three categories:

(1) Indicative

(2) Basic

(3) Comprehensive

To detect the existence of injected effluent, suggestive samples are taken at intervals of one to four months. To ascertain the impact of recharge effluent on ground water quality and the purification offered by flow via the soil and aquifer system, basic samples are obtained at monthly intervals for wells already effected by recharge. For observation wells and production wells, thorough samples are obtained every six to twelve months to assess the water's quality in relation to the planned use of the water and to establish if it meets those criteria.

Assessing the effects

The effect evaluation of artificial recharge systems may be summarised as follows: a) Conservation and harvesting of excess monsoon runoff in ground water reservoir that would otherwise be wasted outside the watershed/basin and to the sea.An increase in the level of ground water as a result of more recharging. A check to this and/or a reduction in the rate of decline occurs in cases when the level of ground water was continuously falling. Also decreasing is the amount of energy needed to raise the water.

Groundwater structures in the zone of artificial structures that benefit from them become more sustainable, and wells provide water during dry months when these structures were previously running dry. Many places will be free of tankers, and household wells will eventually become viable.A significant shift in the cropping pattern and the emergence of cash crops will occur in the benefitting zone as a result of the additionality of ground water. A new plantation might be established on orchards that previously dried up because of a lack of groundwater.

Due to the increased availability of soil moisture, green plant cover may become more prevalent in the benefit zone and around buildings. Dilution might result in better ground water quality. In addition to their direct, quantifiable effects, artificial recharge schemes will also provide indirect benefits such as a reduction in soil erosion, an enhancement in the fauna and flora, an inflow of migrating birds, etc. The rise in agricultural output would also significantly enhance the social and economic situation of farmers in the benefiting zone.

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CHAPTER 12

ARTIFICIAL GROUNDWATER RECHARGE IN INDIA

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The method of artificial groundwater recharge involves increasing the groundwater reservoir at a pace faster than it would naturally increase under replenishment circumstances [1],[2]. Over-exploitation of groundwater has led to declines in groundwater levels, a scarcity of water supply, and the incursion of salty water in coastal regions in several parts of India. There is a need for artificial groundwater recharge in these places, which may be accomplished by enhancing the natural penetration of precipitation or surface water into subsurface formations by techniques including water dispersion and recharging through pits, shafts, and wells, among others. Local topographical, geological, and soil factors; the amount and quality of water available for recharge; the technological-economic feasibility and social acceptability of such schemes—all influence the choosing of a specific approach [3],[4].

Today, along with other phenomena like climate change, changes in land use, the extinction of species, and so on, intense aquifer exploitation is recognised as one of the major environmental challenges facing the whole globe. In that regard, artificial groundwater recharge is almost the sole option for directly reducing the impacts of aquifer exploitation. In order to fill water deficiencies in aquifers, the method utilised to inject water into the earth is called recharging of aquifers [5],[6].

Feasibility

This requires analysing the dynamics of groundwater flow and basin recharging as well as considering potential artificial recharge approaches. Finding impermeable layers within the aquifer or basin compartmentalization that prevents recharging to the basin aquifers is a major challenge. Concerns about the nature of the likely movement of recharged water, the hydrological variability within the aquifers, and worries about the chemical mixing of surface fluids and local groundwater are also significant. As part of the feasibility programme, other surface-water sources are also assessed, as well as any regulatory difficulties. Prepare the appropriate hydrological and feasibility studies as needed for regulatory supervision and permitting organisations.

Program Design and Execution for Tests

A test programme is devised, using existing facilities if feasible, based on the findings of the feasibility investigation. This effort involves measuring recharge rates throughout the test programme, thorough chemical investigations of co-mingled waters with various beginning chemical signatures, and chemical and physical modelling of recharge possibilities.

Project Implementation at Full Scale

In order to recommend final, full-scale programme parameters, test programme results are used. These recommendations include locations for additional wells or infiltration ponds (if necessary), potential future options for surface-water sourcing, planning of recharge management during regular operations, and necessary monitoring. The system architecture is adaptable to allow for integration of evolving customer demands with current recharging operations and infrastructure.

Groundwater has been extensively used in India and other countries as a consequence of technological advancements in well building and pumping techniques. The dependency on groundwater has grown significantly in recent years owing to the unpredictable nature of the monsoon in many areas of India and the shortage or absence of surface-water supplies in arid and semi-arid areas. Therefore, it is crucial that effective storage and management of the available groundwater resources be implemented considering the likelihood of the existing groundwater resources in these regions being over-exploited. In the arid and semi-arid parts of India, artificial recharging of aquifers is necessary to replenish groundwater since natural rainfall intensity is woefully insufficient to provide any moisture surplus under normal penetration circumstances. Although artificial groundwater recharge techniques have been widely employed in wealthy countries for many years, emerging countries like India have just lately begun to adopt them.

Techniques like building percolation tanks, trenches around hills and slopes, etc., have been used for a while, but they typically lack a scientific foundation (such as understanding of the geological, hydrological, and morphological features of the areas) for choosing the sites on which the recharge structures are located. In the states of Maharashtra, Gujarat, Tamil Nadu, and Kerala, a variety of methods for artificial groundwater recharge have been used.

Seven percolation tanks in the Sina and Main River basins of Maharashtra were studied. If the tank bottom was kept clean by removing accumulated silt and debris before the yearly monsoon, the average recharge volume of these tanks was 50 percentage points of the tank's capacity. Systems installed in vesicular or cracked basalt regions produced the best results. Because the surface area exposed to evaporation was, on average, 10 percentage points less than that of an average-sized percolation tank, canal barriers where the recharge structure was positioned inside the course of the canal were determined to be the most effective and inexpensive.

The rate of infiltration inside canal barriers ranged from 50 to 70 percent of the reservoir's capacity. A connector well that connected the shallower, confined basaltic aquifer at 63 metres deep with the deeper, phreatic alluvial aquifer at 6 metres deep allowed water to freely flow by gravity at a rate of 0.19 million cubic metres per year from the phreatic aquifer to the confined aquifer, aiding in infiltration. The restricted aquifer's piezometric level was 30 metres below ground level, while the water level in the phreatic aquifer, which was saturated by infiltration from the surface reservoir, was 3 metres below earth.

Nine percolation tanks in the semi-arid sections of the Noyil Ponani and Vattamalai River basins in Tamil Nadu and Kerala have been the subject of investigations. At the start of the rainy season, percolation rates reached as high as 163 mm per day, but they quickly declined owing to silt buildup in the tank bottoms. Therefore, it was established that regular de-silting was crucial to maintaining these tanks. Contrarily, it was discovered that subsurface dykes of 1 to 4 metres in height were successful in increasing groundwater supplies, especially in the regions of hard rock covered by fractured aquifers.

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