

# International Journal of Innovative Research in Science, Engineering and Technology

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## Physical and Chemical Methods for Removal of Hazardous Ions from Groundwater in Banswara District, Rajasthan

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**ABSTRACT:** Various treatment technologies have been used for the treatment of groundwater: physical, chemical, and biological technologies with different success rates. In the literature, various adsorbents have been successfully synthesized from low-cost and environmentally friendly materials. Adsorption is considered an efficient treatment technique for the removal of both toxic elements and pathogens by utilizing different adsorbents. For example, the nanostructures of MgO with a BET surface area of up to 171 m<sup>2</sup>/g obtained a very high adsorption capacity of 29,131 mg/g for fluoride ions in water, while the incorporation of iron in activated carbon has improved its adsorption capacity to 51.3 mg/g for arsenic. Moreover, certain adsorbents have shown the capability to remove 99% of the rotavirus and adenovirus from groundwater in Banswara district, Rajasthan

**KEYWORDS:** physical, chemical, groundwater, low cost, biological, adsorbents, ions, Banswara

### I. INTRODUCTION

The removal of Pb(II), Cd(II) and Ni(II) ions from aqueous solutions by means of nonthermal plasma with a dielectric barrier discharge is investigated in Groundwater of Banswara district in Rajasthan. Aqueous solutions with metal ion concentrations from 10 to 100 mg/dm<sup>3</sup> in spring water were used. In the first stage, the optimization of the solution flow rate, generator modulation frequency and duty cycle was made in terms of the removal efficiency of the considered metals. The removal was then investigated as a function of the number of passes of the solution through the cold plasma reactor. The effect of the initial concentration of ions in the solution was studied. Techniques such as composite central design, least squares method and Fourier transform infrared spectroscopy were used. The physical and chemical parameters of the solutions, such as electrical conductivity, pH, temperature, concentration of metal ions and the content of other substances (e.g., total organic carbon), were measured, and the presence of microorganisms was also examined. It was found that each pass of the solution through the cold plasma reactor causes a decrease in the concentration of Cd(II) and Ni(II); the concentration of Pb(II) drops rapidly after one pass, but further passes do not improve its removal. The removal percentage was 88% for Cd(II) after six passes and 72% for Pb(II) after one pass, whereas 19% for Ni(II). The purification mechanism corresponds to the precipitation of metal ions due to the increasing pH of the solution after exposure to cold plasma in groundwater of Banswara, Rajasthan.

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Due to the inevitable emissions of pollutants into the environment, it is necessary to remove them in order to meet stringent regulations on the quality of water discharged into aquatic ecosystems groundwater basically in Banswara. The sustainable management of water resources and the constantly deepening water deficit in Banswara forces the search for new technologies of wastewater treatment and the use of closed water circuits [12,13]. Currently, various methods are used to remove heavy metals from water, such as precipitation [14], adsorption [11,15,16,17], ion exchange [18], reverse osmosis [19], membrane filtration [20], electrolysis [21] and others [3]. However, many of these methods are associated with recontamination, low efficiency and high costs. Among water and wastewater methods, advanced oxidation processes (AOPs) are becoming more and more important in the degradation of hazardous and difficult-to-decompose pollutants [22,23,24,25]. A common feature of AOPs is the generation of a wide spectrum of reactive molecular forms, such as free electrons,  $H^{\bullet}$ ,  $O^{\bullet}$ ,  $\cdot OH$ ,  $OH^{\bullet}$ ,  $H^+$ ,  $HO_2^{\bullet}$ ,  $HO_2^+$ ,  $H_3O^+$ ,  $O^{\bullet-}$ ,  $O_2^{\bullet-}$ ,  $O_3^{\bullet-}$ ,  $H_2O_2$ ,  $O_3$  and  $H_2O^*$  [26]. The species easily react with various chemical substances, which allows for the decomposition of toxic compounds, modification of polymer structures, destruction of bacteria and fungi and influencing their biological structures and DNA [27,28]. One of the methods used in AOPs is the generation of plasma.



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In addition to reactive molecular forms, plasma technologies are able to produce shock wave, UV light quanta and electrohydraulic cavitation [22,27,29,30]. Electrical discharges in plasma above or in a liquid also initiate redox processes [31]. Therefore, plasma-based processes are generally considered to be combined with other AOPs, including ozonation, UV photolysis and pyrolysis [32]. They have the advantages of not requiring temperature and pressure and being energy saving and ecological, and therefore environmentally friendly [22]. Among plasma technologies, nonthermal plasma (NTP) with dielectric barrier discharges (DBDs) is often used for water treatment [33]. This technology uses thin-film reactors, usually consisting of two coaxial quartz tubes and a disc and mesh electrodes made of stainless steel [34]. In systems of this type, a large number of oxidizing species with a short lifetime is formed, in contrast to the chemical reagents used in other APO methods [25] in Banswara of Rajasthan.

## II. DISCUSSION

In general in Banswara district, groundwater, Salinity, alkalinity, fluoride, nitrate and TDS are the major factors, which affect the water quality most. pH: the pH of ground water in this area varies within minimum 7.5 to maximum 8.5 in both seasons. Almost all the water samples in this area are alkaline in nature though the values of pH of all water samples were found to be within the permissible limits in both seasons. The standard limits prescribed by WHO and IS 10500:2012 are 6.5- 8.5. Electrical Conductivity (EC): E.C. depends on the concentration of dissolved mineral matter content. The salt concentration is generally measured by detecting EC. In the present study area the EC has been observed from 942 to 9771  $\mu\text{S}\cdot\text{cm}^{-1}$ . About 60 % water samples have EC more than permissible limit. If the TDS is high then EC will be high .[1] Total Dissolved Solids(TDS):The value of T.D.S. is very important for the assessment of water quality . High TDS value of water indicates the higher mineralization of water. The desirable limit for TDS is 500 mg/L and maximum permissible limit is 2000 mg/L .As the result of analysis the values of total dissolved solid ranges from 660 to 6840 mg/L during pre-monsoon and 780 to 6280 mg/L in Post-monsoon season. Maximum TDS has been observed at handpump of villages. About 46% samples have TDS beyond permissible limit of 2000 mg/L. It concludes that mostly water is saline in a certain block. This shows that anthropogenic impact which can be due to agricultural activity leading to local spatial and temporal variability of runoff Away from the permissible level, palatability decreases and may cause gastrointestinal irritation. Alkalinity: Alkalinity of the water is due to presence of carbonates, bicarbonates and hydroxide salts. The alkalinity values in the study area were recorded between 260 to 1220 mg/L in pre monsoon season and 220 to 1220 mg/L during Post-monsoon season. The hydroxide, carbonates and bicarbonate probably released from limestone sedimentary rocks, carbonate rich soils, cleaning agents etc.The Maximum value (1220 mg/l) is observed . The Maximum permissible level of alkalinity is 600 mg/L (BIS Standard). About 83 %of water samples tested were found to be within permissible limits. High amount of alkalinity in water is harmful for irrigation which leads to soil damage and reduces crop yields. Chloride ( $\text{Cl}^-$ ): All the natural types of water contain chlorides. Chloride is added to water due to the agricultural activities, industries and chloride rich rocks. It is a widely distributed element in all types of rocks in one or the other form. Its affinity towards sodium is high. High concentration of chloride is due to the invasion of domestic wastes and disposals by human activities . Soil porosity and permeability also play a key role in building up the chlorides concentration . According to IS:10500:2012the desirable limit of chloride is 250 mg/Land the permissible limit is 1000mg/l. In the present analysis, chloride concentration lies between the range of 90 mg/L to 2370 mg/L in pre-monsoon season and Minimum and Maximum values are decreasing in post monsoon seasons.(120 to 2270 mg/l.). The highest value of 2370 mg/l is observed at Handpump area. Excessive chloride in water is particularly not harmful but increase of chloride level in water is injurious to People suffering from heart

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and kidney diseases. Hardness: The total hardness is the measure of the capacity of water to precipitate soap. Hardness of the water is due to presence of Ca and Mg salts. Usually the hardness is not harmful to health but it has been suspected to play some role in heart diseases . In this study area, the range of total hardness was found to be from 260 mg/L to maximum 3880mg/L in Premonsoon season and 320mg/L to 3050mg/L in Postmonsoon season in more than 50% of samples hardness as crossed permissible limit. The hardness of the water is due to dissolved minerals from sedimentary rocks through seepage and runoff ,Detergents and soaps also aggravate the situations. The standard limits of total hardness are 200 to 600 mg/l. as per IS 10500:2012. Sulphate (SO<sub>4</sub> ) : In Present study area the sulphate values exhibited between 16 to 660 mg/l in pre monsoon season, and 16 mg/l to 555 mg/l. in Postmonsoon season Sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals.Discharge of industrial wastes and domestic sewage tends to increase concentration of sulphate in water. Only 3 samples have concentration beyond the permissible limit as prescribed by IS 10500:2012 (400 mg/l.).High concentration of sulphate may cause gastro intestinal irritation particularly when concentration of magnesium and sodium is high. [2] Nitrate(NO<sub>3</sub> ) : The values of nitrates in the study area were recorded between 30 mg/L and 860 mg/L.About 75% of samples exceed the desirable limit of 45 mg/L. If the concentration of nitrate is higher than 45 mg/L, it will cause a disease called blue baby disease or methaemoglobinaemia in infants .The high level of nitrate in study area has reported that nitrate contamination of water is due to increasing use of nitrogenous fertilizers and nitrites can cause depletion of dissolve oxygen content of water . NAEP have concluded that residual nitrate in the soil in the major cause of nitrate contamination in ground water. The appreciable quantities of nitrates and nitrites found in these investigations have some public health implications. Calcium: The Calcium in the sampling sources ranges from 48 to 808 mg/L during pre-monsoon season and 48 to 660 mg/L during Post-monsoon season of 2013. In most of the samples it falls above the desirable limit of 75 mg/ L(IS:10500:2012), and only 30% samples have calcium concentration above the permissible limit of 200 mg/L. The higher value is mainly attributed due to the abundant availability of lime stone in the area. Consequently more solubility of calcium ions is present. Magnesium: In these samples, the minimum concentration of magnesium has been increased from 26 mg/L in Pre-monsoon to 36 mg/L in Post- monsoon season. But the maximum value decrees from 446 mg/L to 336 mg/L in post-monsoon season 2013.In all most of all the samples magnesium falls above the standard desirable limit 30 mg/L in both seasons. The concentration of magnesium may be due the dissolution of magnesium calcite, gypsum and dolomite .All the major parameters in both seasons were found to be in excess of the desirable limit given by WHO / ICMR / IS (10500:2012) standards, so that water quality of the study areas of poor quality.[3]

### III. RESULTS

Treatment technologies in Banswara are utilized:-

Ground water remediation techniques span biological, chemical, and physical treatment technologies. Most ground water treatment techniques utilize a combination of technologies. Some of the biological treatment techniques include bioaugmentation, bioventing, biosparging, bioslurping, and phytoremediation. Some chemical treatment techniques include ozone and oxygen gas injection, chemical precipitation, membrane separation, ion exchange, carbon absorption, aqueous chemical oxidation, and surfactant enhanced recovery. Some chemical techniques may be implemented using nanomaterials. Physical treatment techniques include, but are not limited to, pump and treat, air sparging, and dual phase extraction.

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Biological treatment technologies

Bioaugmentation

If a treatability study shows no degradation (or an extended lab period before significant degradation is achieved) in contamination contained in the groundwater, then inoculation with strains known to be capable of degrading the contaminants may be helpful. This process increases the reactive enzyme concentration within the bioremediation system and subsequently may increase contaminant degradation rates over the nonaugmented rates, at least initially after inoculation.<sup>[2]</sup>

Bioventing

Bioventing is an on site remediation technology that uses microorganisms to biodegrade organic constituents in the groundwater system. Bioventing enhances the activity of indigenous bacteria and archaea and stimulates the natural in situ biodegradation of hydrocarbons by inducing air or oxygen flow into the unsaturated zone and, if necessary, by adding nutrients.<sup>[3]</sup> During bioventing, oxygen may be supplied through direct air injection into residual contamination in soil. Bioventing primarily assists in the degradation of adsorbed fuel residuals, but also assists in the degradation of volatile organic compounds (VOCs) as vapors move slowly through biologically active soil.<sup>[4]</sup>

Biosparging

Biosparging is an in situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents in the saturated zone. In biosparging, air (or oxygen) and nutrients (if needed) are injected into the saturated zone to increase the biological activity of the indigenous microorganisms. Biosparging can be used to reduce concentrations of petroleum constituents that are dissolved in groundwater, adsorbed to soil below the water table, and within the capillary fringe.

Bioslurping

Bioslurping combines elements of bioventing and vacuum-enhanced pumping of free-product that is lighter than water (light non-aqueous phase liquid or LNAPL) to recover free-product from the groundwater and soil, and to bioremediate soils. The bioslurper system uses a “slurp” tube that extends into the free-product layer. Much like a straw in a glass draws liquid, the pump draws liquid (including free-product) and soil gas up the tube in the same process stream. Pumping lifts LNAPLs, such as oil, off the top of the water table and from the capillary fringe (i.e., an area just above the saturated zone, where water is held in place by capillary forces). The LNAPL is brought to the surface, where it is separated from water and air. The biological processes in the term “bioslurping” refer to aerobic biological degradation of the hydrocarbons when air is introduced into the unsaturated zone contaminated soil.<sup>[5]</sup>

Phytoremediation

In the phytoremediation process certain plants and trees are planted, whose roots absorb contaminants from ground water over time. This process can be carried out in areas where the roots can tap the ground water. Few examples of plants that are used in this process are Chinese Ladder fern *Pteris vittata*, also known as the brake fern, is a highly efficient accumulator of arsenic. Genetically altered cottonwood trees are good absorbers of mercury and transgenic Indian mustard plants soak up selenium well.<sup>[6]</sup>

Permeable reactive barriers

Certain types of permeable reactive barriers utilize biological organisms in order to remediate groundwater.

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Chemical treatment technologies

Chemical precipitation

Chemical precipitation is commonly used in wastewater treatment to remove hardness and heavy metals. In general, the process involves addition of agent to an aqueous waste stream in a stirred reaction vessel, either batchwise or with steady flow. Most metals can be converted to insoluble compounds by chemical reactions between the agent and the dissolved metal ions. The insoluble compounds (precipitates) are removed by settling and/or filtering.

Ion exchange

Ion exchange for ground water remediation is virtually always carried out by passing the water downward under pressure through a fixed bed of granular medium (either cation exchange media and anion exchange media) or spherical beads. Cations are displaced by certain cations from the solutions and ions are displaced by certain anions from the solution. Ion exchange media most often used for remediation are zeolites (both natural and synthetic) and synthetic resins.<sup>[2]</sup>

Carbon adsorption

The most common activated carbon used for remediation is derived from bituminous coal. Activated carbon adsorbs volatile organic compounds from ground water; the compounds attach to the graphite-like surface of the activated carbon.

Chemical oxidation

In this process, called In Situ Chemical Oxidation or ISCO, chemical oxidants are delivered in the subsurface to destroy (converted to water and carbon dioxide or to nontoxic substances) the organics molecules. The oxidants are introduced as either liquids or gasses. Oxidants include air or oxygen, ozone, and certain liquid chemicals such as hydrogen peroxide, permanganate and persulfate. Ozone and oxygen gas can be generated on site from air and electricity and directly injected into soil and groundwater contamination. The process has the potential to oxidize and/or enhance naturally occurring aerobic degradation. Chemical oxidation has proven to be an effective technique for dense non-aqueous phase liquid or DNAPL when it is present.

Surfactant enhanced recovery

Surfactant enhanced recovery increases the mobility and solubility of the contaminants absorbed to the saturated soil matrix or present as dense non-aqueous phase liquid. Surfactant-enhanced recovery injects surfactants (surface-active agents that are primary ingredient in soap and detergent) into contaminated groundwater. A typical system uses an extraction pump to remove groundwater downstream from the injection point. The extracted groundwater is treated aboveground to separate the injected surfactants from the contaminants and groundwater. Once the surfactants have separated from the groundwater they are re-used. The surfactants used are non-toxic, food-grade, and biodegradable. Surfactant enhanced recovery is used most often when the groundwater is contaminated by dense non-aqueous phase liquids (DNAPLs). These dense compounds, such as trichloroethylene (TCE), sink in groundwater because they have a higher density than water. They then act as a continuous source for contaminant plumes that can stretch for miles within an aquifer. These compounds may biodegrade very slowly. They are commonly found in the vicinity of the original spill or leak where capillary forces have trapped them.<sup>[7]</sup>

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### Permeable reactive barriers

Some permeable reactive barriers utilize chemical processes to achieve groundwater remediation.

### Physical treatment technologies

#### Pump and treat

Pump and treat is one of the most widely used ground water remediation technologies. In this process ground water is pumped to the surface and is coupled with either biological or chemical treatments to remove the impurities.

#### Air sparging

Air sparging is the process of blowing air directly into the ground water. As the bubbles rise, the contaminants are removed from the groundwater by physical contact with the air (i.e., stripping) and are carried up into the unsaturated zone (i.e., soil). As the contaminants move into the soil, a soil vapor extraction system is usually used to remove vapors.<sup>[8]</sup>

#### Dual phase vacuum extraction

Dual-phase vacuum extraction (DPVE), also known as multi-phase extraction, is a technology that uses a high-vacuum system to remove both contaminated groundwater and soil vapor. In DPVE systems, a high-vacuum extraction well is installed with its screened section in the zone of contaminated soils and groundwater. Fluid/vapor extraction systems depress the water table and water flows faster to the extraction well. DPVE removes contaminants from above and below the water table. As the water table around the well is lowered from pumping, unsaturated soil is exposed. This area, called the capillary fringe, is often highly contaminated, as it holds undissolved chemicals, chemicals that are lighter than water, and vapors that have escaped from the dissolved groundwater below. Contaminants in the newly exposed zone can be removed by vapor extraction. Once above ground, the extracted vapors and liquid-phase organics and groundwater are separated and treated. Use of dual-phase vacuum extraction with these technologies can shorten the cleanup time at a site, because the capillary fringe is often the most contaminated area.<sup>[9]</sup>

#### Monitoring-well oil skimming

Monitoring-wells are often drilled for the purpose of collecting ground water samples for analysis. These wells, which are usually six inches or less in diameter, can also be used to remove hydrocarbons from the contaminant plume within a groundwater aquifer by using a belt-style oil skimmer. Belt oil skimmers, which are simple in design, are commonly used to remove oil and other floating hydrocarbon contaminants from industrial water systems.

A monitoring-well oil skimmer remediates various oils, ranging from light fuel oils such as petrol, light diesel or kerosene to heavy products such as No. 6 oil, creosote and coal tar. It consists of a continuously moving belt that runs on a pulley system driven by an electric motor. The belt material has a strong affinity for hydrocarbon liquids and for shedding water. The belt, which can have a vertical drop of 100+ feet, is lowered into the monitoring well past the LNAPL/water interface. As the belt moves through this interface, it picks up liquid hydrocarbon contaminant which is removed and collected at ground level as the belt passes through a wiper mechanism. To the extent that DNAPL hydrocarbons settle at the bottom of a monitoring well, and the lower pulley of the belt skimmer reaches them, these contaminants can also be removed by a monitoring-well oil skimmer.

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Typically, belt skimmers remove very little water with the contaminant, so simple weir-type separators can be used to collect any remaining hydrocarbon liquid, which often makes the water suitable for its return to the aquifer. Because the small electric motor uses little electricity, it can be powered from solar panels or a wind turbine, making the system self-sufficient and eliminating the cost of running electricity to a remote location.<sup>[10]</sup>

## IV. CONCLUSIONS

Groundwater recharging is also done in Banswara, Rajasthan:-

Groundwater recharge or deep drainage or deep percolation is a hydrologic process, where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Groundwater recharge also encompasses water moving away from the water table farther into the saturated zone.<sup>[1]</sup> Recharge occurs both naturally (through the water cycle) and through anthropogenic processes (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface.

The most common methods to estimate recharge rates are: chloride mass balance (CMB); soil physics methods; environmental and isotopic tracers; groundwater-level fluctuation methods; water balance (WB) methods (including groundwater models (GMs)); and the estimation of baseflow (BF) to rivers.<sup>[2]</sup>

Diffused or focused mechanisms

Groundwater recharge can occur through diffuse or focused mechanisms. Diffuse recharge occurs when precipitation infiltrates through the soil to the water table, and is by definition distributed over large areas. Focussed recharge occurs where water leaks from surface water sources (rivers, lakes, wadis, wetlands) or land surface depressions, and generally becomes more dominant with aridity.<sup>[2]</sup>

Water is recharged naturally by rain and snow melt and to a smaller extent by surface water (rivers and lakes). Recharge may be impeded somewhat by human activities including paving, development, or logging. These activities can result in loss of topsoil resulting in reduced water infiltration, enhanced surface runoff and reduction in recharge. Use of groundwater, especially for irrigation, may also lower the water tables. Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate abstracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged.

Recharge can help move excess salts that accumulate in the root zone to deeper soil layers, or into the groundwater system. Tree roots increase water saturation into groundwater reducing water runoff.<sup>[3]</sup> Flooding temporarily increases river bed permeability by moving clay soils downstream, and this increases aquifer recharge.<sup>[4]</sup>

Wetlands

Wetlands help maintain the level of the water table and exert control on the hydraulic head.<sup>[5]</sup> This provides force for groundwater recharge and discharge to other waters as well. The extent of groundwater recharge by a wetland is dependent upon soil, vegetation, site, perimeter to volume ratio, and water table gradient.<sup>[6]</sup> Groundwater recharge occurs through mineral soils found primarily around the edges of wetlands.<sup>[7]</sup> The soil under most wetlands is

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relatively impermeable. A high perimeter to volume ratio, such as in small wetlands, means that the surface area through which water can infiltrate into the groundwater is high.<sup>[8]</sup> Groundwater recharge is typical in small wetlands such as prairie potholes, which can contribute significantly to recharge of regional groundwater resources.<sup>[8]</sup> Researchers have discovered groundwater recharge of up to 20% of wetland volume per season.<sup>[8]</sup>

### Artificial groundwater recharge

Managed aquifer recharge (MAR) strategies to augment freshwater availability include streambed channel modification, bank filtration, water spreading and recharge wells.<sup>[9]:110</sup>

Artificial groundwater recharge is becoming increasingly important in India, where over-pumping of groundwater by farmers has led to underground resources becoming depleted. In 2007, on the recommendations of the International Water Management Institute, the Indian government allocated ₹1,800 crore (equivalent to ₹46 billion or US\$580 million in 2020) to fund dug-well recharge projects (a dug-well is a wide, shallow well, often lined with concrete) in 100 districts within seven states where water stored in hard-rock aquifers had been over-exploited. Another environmental issue is the disposal of waste through the water flux such as dairy farms, industrial, and urban runoff.

Pollution in stormwater run-off collects in retention basins. Concentrating degradable contaminants can accelerate biodegradation. However, where and when water tables are high this affects appropriate design of detention ponds, retention ponds and rain gardens.

### Depression-focused recharge

If water falls uniformly over a field such that field capacity of the soil is not exceeded, then negligible water percolates to groundwater. If instead water puddles in low-lying areas, the same water volume concentrated over a smaller area may exceed field capacity resulting in water that percolates down to recharge groundwater. The larger the relative contributing runoff area is, the more focused infiltration is. The recurring process of water that falls relatively uniformly over an area, flowing to groundwater selectively under surface depressions is depression focused recharge. Water tables rise under such depressions.

Depression focused groundwater recharge can be very important in arid regions. More rain events are capable of contributing to groundwater supply.

Depression focused groundwater recharge also profoundly effects contaminant transport into groundwater. This is of great concern in regions with karst geological formations because water can eventually dissolve tunnels all the way to aquifers, or otherwise disconnected streams. This extreme form of preferential flow, accelerates the transport of contaminants and the erosion of such tunnels. In this way depressions intended to trap runoff water—before it flows to vulnerable water resources—can connect underground over time. Cavitation of surfaces above into the tunnels, results in potholes or caves.

Deeper ponding exerts pressure that forces water into the ground faster. Faster flow dislodges contaminants otherwise adsorbed on soil and carries them along. This can carry pollution directly to the raised water table below and into the groundwater supply. Thus the quality of water collecting in infiltration basins is of special concern.

Rates of groundwater recharge are difficult to quantify.<sup>[10][2]</sup> This is because other related processes, such as evaporation, transpiration (or evapotranspiration) and infiltration processes must first be measured or estimated to

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determine the balance. There are no widely applicable method available that can directly and accurately quantify the volume of rainwater that reaches the water table.<sup>[2]</sup>

The most common methods to estimate recharge rates are: chloride mass balance (CMB); soil physics methods; environmental and isotopic tracers; groundwater-level fluctuation methods; water balance (WB) methods (including groundwater models (GMs)); and the estimation of baseflow (BF) to rivers.<sup>[2]</sup>

Regional, continental and global estimates of recharge commonly derive from global hydrological models.<sup>[2]</sup>

## Physical

Physical methods use the principles of soil physics to estimate recharge. The direct physical methods are those that attempt to actually measure the volume of water passing below the root zone. Indirect physical methods rely on the measurement or estimation of soil physical parameters, which along with soil physical principles, can be used to estimate the potential or actual recharge. After months without rain the level of the rivers under humid climate is low and represents solely drained groundwater. Thus, the recharge can be calculated from this base flow if the catchment area is already known.

## Chemical

Chemical methods use the presence of relatively inert water-soluble substances, such as an isotopic tracer<sup>[11][12][13]</sup> or chloride,<sup>[14]</sup> moving through the soil, as deep drainage occurs.

## Numerical models

Recharge can be estimated using numerical methods, using such codes as Hydrologic Evaluation of Landfill Performance, UNSAT-H, SHAW (short form of Simultaneous Heat and Water Transfer model), WEAP, and MIKE SHE. The 1D-program HYDRUS1D is available online. The codes generally use climate and soil data to arrive at a recharge estimate and use the Richards equation in some form to model groundwater flow in the vadose zone.

## Climate change

The impacts of climate change on groundwater may be greatest through its indirect effects on irrigation water demand via increased evapotranspiration.<sup>[15]:5</sup> There is an observed decline in groundwater storage in many parts of the world. This is due to more groundwater being used for irrigation activities in agriculture, particularly in drylands.<sup>[16]:1091</sup> Some of this increase in irrigation can be due to water scarcity issues made worse by effects of climate change on the water cycle.

Climate change causes changes to the water cycle which in turn affect groundwater in several ways: There can be a decline in groundwater storage, and reduction in groundwater recharge and water quality deterioration due to extreme weather events.<sup>[17]:558</sup> In the tropics intense precipitation and flooding events appear to lead to more groundwater recharge.<sup>[17]:582</sup>

However, the exact impacts of climate change on groundwater are still under investigation.<sup>[17]:579</sup> This is because scientific data derived from groundwater monitoring is still missing, such as changes in space and time, abstraction data and "numerical representations of groundwater recharge processes".<sup>[17]:579</sup>

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Effects of climate change could have different impacts on groundwater storage: The expected more intense (but fewer) major rainfall events could lead to increased groundwater recharge in many environments.<sup>[15]:104</sup> But more intense drought periods could result in soil drying-out and compaction which would reduce infiltration to groundwater.<sup>[18]</sup>

### Urbanization

Further implications of groundwater recharge are a consequence of urbanization. Research shows that the recharge rate can be up to ten times higher<sup>[19]</sup> in urban areas compared to rural regions. This is explained through the vast water supply and sewage networks supported in urban regions in which rural areas are not likely to obtain. Recharge in rural areas is heavily supported by precipitation<sup>[19]</sup> and this is opposite for urban areas. Road networks and infrastructure within cities prevents surface water from percolating into the soil, resulting in most surface runoff entering storm drains for local water supply. As urban development continues to spread across various regions, rates of groundwater recharge will increase relative to the existing rates of the previous rural region. A consequence of sudden influxes in groundwater recharge includes flash flooding.<sup>[20]</sup> The ecosystem will have to adjust to the elevated groundwater surplus due to groundwater recharge rates. Additionally, road networks are less permeable compared to soil, resulting in higher amounts of surface runoff. Therefore, urbanization increases the rate of groundwater recharge and reduces infiltration,<sup>[20]</sup> resulting in flash floods as the local ecosystem accommodates changes to the surrounding environment.

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