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Recharge of groundwater aquifers for dryland farming

Abstract

Aquifers are a vital source of groundwater for agriculture, industry, and human consumption; however, in recent years, they have been subjected to overexploitation, resulting in significant social and economic damage. Given the water scarcity facing Chile, groundwater aquifer recharge has emerged as a new water storage strategy to increase the water supply for agriculture. The general objective of this work is to evaluate the progress made in groundwater aquifer recharge as a strategy to help address water scarcity in the context of climate change. It concludes that groundwater recharge via infiltration or injection is a novel strategy for enhancing irrigation security. Infiltration ponds and infiltration trenches stand out as the most viable infrastructure options for increasing water availability for agriculture. In Chile the General Directorate of Water (GDA) and the National Irrigation Commission (NIC) are the agencies that have promoted public policies regarding aquifer recharge. Furthermore, it is essential to encourage agronomic management practices that improve the soil water infiltration process, a fundamental component of the hydrological cycle.

Keywords: infiltration, injection, water quality, public policies

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Introduction

Agriculture is the sector that consumes the most freshwater, yet it is currently facing a water shortage that has persisted for over a decade. Irrigated agriculture represents 20% of cultivated land and 40% of food production globally; climate predictions are expected to increase the effects of scarcity of water.[1] Therefore, it is essential to increase water availability and the water resource management; key strategies include recharging underground aquifers through infiltration, a process compromised by deforestation, land-use changes, soil compaction, loss of organic matter, and the excessive construction of deep wells that have depleted groundwater reserves in the watersheds of Northern and South Central Chile.[2]

Aquifer recharge is defined as the vertical flow of water reaching the water table to build up groundwater reserves; this process can be natural or artificial[3] and represents a viable method for sustainable water management, maximizing natural storage, enhancing irrigation security, and improving water quality.

Water infiltration is a fundamental process of the hydrological cycle (Figure 1) that has been significantly affected by reduced precipitation, soil resource degradation, desertification, deforestation, and the conversion of land from agricultural to urban use. The infiltration rate is a highly variable hydrological property that depends on various factors, such as texture, structure, macroporosity, bulk density, compaction, slope, vegetation cover, and organic matter content.[4]

Excessive groundwater extraction lowers the water table; however, losses from over-irrigation as well as seepage losses from canal networks can contribute to aquifer recharge through return flows. In this regard, Talib et al.[5] determined that, on average, 33% of applied irrigation water becomes return flow, contributing to groundwater recharge in arid zones. Return flow consists of excess irrigation water that is neither lost to evapotranspiration nor removed via drainage; it ultimately returns to the aquifer, contributing a significant amount to a region's water supply.

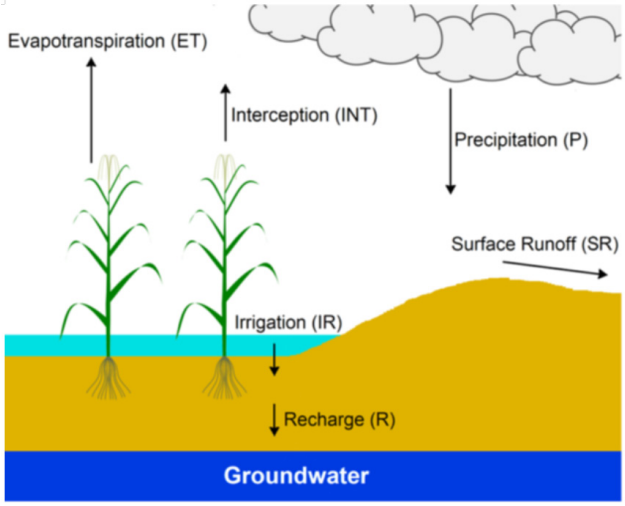


Figure 1 Hydrological cycle and groundwater recharge simulation.

In Chile, due to water scarcity, technical agencies are promoting groundwater recharge. The general objective of this publication is to describe natural and artificial groundwater recharge strategies and to analyze public policies regarding groundwater recharge, using a territorial approach to help address water scarcity in the context of climate change.

Development and discussion

Groundwater aquifer recharge structures

The groundwater balance comprises inflows and outflows. Water inflows include the infiltration of rainwater and surface water; recharge from unused surface water applied during irrigation; artificial recharge from surface water flows; and rainwater that would otherwise flow into the sea due to a lack of reservoirs, or be extracted for irrigation or consumption via wells. In this regard, Arumi et al.[6] in an analysis

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of the water balance between two basins in the Biobío region of Chile (Renegado and Diguillín), it was estimated that 75% of the baseflow that would otherwise flow within the Renegado basin infiltrates the ground and contributes-via subsurface flow-to the Diguillín basin, downstream from the confluence of two basins. In Chile, infiltration via canals is the primary cause of groundwater recharge. Therefore, if the canal network can be managed, it is possible to control recharge a significant finding given that there are 38,500 km of canals in Chile, the majority of which are unlined.

In general, recharge methods fall into two broad categories: surface methods and deep methods. Surface methods rely on water infiltrating through a permeable surface and are suitable for unconfined aquifers located near the surface. Deep methods involve the direct introduction of water into the aquifer; these are used when surface layers have low permeability and/or the confined aquifer lies at a great depth. The most viable structures that can be used for groundwater recharge (Figure 2) are the following:

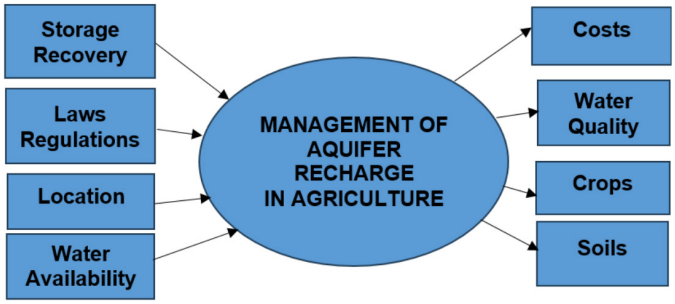


Figure 2 Factors influencing groundwater recharge management in agriculture.

Source: CNR – CSIRO[9] (2020)

Infiltration wells

These are deep recharge devices in which water is directed into a well filled with sand or gravel, allowing it to infiltrate the aquifer. Typically, this involves using runoff from a plot of land or a rooftop, which is collected and channeled into the well. Ideal conditions for their implementation include sandy aquifers and highly permeable soils.

Injection wells

These consist of vertical wells that receive surface water to recharge various subsurface strata. According to Vanegas –Espinoza,[7] unlike infiltration wells, the alternating strata involved here possess varying degrees of permeability.

When direct aquifer injection is performed, it is carried out via deep wells or boreholes, using either gravity or pressure. Water is injected below the piezometric level, referring to the elevation or depth of the boundary between the water table and the vadose zone within an aquifer. The useful life of such systems, when properly operated, is typically 5 to 10 years.

Infiltration lagoons

These are infiltration ponds or basins usually rectangular constructed over sand or gravel aquifers. Water is diverted into these lagoons, which are designed to facilitate infiltration into the aquifer through the unsaturated zone. As surface-level structures, infiltration basins are generally built off-channel; surface water is diverted via gravity or pumping and collected in one or more shallow, large-surface-area lagoons. The water then infiltrates through the unsaturated zone into the unconfined aquifer.

Infiltration trenches

These are ditches excavated along contour lines, perpendicular to the slope of the ground. Their function is to capture runoff, control erosion, and promote soil infiltration. They feature a trapezoidal cross-section with a minimum top width of 50 cm and a base width of 25 cm. The excavated soil is placed along the lower edge of the trench to create a raised berm.[8]

Rainwater infiltration

This method does not require major infrastructure to divert water for storage and subsequent infiltration. It is a technique widely used in rural areas for surface water collection and is increasingly employed to boost natural aquifer recharge rates. Runoff from the roof of a house or structure is diverted into a well or cell filled with sand or gravel, allowing the water to percolate down to the underlying water table.

Aquifer recharge

Aquifer recharge is influenced by various factors, including costs, quantity and quality of available water, and geographical boundaries, among others. Numerous international studies support recharge systems, yet their implementation in Chile remains limited due to low public interest in the agriculture. However, irrigation can contribute around 75% of groundwater aquifer recharge through seepage losses from canals.

Among existing recharge methods, in-channel methods tend to be more cost-effective than off-channel methods. more economical than off-stream methods. Consequently, infiltration trenches and ponds represent the most accessible, cost-effective, and least complex options for implementation. However, these methods are unsuitable for penetrating low-permeability layers unlike deep systems such as wells, which despite their high cost, are capable of penetrating deep, low-permeability strata.

Public policies regarding groundwater aquifer recharge in Chile

Climate change, drought, and rising water demands for human consumption have created a challenge growing water imbalance in various river basins across the country. The primary lines in creating incentives to conserve and reuse water and to improve use efficiency, as well as to increase water availability in basins are through the construction of infiltration systems.

Agriculture and mining are water-intensive activities carried out in these arid and semi-arid regions of Arica, Antofagasta, Tarapacá, Atacama and Coquimbo in the Northern Zone of Chile (18° and 30° South Latitude), where water resources are scarce, and there is intense competition between fruit and vegetable production and the copper and lithium mining industry, though the latter is already primarily using desalinated water.

Furthermore, it is estimated that rising user demand, land-use changes, and climatic variations will lead to a widespread decline in water resources between 2030 and 2060. Given this situation, there is an urgent need to address water vulnerability and low irrigation security. While planning large-scale reservoir projects offers a potential solution, these initiatives require lengthy periods for technical, social, and environmental studies and approvals, as well as for construction, system commissioning, and farmer training. However, while the mining sector has made significant progress through the construction of desalination plants, the agricultural sector lacks applied research regarding groundwater aquifer recharge

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Importance for Agriculture

The hydrological consequences of climate change are also reflected in increased precipitation energy, as well as higher evapotranspiration rates and crop irrigation requirements, and a potential reduction in groundwater recharge, among other factors. Contributing to this situation is the lack of vegetation cover on hillsides and ravines, which has accelerated runoff and reduced groundwater recharge.

The area's most vulnerable to environmental changes particularly hydrological ones are arid regions and rain-fed zones experiencing severe water and soil degradation. These areas face pressure from population growth, food production demands, and the uncontrolled use of surface water and groundwater for irrigation.[10] Therefore, estimating groundwater recharge is essential to ensure the sustainable use of the resource; soil water balances serve as valuable tools for this purpose.[11]

Groundwater is a vital water source for the country's population and economic activities. Furthermore, its storage potential and capacity for conjunctive use with surface water make it immensely valuable for addressing climate change. However, the sustainability of this resource is at risk in certain aquifers because water use rights have been granted that exceed the sustainable extraction capacity of the river basins. The full extent of the problem is not yet widely apparent, as only a few aquifers currently show signs of overexploitation. This is because intensive groundwater use is a relatively recent development in Chile, and, in most of these aquifers, actual water consumption remains far below the volume of rights granted. Nevertheless, the process of overexploitation is intensifying alongside the progressive increase in water use.

It is also important to highlight that land management plays a fundamental role in soil water infiltration and storage. These processes can be improved through practices such as subsoiling, chisel plowing, crop rotation, crop residue incorporation, and the application of organic matter, compost and mulching.

Further studies should focus on the impacts of groundwater management strategies on agriculture and on groundwater quality, specifically regarding fertilizers residues, nitrate leaching, heavy metals, pesticides, pathogens and salts. These factors are directly linked to improving soil health and reducing the pollutant load in groundwater, which is essential for ensuring long-term groundwater quality. Nitrogen fertilizers are the major concern for groundwater contamination due to their excessive application in regions of agricultural development. Another potential risk to human health is the presence of microbial pathogens, arsenic (As) and leaching of pesticide residues below the root zone can be found years after their surface application.[12] Electrical conductivity (< 0,75 dS^{-1}) m and total dissolved solids(TDS)(<500 mg/L), are the key parameters to determine soil water salinity, realizing an water quality analysis so that the groundwater meets the parameters for irrigation water without damage to the soil, pressurized irrigation systems and crop yields.[13]

Conclusion

Groundwater recharge within a territory represents a novel strategy for water storage and the enhancement of irrigation security. Infiltration ponds and infiltration trenches emerge as the most viable measures for increasing water availability for agriculture. Soil management practices are crucial for improving the process of water infiltration into the soil a fundamental component of the hydrological cycle as well as groundwater quality.

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None

Conflicts of interest

The author declare no conflict of interest exists.

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