Ecosystem Service: Groundwater Recharge Service, a Regulating Service

# Introduction

## Definition of Groundwater Recharge Ecosystem Service

Groundwater recharge broadly describes the replenishment of water to a groundwater flow system (Winter 2000). IT is a part of the hydrological regulation process. There are two mains ways about how groundwater recharge service contributes to human well-being: (i) provision of water resources for human use (drinking, irrigation, and industrial use) and (ii) regulating the levels of groundwater table, which make the access to groundwater resources easier and more reliable.

## Previous literature

The studies that valuing groundwater recharge service per se is not many. Most of the previous GEP studies do not isolate groundwater recharge service as a distinct service, but they view the service as a part of the broader categories of hydrological services such as water provisioning service. Therefore, the value of groundwater recharge service is implicitly included in the value of these broader categories. For example, Ouyang et al. (2020) implicitly accounted for the groundwater recharge as part of water provisioning and flood regulation services. Such a treatment of groundwater recharge service can be found in other studies as well (e.g., Deng et al. (2025); Joshi et al. (2025); Pacetti et al. (2024)).

As a studies that explicitly value groundwater recharge service per se, Acharya and Barbier (2000) studies quantify the value of groundwater recharge as a regulating service in the context of agricultural production in wetlands in northern Nigeria. They link the crop yields from recharge-supported irrigation to ecosystem value of groundwater recharge. Based on hypothetical scenarios of groundwater recharge rates, they estimate the value of groundwater recharge as a welfare change for irrigation-dependent agricultural producers in the region. Another study by Brauman, Freyberg, and Daily (2015) estimates the value of groundwater recharge regulating service as a pumping cost for water extraction saved owing to natural groundwater recharge associated with different land use types in Kona, Hawaii. They estimate the monetary value of the groundwater recharge service attributed to a specific land cover scenario as the difference in pumping costs for water before and after the land-use change.

## Research Question

The previous GEP literature does not provide a standalone estimate for groundwater recharge service, rather the value of the service is accounted primarily as a provisioning service, focusing on its contribution to current water supply. Meanwhile, there are some agricultural economics and hydrology studies that focus on valuing groundwater recharge service as a regulating service.

To fill this gap, I estimate the value of groundwater recharge service as a regulating service, focusing on its role in stabilizing aquifer levels. From the perspective of human well-being, this regulating service is important because it helps maintain (or slow) the long-term decline of groundwater levels, thereby avoiding increased pumping costs to extract groundwater and the need for investment in alternative water supply sources or infrastructure adaptation (e.g., drilling deeper wells, more energy-intensive pumping system, or building reservoirs). To quantify this service, I pose the following question: *“If the recharge didn’t happen, what would it cost to deliver the same amount of water to people or systems that currently benefit from it?”*.

For example, groundwater table would decrease in the absence of groundwater recharge regulating service. This would lead to the following two consequences to people (Acharya and Barbier 2000): (i) increased pumping costs to extract groundwater as the groundwater table declines below a certain level, (ii) the need for investment in alternative water supply sources or infrastructure adaptation if the groundwater table declines beyond the maximum depth that can be pumped.

This framing aligns with the idea of the replacement cost approach. The saving in pumping costs associated with the groundwater recharge service has been used as a measure of the value of groundwater recharge in the literature (e.g., Acharya and Barbier (2000), Brauman, Freyberg, and Daily (2015)). This allows for estimating the gross ecosystem product (GEP) of recharge based on the costs that would be incurred to replicate its function artificially or offset the consequences of its absence.

# Methods

I will conduct the analysis on a watershed scale.

[Figure 1](#fig-watershed) shows the 106 major watersheds of the world. The watershed is a convenient scale for this analysis because it is a natural hydrological unit that collects precipitation and drains it into a common outlet, such as a river or lake.

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| --- |
| Figure 1: 106 major watersheds of the world - [Source: UN ATLAS OF THE OCEANS](https://www.oceansatlas.org/subtopic/en/c/593/) |

Due to the lack of data on actual measurement of natural groundwater recharge rate globally, I will use the InVEST Seasonal Water Yield (SWY) model to estimate the amount of groundwater recharge provided from natural ecosystems. I use one of the key outputs of the SWY model called local recharge, which is the amount of net rainfall that infiltrates into soil beyond the root zone.

The valuation of groundwater recharge regulating service is done in the following ways: First, I estimate natural groundwater recharge rate per year for each watershed , () which is derived from the InVEST SWY model. Next, I derive the unit cost of pumping groundwater from the aquifer to the surface as a function of the depth of the water table. The total cost of pumping groundwater consists of three components (Naggar 2003); (i) capital cost of the pumping system, (ii) operation and maintenance cost, and (iii) energy cost which is a function of the depth of the water table. Since I will derive the value of groundwater recharge service as a difference in pumping costs with and without groundwater recharge, the capital cost and operation and maintenance cost of the pumping system, which is assumed to be constant regardless of the depth of the water table, will cancel out in the difference. Thus, all the information I need to proceed the analysis is the marginal cost of pumping water as a function of the depth of the water table. To this end, I will rely on the engineering formula to approximate it (Naggar 2003). The energy cost of pumping a unit volume of water is given by the following formula:

, where is the cost of pumping water (in ) which is a function of the lift height (in ), given that the specific weight of water (approximately ), the pumping efficiency (dimensionless, typically between 0.6 and 0.9), and the energy price (in ). The factor is used to convert energy from joules to kilowatt-hours (), as electricity prices are typically expressed in units of kilowatt-hours (USD/kWh). The energy cost of pumping water is a linear function of the lift height .

Then the total energy cost required to pump of water is given by:

Finally, based on the estimated groundwater recharge rate and the marginal cost function, I will estimate the GEP of groundwater recharge. Suppose that is the status quo water table depth in the presence of groundwater recharge. I will assume is the average depth of the water table in the watershed in the last x years (e.g., 10 years). Let be the water table depth in the absence of groundwater recharge. is obtained by subtracting the estimated groundwater recharge rate from (i.e., ). Then the value of groundwater recharge service in the watershed is estimated as the pumping cost saved due to the groundwater recharge service, which is given by the difference in pumping costs with and without groundwater recharge:

, where of water is pumped from the aquifer in watershed in that year.

# Data

The InVEST SWY model requires the following data inputs: (i) Monthly precipitation (raster data), (ii) Monthly reference evapotranspiration (raster data), (iii) Digital elevation model (raster data), (iv) Land use/land cove (raster data), (v) Soil hydrologic group, and (vi) Biophysical table (.csv file). All of these data are publicly available. The data sources are summarized in Table X. The data on energy price is obtained from IEA (2019).

| Data Type | Description | Source |
| --- | --- | --- |
| Monthly precipitation | Raster data of monthly precipitation | [WorldClim](https://www.worldclim.org/data/worldclim21.html) |
| Monthly reference evapotranspiration | Raster data of monthly reference evapotranspiration | [WorldClim](https://www.worldclim.org/data/worldclim21.html) |

# Limitations and Future Work

While I use the cost of pumping water from the aquifer to the surface as a proxy for the value of groundwater recharge service, the decreasing water table can also lead to other adverse economic consequences in other forms. For example, the declining water table decreases the well yield (i.e., the amount of water that can be pumped from a well per unit time). In the context of agricultural production that depends on irrigation, this can lead to reduce crop yields, as farmers may not be able to satisfy the water demand of their crops in a timely manner. The loss of productivity and the consequential income loss is not captured in the current analysis.

# References

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