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GLASSNET Geospatial Data for Sustainability

A Gridded Dataset for Groundwater Sustainability Restriction Policy Scenarios for the Contiguous U.S.

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Baldos, U. L. C., Haqiqi, I., Hertel, T., Horridge, M., and Liu, J. (2020). SIMPLE-G: A Multiscale Framework for Integration of Economic and Biophysical Determinants of Sustainability *Environmental Modelling & Software, 133:* 104805, DOI: 10.1016/j.envsoft.2020.104805.

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A Gridded Dataset for Groundwater Sustainability Restriction Policy Scenarios for the Contiguous U.S.

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Keywords:

Agricultural economics; water resources; conservation; sustainability; groundwater recharge

Data Items

Three scenarios of "low", "medium", and "high" levels of restriction on groundwater are developed. This dataset includes likely groundwater sustainability restriction policies (GSPs) considering 2010 levels of groundwater withdrawals in the United States. Groundwater sustainability is defined in a rather simplified way assuming the groundwater extraction should not exceed the average recharge rates. The data is provided in NetCDF, GeoTIFF, CSV, and HAR file formats. Table 1 provides a list of data items with brief notes on the method of calculations. The next sections provide more details on the methods.

Table 1. Variable details

Variables	Note	Resolution	Scope	Units
Groundwater extraction to recharge (x/r)*	USGS- Reitz, Circa 2010	5 arc-min	CONUS	ratio
Irrigated area shares in cropland	USGS-MIrAD, Circa 2010	5 arc-min	CONUS	%
Groundwater sustainability restriction GSP2	Keep the x/r ratio at the 2010 level	5 arc-min	CONUS	%
Groundwater sustainability restriction GSP3	Lowering x/r ratio but >> 1	5 arc-min	CONUS	%
Groundwater sustainability restriction GSP4*	Dictate x/r = 1 before re-use	5 arc-min	CONUS	%

* x/r is the extraction to recharge ratio. ** Available in separate files in NetCDF and geoTIFF and combined in HAR and CSV formats. Here, CONUS stands for the Contiguous United States.

Purpose

The study of groundwater sustainability impacts is important, especially in dry regions of the world where water is scarce. Climate change and human activities (over-pumping, contamination, and land use changes) threaten groundwater quality and quantity, causing the drying up of wells, reduction of water in streams and lakes, deterioration of water quality, increased pumping costs, and land subsidence (Bartolino & Cunningham, 2003). Moreover, once groundwater is polluted or depleted, it is very difficult to reverse it. However, the magnitude of a groundwater sustainability policy varies depending on hydrological processes.

Therefore, it is essential to understand the magnitude of such groundwater sustainability policy. This dataset was developed to provide insights into the magnitude and the impacts of likely groundwater sustainability restriction policies (GSPs) for potential use in quantitative studies evaluating the agricultural and economic consequences of water policies in the long run.

Methods

As described by Haqiqi et al (2023), the ratio of groundwater extraction to recharge is calculated over cultivated Contiguous United States (CONUS) around the year 2010, based on average values from 2007 to 2013 for 5 arc-min grid cells.

$$\bar{z}_g = \sum_t X_{g,t} \Big/ \sum_t R_{g,t}$$

$$X_{g,t} = x_{g,t}(\alpha_g A_g)$$

$$R_{g,t} = r_{g,t}(a_g A_g)$$

Where $\bar{z}_g$ shows the average ratio of extraction to recharge for grid cell g; *X* is the groundwater extraction for irrigation indexed by grid cell *g* and year *t*; and *R* is groundwater recharge on irrigated cropland indexed by g and t. Also, *x* is the extraction rate in m/yr; *r* is the recharge rate in m/yr; α shows the share of irrigated area in total cropland in each grid cell; and *A* is the cropland area in the grid cell.

Data sources

As described by Haqiqi et al (2023), the calculation is based on three main gridded datasets for the United States including cultivated cropland, the share of irrigated area, and groundwater extraction and recharge rates. The cropland data is obtained from the United States Department of Agriculture Cropland Data Layer (CDL) at 30-meter resolution and is aggregated to 5 arc-min averages around the year 2010 (Baldos et al., 2020). The share of irrigated area is from Moderate Resolution Imaging Spectroradiometer (MODIS) Irrigated Agriculture Datasets for the Conterminous United States (MIrAD-US) averaged over 2007 and 2012 (Brown et al, 2019). And the data on groundwater recharge is from Reitz et al (2017) averaged over 2007-2013. The results of these calculations are illustrated in Figure 1 (extraction to recharge rates) and Figure 2 (required reduction in extraction in %).

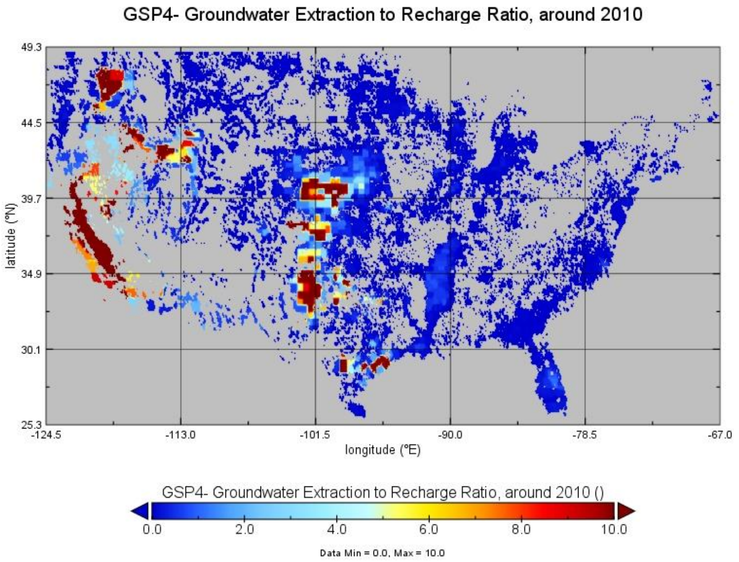
GSP4- Groundwater Extraction to Recharge Ratio, around 2010
49.3
44.5
39.7
34.9
30.1
25.3
latitude (°N)
-124.5
-113.0
-101.5
-90.0
-78.5
-67.0
longitude (°E)
GSP4- Groundwater Extraction to Recharge Ratio, around 2010 ()
0.0
2.0
4.0
6.0
8.0
10.0
Data Min = 0.0, Max = 10.0

Figure 1. The ratio of groundwater extraction to recharge over the United States around the year 2010 is calculated based on USGS MIrAD and Reitz et al (2017).

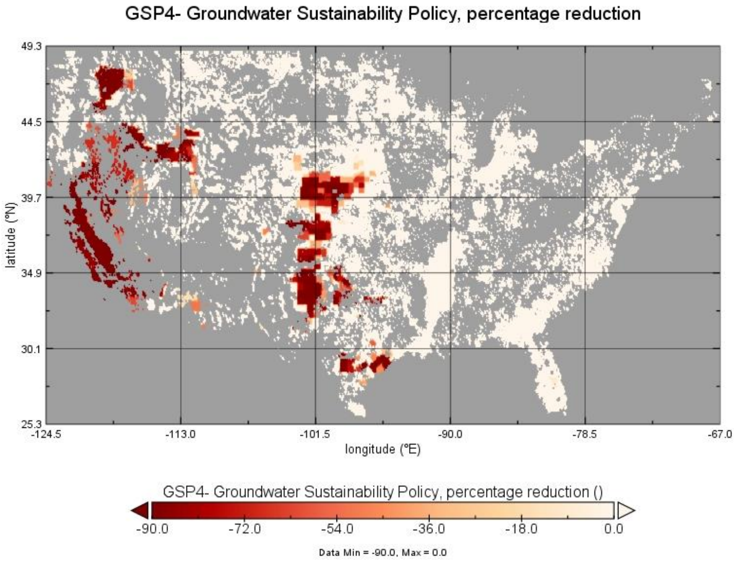
GSP4- Groundwater Sustainability Policy, percentage reduction
49.3
44.5
39.7
34.9
30.1
25.3
latitude (°N)
-124.5
-113.0
-101.5
-90.0
-78.5
-67.0
longitude (°E)
GSP4- Groundwater Sustainability Policy, percentage reduction ()
-90.0
-72.0
-54.0
-36.0
-18.0
0.0
Data Min = -90.0, Max = 0.0

Figure 2. The % change required in groundwater extractions to limit the withdrawals to the recharge rates. This is calculated based on USGS MIrAD and Reitz et al (2017).

For agricultural and economic evaluation purposes, multiple groundwater sustainability policy scenarios (GSP) can be specified. Each GSP dictates a location-specific % reduction in groundwater extraction. GSP2 offers a very low restriction, assuming little to no intervention from local and federal governments but not allowing extraction of more than 2010 average levels (Baldos et al, 2020). This scenario assumes the depletion of groundwater continues but does not speed up. The GSP3 offers a middle-of-the-road scenario with more intervention but not achieving sustainable levels. This scenario attempts to lower the speed of depletion. The GSP4 scenario offers a close-to-sustainability scenario to keep the groundwater table at the 2010 levels (Ray et al, 2023). There is a GSP5 Scenario at the global level that offers a sustainability scenario considering the re-use of extracted groundwater (Haqiqi et al, 2022). The current dataset includes GSP2, GSP3, and GSP4.

How to read the HAR and CSV files

The CSV file includes 75,651 rows of data and one top row for labels. The columns x and y are the coordinates of the center of the grid cell in 5-arcmin, considering "+proj=longlat +datum=WGS84". The FIPS column shows the US county codes. The sub-region column is the code for Farm Resource Regions as described in Haqiqi et al (2023). Note that the LON and LAT headers in the HAR files are showing the coordinate values (longitude and latitude) for the center of the grid cell (in some versions they are multiplied by 120, and the user needs to divide them by 120 to get to the precise coordinates). A working GEMPACK is required to read the HAR files. A free version of GEMPACK software is available on the CoPS website (Harrison & Pearson, 1996; Horridge et al, 2018): www.copsmodels.com/gpwingem.htm and www.copsmodels.com/gpmark9.htm.

R script for calculating the scenarios

```
library(raster)

# This is the irrigated area from USGS MIrAD aggregated to 5 arc-min
mirad_5min = raster("USGS_MIrAD_5min_2010.tif")

# This is the groundwater extraction to recharge rates from Reitz et al (2017)
rate_5min  = raster("Reitz_rate_5min_2010.tif")

# This is the grid IDs of the SIMPLE-G-US model
grid_5min  = raster("SIMPLEG_GRID_5min.tif")

# Excluding the grid cells outside MIrAD
X2R <- (mirad_5min/mirad_5min)*rate_5min

# Calculate the shock and save
shock = 100*(1- X2R)/ X2R
shock[shock > 0] = 0
df <- as.data.frame(rasterToPoints(shock))

write.csv(df, file = "GSP4_GroundwaterSustainabilityPolicy.csv")

writeRaster(shock,
            "GSP4_GroundwaterSustainabilityPolicy_pct.tif",
            format="GTiff",
            overwrite=T)
```

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