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Annual groundwater recharge estimation in Nineveh plain, northern Iraq using Chloride Mass Balance (CMB) method

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Abstract:

This study evaluates groundwater recharge in the Nineveh Plain, northern Iraq, using the Chloride Mass Balance (CMB) method. The CMB method estimates recharge based on the conservation of chloride mass, relying on the comparison of chloride concentrations in precipitation and groundwater. Recharge rates calculated using this method ranged from 0.22 to 2.54 cm/year, with higher values observed in the northern regions due to greater precipitation and favourable infiltration conditions. Validation of the CMB-derived recharge map against hydrological parameters, such as the Curve Number (CN), yielded a strong correlation coefficient of 0.71, affirming the reliability of this method for estimating recharge.

Keywords: CN, Groundwater recharge, Chloride mass balance, Nineveh plain, Iraq

1. Introduction:

The Nineveh Plain in northern Iraq is of significant economic and historical value, known for its fertile soil and abundant archaeological sites, such as the ancient city of Nineveh (MacGinnis & Matney, 2009). The local economy is primarily based on agriculture, which relies extensively on groundwater for irrigation. This dependence has precipitated severe challenges, notably the depletion of groundwater, endangering the sustainability of agriculture, economic security, and the ecological balance (Al-Abadi, Al-Mohammdawi, et al., 2024; Al-Abadi, Hassan, et al., 2024; Al-Mohammdawi et al., 2022; Voss et al., 2013). The excessive withdrawal of groundwater has led to problems like land subsidence, environmental damage, and heightened susceptibility to climate change (Foster & Chilton, 2003; Konikow & Kendy, 2005).

Groundwater recharge, the process of replenishing aquifers through surface water infiltration, is vital for ensuring water availability and addressing these challenges (Mehner, 2009). Recharge supports agricultural, urban, and industrial activities, enhances water quality, and maintains ecological systems. Despite its importance, accurately quantifying recharge in the Nineveh Plain remains difficult due to limited hydrological data, diverse subsurface conditions, and variations in climate and land use patterns.

To address these complexities, various methods are used to estimate recharge, including the water balance method, tracer studies, and soil moisture monitoring, often enhanced by GIS and remote sensing technologies. This study employs the chloride mass balance (CMB) technique to estimate groundwater recharge, overcoming data limitations and providing critical insights for sustainable water resource management. Accurate recharge estimation is key to safeguarding the region's economic and environmental sustainability.

2. Material and Methods:

2.1 The study area:

The Nineveh Plain is located in northern Iraq, within the latitudinal range of 36°47'27.47''N to 35°59'3.57''N and the longitudinal range of 42°44'33.51''E to 43°33'33.91''E. The study area spans approximately 2547 km² in the eastern part of Mosul Governorate. It is bounded by Lake Mosul to the north, the Great Zab River to the south, and the Tigris River along its western edge, as shown in Fig. (1). The region experiences a climate transitioning from semi-arid to Mediterranean, characterized by hot, dry summers with temperatures exceeding 40°C and mild winters ranging from 5°C to 15°C. Most of the rainfall occurs during the winter months (November to March), with an annual average of 400–600 mm, which is vital for agriculture. However, the arid summers pose significant challenges for water resource management.

The terrain elevation ranges between 182 and 1049 m, averaging 328.64 ± 104.26 m, Fig. (1). the area's central and southern regions are comparatively flat, whereas the northern and northeastern parts are characterized by hills and valleys.

The Nineveh Plain soils are categorized into three hydrological soil groups (HSGs): B Soils with moderate infiltration rates. Typically consist of sandy loam soils, allowing moderate water infiltration, C soil with low infiltration rates. Often contain higher clay content or partially impervious layers, reducing water infiltration and increasing surface runoff, D Soils with very low infiltration rates or almost no infiltration. Include heavy clay soils or soils with shallow rock layers, severely limiting water infiltration and causing high surface runoff. The study area is primarily dominated by HSGs C and D, covering 36% (919 km²) and 54% (1383 km²), respectively. Group B covers only 9% (244 km²). This suggests that low recharge and high runoff generation are the dominant hydrological processes in the region.

The hydrogeological framework of the region is characterized by a dominance of sedimentary rocks, including limestone, sandstone, and alluvial deposits. Groundwater resources are primarily contained within Quaternary and Tertiary formations, notably the Mukdadiya, Bai Hassan, and Injana formations. The absence of a regional confining layer, coupled with the presence of faults and fractures, gives rise to a hydraulically interconnected, unconfined aquifer system. Groundwater depths exhibit spatial variability, ranging from 11 to 66 m, with an average depth of 116.47 ± 19.44 m. A general trend of decreasing depth from west to east is observed.

Transmissivity and specific yield, critical parameters for aquifer characterization, were assessed through pumping tests at 12 boreholes (Al-Ozeer et al., 2021). The transmissivity values displayed considerable variability, ranging from 4.7 to 524.5 m²/d, with an average of 113.71 ± 161.31 m²/d. In comparison, the specific yield values were more consistent, spanning from 0.001 to 0.009 v/v , and averaging 0.005 ± 0.0027.

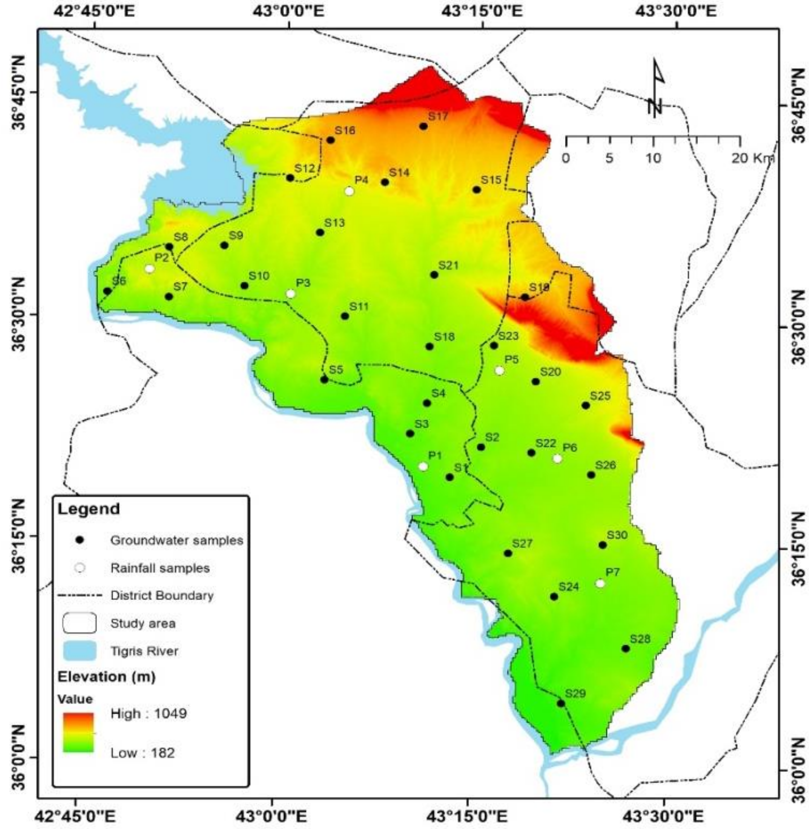

Fig. 1 Location of the study area with elevation in m.

2. 1Data Sate:

Water samples were collected from available wells and analysed, along with previously collected data, to map the spatial distribution of chloride ions. This map, combined with chloride concentrations in rainwater samples, enabled the calculation of the annual groundwater recharge rate. Water samples were analysed at Nahran Omar laboratories, Basra Oil Company. A total of 30 groundwater samples and 7 rainwater samples were analysed. Groundwater samples were collected in pre-cleaned bottles and stored in a refrigerator. Temperature, electrical conductivity, pH, and total dissolved solids (TDS) were measured in situ for both rain and groundwater samples.

2.2 Chloride Mass Balance (CMB) method:

The Chloride Mass Balance (CMB) technique is a widely used approach for estimating groundwater recharge, particularly in arid and semi-arid regions (Gebru & Tesfahunegn, 2019). This method relies on the principle of mass conservation, using chloride as a conservative tracer to calculate the volume of water that replenishes the groundwater system (Xu & Beekman, 2019).

The Chloride Mass Balance (CMB) method assumes that chloride originates mainly from atmospheric deposition, including precipitation and dry fallout. It is considered a conservative tracer in the unsaturated zone (Cooper et al., 2013), implying it undergoes minimal chemical or biological alterations affecting its concentration. As water filters down through the soil to the groundwater, chloride levels rise owing to evapotranspiration, which extracts water but retains chloride.

The groundwater recharge (R) can be estimated using CMB method via the following equation (Wood & Sanford, 1995):

$$R = \frac{P \times C_P}{C_{gw}} \qquad (1)$$

where, P is the annual precipitation (mm/y), C_P is the chloride concentration in precipitation (mg/L), and C_{gw} is the chloride concentration in groundwater (mg/L).

A time-averaged map of total precipitation for the years 2000 to 2019 was created using data from the Tropical Rainfall Measuring Mission (TRMM), which has a spatial resolution of 0.25° × 0.25°. This data was accessed through NASA's Giovanni, a web-based platform that offers a variety of Earth, climate, and environmental datasets (Hassan et al., 2024). Figure 2 displays the total precipitation map for the study area, which was resampled to a resolution of 30 × 30 m and adjusted to fit the polygon representing the study area.

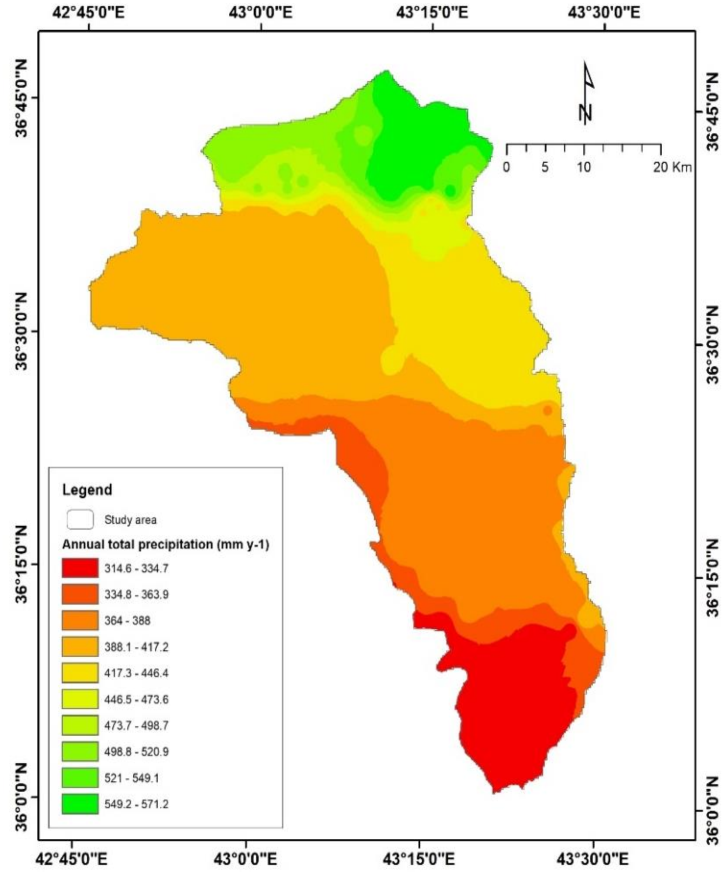

Fig. 2 Distribution of annual total precipitation (mm/y)

The ordinary kriging (OK) method was used to interpolate the field data of groundwater and rainfall chloride concentrations (Fig. 3a, b). Finally, the raster calculator in ArcGIS software was used to apply Eq. (1) and generate a map of the annual groundwater recharge in the study area (Fig. 4).

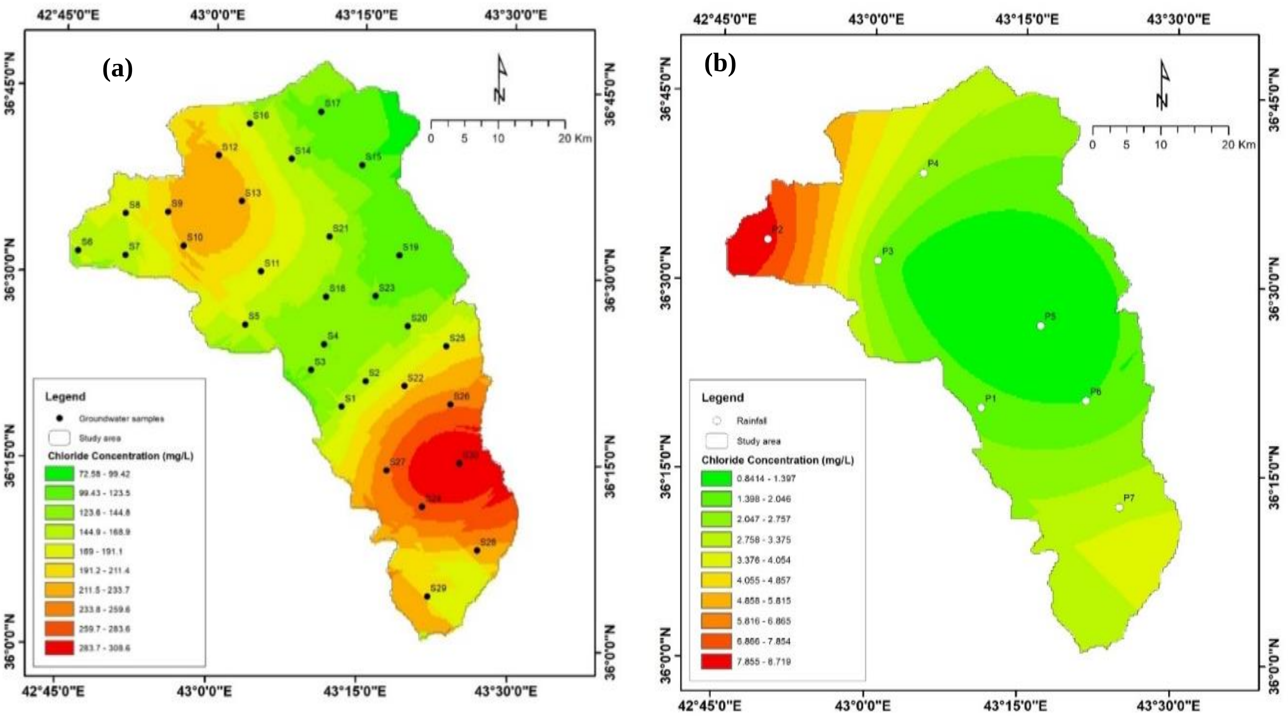

Fig. 3 Distribution of chloride concentration in (a) groundwater (mg/L) and (b) rainfall (mg/L)

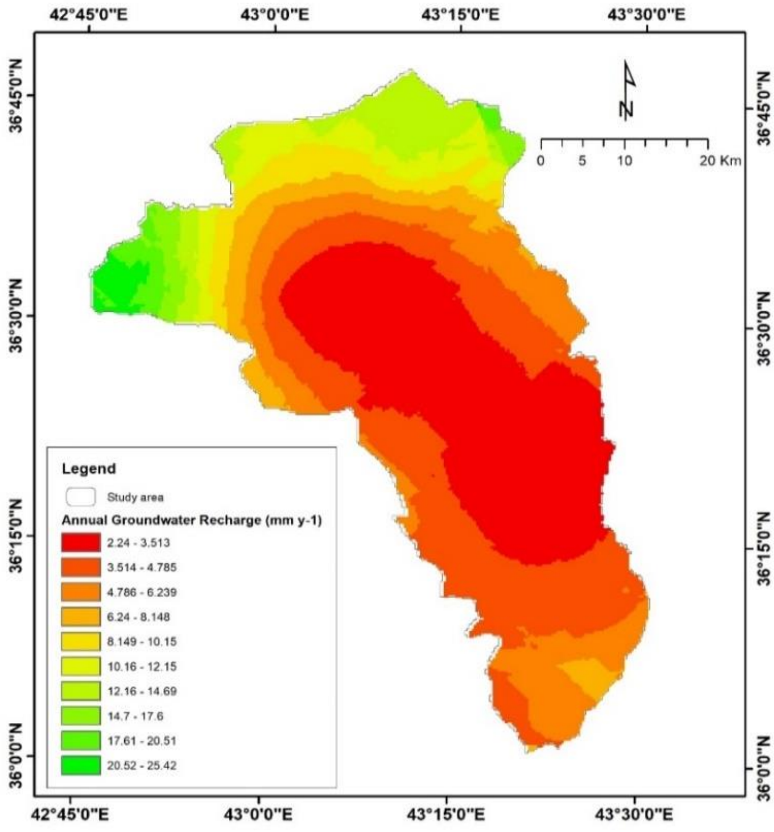

Fig. 4 Annual groundwater recharge (mm/y) estimated by CMB technique

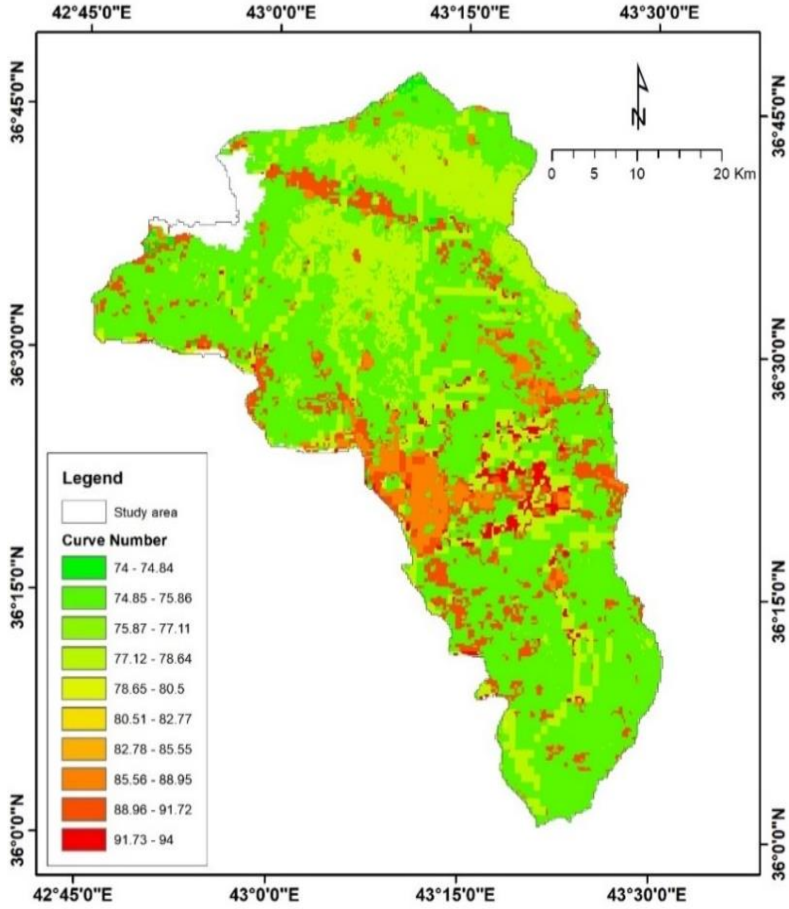

Fig. 5 Curve number of the study area (After Jaafar et al. (2019))

2.3 Validation of the groundwater recharge map:

To validate the groundwater recharge map, the global hydrological curve number (CN) map (Jaafar et al., 2019) was used. The CN, an empirical parameter in hydrology, predicts direct runoff from excess rainfall (Ahmad et al., 2015). A higher CN indicates a greater potential for runoff, implying a lower potential for groundwater recharge. The original data, gridded globally at 250 × 250 m resolution based on 300 m spatial resolution land cover and 250 m resolution soil data, was resampled to 30 × 30 m to align with other maps created for this study. Figure (5) displays the CN map for the study area.

3. Results And Discussion:

The precipitation map (Fig. 2) indicates that annual precipitation ranges from 314.58 to 571.19 mm/year, with an average of 409.68 ± 60.95 mm/year. Precipitation increases from west to east, with the lowest amounts in the southern region and the highest in the northern and northeastern regions. Chloride concentrations in groundwater samples range from 5.8 mg/L to 660.7 mg/L, with an average of 173.75 ± 160.01 mg/L. For rainfall, chloride concentrations range from 0.9 mg/L to 8.3 mg/L, with an average of 2.85 ± 2.33 mg/L. Spatially, the chloride concentration in groundwater (Fig.3a) is higher in the southern region.

and parts of the north western region near Mosul lake, while the central, northern, and northeastern regions exhibit lower chloride concentrations. The chloride concentration in rainfall (Fig. 3b) is relatively higher in the north western region compared to other areas within the study area. Groundwater recharge values derived from the CMB method (Fig. 4) range from 0.22 to 2.54 cm/year, with an average of 0.61 ± 0.43 cm/year. Recharge is highest in the northern regions, lower in the central plain, and moderate in the southern regions.

The groundwater recharge map (Fig. 4), derived using the CMB method, and was validated using the CN map (Fig. 5) by calculating the correlation coefficient (*r*) through the *Band Collection Statistics module* in ArcGIS 10.8 software. The calculated *r* between the two maps was 0.71, indicating that the CMB map successfully passed the validation test based on the assumption that CN is a good indicator of runoff generation and the absence of recharge. Overall, the CN values were extremely high, ranging from 74 to 94, with an average of 78.23 ± 5.57, which suggests the dominance of runoff generation over groundwater recharge.

Groundwater recharge calculations utilizing the CMB method offer granular insights into localized recharge dynamics within the study area. This method, grounded in the analysis of chloride concentrations in precipitation and groundwater, provides an estimate of recharge rates principally driven by direct rainfall infiltration. The spatial variability observed in the recharge rates derived from the CMB method mirrors the heterogeneity of the study area's geographical and hydrological conditions.

The northern regions of the study area demonstrated higher recharge rates than those in the south. This trend aligns with the climatic characteristics of the area, where the northern zones generally experience greater precipitation. Additionally, the favourable topography and soil conditions in these regions further promote enhanced infiltration. Despite the localized focus of the CMB method, it effectively captured the recharge distribution across the study area. The results highlight the importance of considering rainfall and infiltration as primary contributors to groundwater recharge, especially in semi-arid regions where these processes are critical for aquifer sustainability. The validation of the CMB-derived recharge map using the Curve Number (CN) method further substantiated the results, with a correlation coefficient of 0.71, indicating a good agreement between the two methods. This validation enhances confidence in the CMB method's ability to accurately identify recharge zones and provides a reliable basis for regional groundwater management strategies.

4. Conclusions:

The main conclusions of this study are: (1) The CMB method effectively estimates groundwater recharge by directly linking rainfall infiltration to groundwater replenishment. In this study, recharge rates varied from 0.22 to 2.54 cm/year, highlighting the significant contribution of precipitation. (2) While the CMB method is primarily suited for regions where rainfall is the dominant recharge source, it may not fully account for other water inputs like surface water or irrigation return flows. (3) The CMB method revealed a clear spatial trend of increasing recharge rates from south to north, aligning with regional climatic and geographic factors. This underscores the method's ability to capture spatial variability in recharge dynamics. (4) To gain a more comprehensive understanding of groundwater recharge, integrating the CMB method with other techniques like remote sensing or hydrological modeling is recommended.

References:

Al-Abadi, A. M., Al-Mohammdawi, J. A., Abass, A. K., Jabbar, F. K., Mohamod, M. S., & Alzahrani, H. (2024). The spatial and temporal variation of the terrestrial water storage anomaly (TWSA) of Iraq for the period 2002–2019 based on GRACE gravity data. *Kuwait Journal of Science*, *51*(4), 100275.

Al-Abadi, A. M., Hassan, A. A., Al-Moosawi, N. M., Handhal, A. M., Alzahrani, H., Jabbar, F. K., & Anderson, N. L. (2024). Drought susceptibility mapping in Iraq using GRACE/GRACE-FO, GLDAS, and machine learning algorithms. *Physics and Chemistry of the Earth, Parts A/B/C*, 103583.

Al-Mohammdawi, J. A., Al-Abadi, A. M., Al-Ali, A. K., Shahid, S., Fryar, A., & Wang, X. (2022). Assessing the spatial and temporal variations of terrestrial water storage of Iraq using GRACE satellite data and reliability–resiliency–vulnerability indicators. *Arabian Journal of Geosciences*, *15*(4), 1–13.

Al-Ozeer, A. Z. A., Al-Abadi, A. M., Hussain, T. A., Fryar, A. E., Pradhan, B., Alamri, A., & Abdul Maulud, K. N. (2021). Modeling of Groundwater Potential Using Cloud Computing Platform: A Case Study from Nineveh Plain, Northern Iraq. *Water*, *13*(23), 3330.

Cook, P. G., & Herczeg, A. L. (2012). *Environmental tracers in subsurface hydrology*.

Cooper, C. A., Hershey, R. L., Healey, J. M., & Lyles, B. F. (2013). *Estimation of Groundwater Recharge at Pahute Mesa using the Chloride Mass-Balance Method*. Desert Research Inst.(DRI), Reno, NV (United States).

Foster, S. S. D., & Chilton, P. J. (2003). Groundwater: The processes and global significance of aquifer degradation. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, *358*(1440), 1957–1972.

Gebru, T. A., & Tesfahunegn, G. B. (2019). Chloride mass balance for estimation of groundwater recharge in a semi-arid catchment of northern Ethiopia. *Hydrogeology Journal*, *27*(1).

Hanna, R., & Kruczek, G. J. (2020). Contested control: The future of security in Iraq's Nineveh Plain. *Assyrian Policy Institute, June*.

Healy, R. W. (2010). *Estimating groundwater recharge*. Cambridge university press.

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B. M., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M. N., Geng, X., & Bauer-Marschallinger, B. (2017). SoilGrids250m: Global gridded soil information based on machine learning. *PLoS One*, *12*(2), e0169748.

Konikow, L. F., & Kendy, E. (2005). Groundwater depletion: A global problem. *Hydrogeology Journal*, *13*(1), 317–320.

Kummerow, C., Barnes, W., Kozu, T., Shiue, J., & Simpson, J. (1998). The tropical rainfall measuring mission (TRMM) sensor package. *Journal of Atmospheric and Oceanic Technology*, *15*(3), 809–817.

Liaqat, M. U., Mohamed, M. M., Chowdhury, R., Elmahdy, S. I., Khan, Q., & Ansari, R. (2021). Impact of land use/land cover changes on groundwater resources in Al Ain region of the United Arab Emirates using remote sensing and GIS techniques. *Groundwater for Sustainable Development*, *14*, 100587.

MacGinnis, J., & Matney, T. (2009). Archaeology at the frontiers: Excavating a provincial capital of the Assyrian empire. *Journal of Assyrian Academic Studies*, *23*(1), 3–21.

Mehner, T. (2009). *Encyclopedia of inland waters*. Academic Press.

Ross, C. W., Prihodko, L., Anchang, J., Kumar, S., Ji, W., & Hanan, N. P. (2018). *Global hydrologic soil groups (HYSOGs250m) for curve number-based runoff modeling. ORNL DAAC, Oak Ridge, Tennessee, USA.*

Scanlon, B. R., Jolly, I., Sophocleous, M., & Zhang, L. (2007). Global impacts of conversions from natural to agricultural ecosystems on water resources: Quantity versus quality. *Water Resources Research*, *43*(3).

Sokolov, A. A., & Chapman, T. G. (1974). *Methods for water balance computations: An international guide for research and practice.*

Theon, J. S. (1994). The tropical rainfall measuring mission (TRMM). *Advances in Space Research*, *14*(3), 159–165.

Voss, K. A., Famiglietti, J. S., Lo, M., De Linage, C., Rodell, M., & Swenson, S. C. (2013). Groundwater depletion in the Middle East from GRACE with implications for transboundary water management in the Tigris-Euphrates-Western Iran region. *Water Resources Research*, *49*(2), 904–914.

Wood, W. W., & Sanford, W. E. (1995). Chemical and isotopic methods for quantifying ground-water recharge in a regional, semiarid environment. *Groundwater*, *33*(3), 458–468.

Xu, Y., & Beekman, H. E. (2019). Groundwater recharge estimation in arid and semi-arid southern Africa. *Hydrogeology Journal*, *27*(3), 929–943.

Conflicts of Interest Statement……………………………………………

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