Irrigated crop production

https://doi.org/10.1038/s44221-023-00185-3

Groundwater depletion reduces drought resiliency

James J. Butler Jr & Donald O. Whittemore

Pioneering empirical assessment shows decreases in aquifer thickness diminish the capacity of groundwater supplies to buffer agricultural production from drought.

Many of the world's major aquifers are under severe stress from intensive pumping of groundwater in support of irrigated agriculture[1]. Large water-level declines and the drying up of groundwater-fed streams are common manifestations of this pumping-induced stress. The future for these aquifers and the food production that they support is a question of utmost urgency in a world of burgeoning population, dietary shifts and climate change.

The High Plains of the central United States is a grain-producing area of global importance. Given the semi-arid conditions common to the region, groundwater-supported irrigated agriculture has become the major means for achieving high levels of agricultural production. Groundwater plays a key role in buffering production from the effects of drought, thereby enhancing the region's drought resiliency. The High Plains Aquifer (HPA) is the primary groundwater source for much of the region, but it has been heavily depleted in many areas[2]. The ramifications of this depletion for drought resiliency and agricultural production are of considerable societal import.

Now, writing in *Nature Water*, Taro Mieno and colleagues address these issues by providing a sorely needed empirical assessment of the resiliency of HPA-supported agricultural production to drought[3]. Using more than 30 years of agricultural and hydrologic data, they show that crop yield and overall production decrease nonlinearly with aquifer thickness in response to drought-induced water deficits. As the aquifer thins, irrigated area decreases as more land transitions to dryland agriculture; drought-related production losses in the thinnest portions of the aquifer can be up to 25% above those in the thickest portions. Previous work has shown that the impact on the region's economy is significant[4].

These findings and Mieno and colleagues' accompanying discussion of thresholds and tipping points indicate that continuation of business as usual will not end well for many areas overlying the HPA (Fig. 1). There is no great mystery about what needs to be done in the HPA and similar settings elsewhere. Simply put, groundwater pumping must be reduced. Three options are commonly proposed. First, replace the groundwater with surface water, either directly through irrigation or indirectly via recharge. However, in many semi-arid areas, there is little to no excess surface water available. In that case, long-distance water transfers could be the answer, but, unless a large governmental entity can fund the transfer project's construction and operation, the finances make little sense for grain production. A second option is to replace inefficient irrigation technology with more efficient means via cost shares and other incentive programmes. Although intuitively appealing, experiences from around the globe have shown that this does not lead to a reduction in groundwater use[5]. In the absence of a binding agreement to reduce pumping, irrigators will follow the economically sensible path and use the 'saved' water for growing more water-intensive crops or increasing their irrigated area. A third option is to directly reduce pumping in conjunction with modification of agricultural practices through precision agriculture, changing crop mixes, and other means. Although the legal, regulatory and social frameworks can introduce significant complexities[6,7], this is likely the only viable option in semi-arid areas without ready access to surface water.

One approach to reduce irrigation pumping in the HPA via this third option is the Local Enhanced Management Area (LEMA) programme in the western portion of the State of Kansas. The underlying idea is that irrigators in a defined area collectively decide how much to reduce water use and for what time period, after which everyone in that area must follow the agreed-upon rules, with the state regulatory agency ensuring compliance. This combination of a grassroots-generated plan to extend the aquifer's lifespan supported by a binding regulatory order appears to hold much promise. Details matter however, as the geographical extent and the plan rules play an important role in determining the effectiveness of such efforts[6]. The first LEMA was established in northwestern Kansas in 2013, and results from that and areas established since have shown that considerable progress can be made by reducing annual pumping by up to 25% with little to no economic impact. But not all areas have plans that will make much of a difference[7–9].

The findings of Mieno and colleagues provide a wake-up call to managers of groundwater resources in semi-arid areas by linking aquifer depletion to agricultural production and drought resiliency. Charting paths forward in these settings can be difficult, particularly in the absence of reliable data. The major stress on aquifers supporting irrigated agriculture is groundwater pumping. Yet, in many areas in the United States and elsewhere, groundwater use is frequently not monitored by water managers or other entities. Groundwater managers in the central and northern portions of the HPA have recognized the value of monitoring pumping. The US leader in this regard is Kansas, where more than 99% of the non-domestic pumping wells have totalizing flowmeters and are subject to annual reporting and regulatory verification; the value of that data has been demonstrated repeatedly[9,10]. In the absence of metering, pumping must be estimated from utility records, remote sensing, crop-water requirements, and other means, which can introduce considerable uncertainty into analyses. The agrohydrology community must resolve to vastly improve monitoring of pumping so that we can heed the call of Mieno and colleagues and take steps to better position our aquifers and the agricultural production that they support to face the climatic challenges that lie ahead.

James J. Butler Jr & Donald O. Whittemore
Kansas Geological Survey, University of Kansas, Lawrence, KS, USA.
e-mail: jbutler@ku.edu

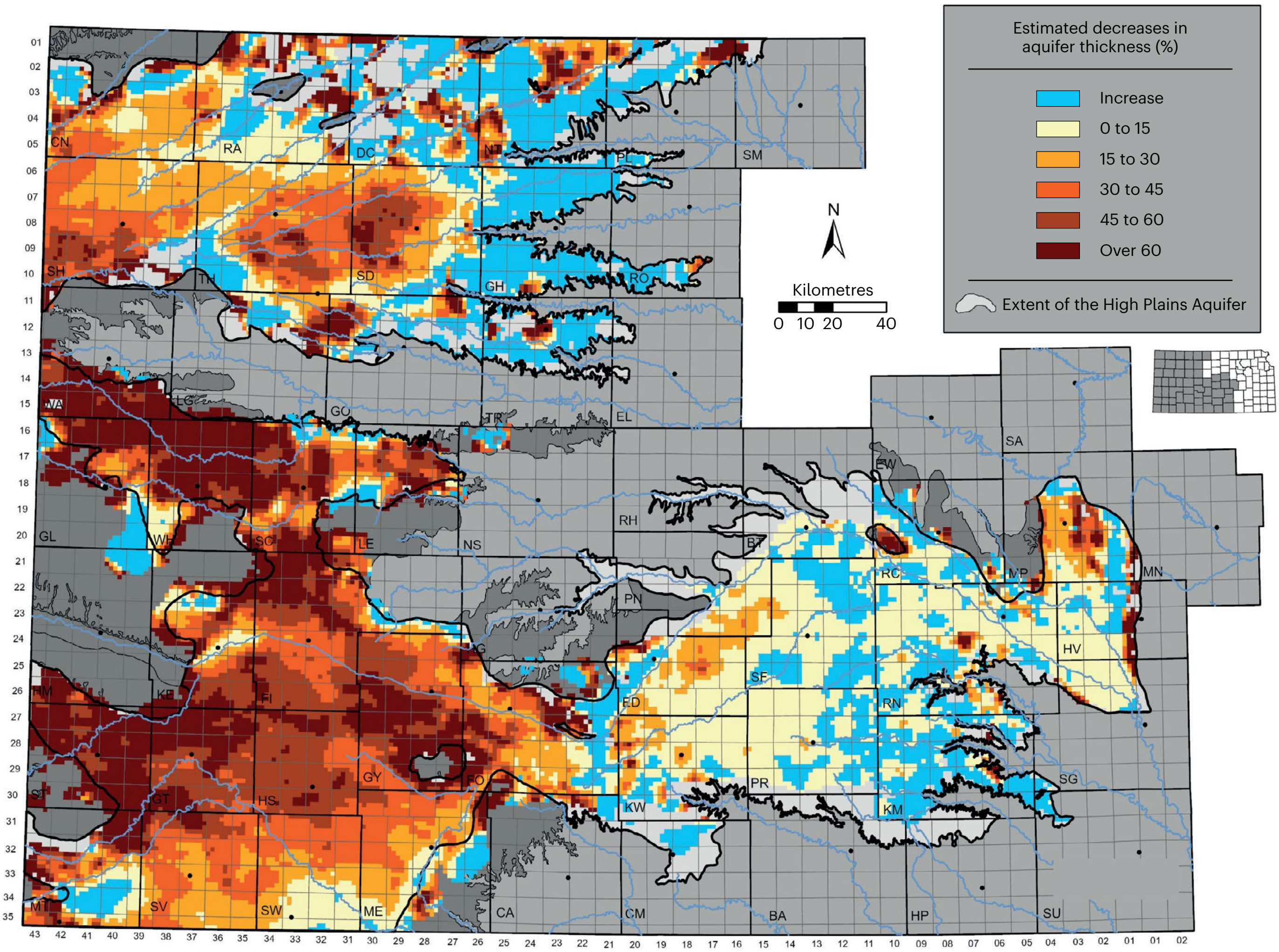

Fig. 1 | Percent change in aquifer thickness from predevelopment to present in the High Plains Aquifer in Kansas. Predevelopment is defined as the period prior to onset of widespread pumping for irrigated agriculture (mid-1950s and earlier); present is defined as the average of 2021–2023 winter conditions. The areas of increase in the western third of the state are areas of thin aquifer with little to no groundwater development and are not of practical importance. The areas of dark grey have similar sediments but little groundwater. The inset on the right shows the portion of the state pictured here. Reproduced with permission from ref. 9, Kansas Geological Survey.

Published online: 15 January 2024

References

1. Alley, W. M. & Alley, R. *High and Dry: Meeting the Challenges of the World's Growing Dependence on Groundwater* (Yale University Press, 2017).
2. McGuire, V. L. & Strauch, K. R. *Water-Level and Recoverable Water in Storage Changes, High Plains Aquifer, Predevelopment to 2017 and 2015–17, Scientific Investigations Report 2022-5080* (US Geological Survey, 2022).
3. Mieno, T., Foster, T., Kakimoto, S. & Brozović, N. *Nat. Water* https://doi.org/10.1038/s44221-023-00173-7 (2024).
4. Deines, J. M. et al. *Agric. Water Manag.* **233**, 106061 (2020).
5. Pérez-Blanco, C. D., Loch, A., Ward, F., Perry, C. & Adamson, D. *Environ. Res. Lett.* **16**, 114032 (2021).
6. Marston, L. T. et al. *Environ. Res. Lett.* **17**, 111001 (2022).
7. Griggs, B. W. *Univ. Pac. Law Rev.* **52**, 495–547 (2021).
8. Whittemore, D. O., Butler, J. J. Jr, Bohling, G. C. & Wilson, B. B. *Agric. Water Manag.* **287**, 108408 (2023).
9. Whittemore, D. O., Butler, J. J. Jr & Wilson, B. B. *2023 Status of the High Plains Aquifer in Kansas*, Technical Series 25 (Kansas Geological Survey, 2023); https://kgs.ku.edu/2023-status-high-plains-aquifer-kansas
10. Butler, J. J. Jr, Bohling, G. C., Perkins, S. P., Whittemore, D. O., Liu, G. & Wilson, B. B. *Groundwater* **61**, 51–65 (2023).

Competing interests

The authors declare no competing interests.