Hydrology and Earth System Sciences Discussions

Interactive Comment

Interactive comment on "Recent trends in groundwater levels in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta" *by* M. Shamsudduha et al.

Anonymous Referee #1

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General comments

The authors have had access to a wonderful set of data and their finding will be a good source of information for hydrologists and managers of groundwater resources. Use of "Seasonal-Trend decomposition procedure based on Loess (STL)" is a good way to highlight seasonality.

Comments to improve the method

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There are several factors that their impact may be quantified:

- The impact of rainfall;

- The delay between the rainfall events and their impact on groundwater levels;

- The underlying trend in groundwater levels.

- The impact of pumping;

- The impact of rising sea levels

Hydrograph analysis-rainfall and time trend (Ferdowsian *et al*, 2001) may be used to quantify the above factors. Accumulative annual residual rainfall may be used to detect seasonality.

The impact of pumping and the impact of rising sea levels may be quantified by including one or two types of dummy variables

The long-term underlying trend of groundwater level over time may or may not be linear. We may observe a trend that reduces or increases over time. Hydrograph of bore DH070_C (Author's hydrograph) is an example of such case. This bore may be located in a concaved aquifer. In such cases, as groundwater levels fall extraction of groundwater will cause an increasing fall in groundwater levels. These issues were explained by Ferdowsian and Pannell (2009).

I have included two abstracts for authors to consider.

Abstract number 1.

Ferdowsian R. Pannell D. J. (2001). "Explaining trends in groundwater depths: distinguishing between atypical rainfall events, time trends, and the impacts of treatments", MODSIM 2001 Congress Proceedings, Canberra, 10-13 December 2001. PP. 549-554 (Modelling and Simulation Society of Australia and New Zealand INC)

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Explaining Trends in Groundwater Depths: Distinguishing Between Atypical Rainfall Events, Time Trends, and the Impacts of Treatments

R. Ferdowsian[a] **and D.J. Pannell**[b]

[a] Department of Agriculture, Albany WA 6330, Australia
(rferdowsian@agric.wa.gov.au)

[b] Faculty of Agriculture, University of Western Australia, Perth, WA 6907, Australia
(dpannell@agric.wa.gov.au)

Abstract: By 1994, an estimated 1.8 million hectares of cleared land in Western Australia was affected by secondary dryland salinity to some extent. The area affected is likely to double in the coming 20 years. The cause of this salinity is excessive recharge under traditional agriculture, leading to rising groundwater levels. Monitoring changes in groundwater levels is helpful in indicating the degree of threat to agricultural land and public assets. Many researchers have studied groundwater level rises and attempted to explain them statistically. We present an approach for statistically estimating trends in groundwater levels and impacts of treatments on those trends. The approach separates the effect of atypical rainfall events from the underlying time trend and the lag between rainfall and its impact on groundwater is explicitly represented. Rainfall is represented as an accumulation of deviations from average rainfall. Two examples of application of the approach are presented.

Keywords: Groundwater; Monitoring; Treatment; Salinity; Sustainability indicators

Abstract number 2.

Ferdowsian R. Pannell D. J. (2009). "Explaining long-term trends in groundwater hydrographs", 18th World IMACS Congress and MODSIM09 International Congress on

Explaining long-term trends in groundwater hydrographs

Ferdowsian, R.[1] **and D.J. Pannell**[2]

[1] *Department of Agriculture and Food, Western Australia*

[2] *School of Agricultural and Resource Economics, University of Western Australia*

Email: rferdowsian@agric.wa.gov.au

Abstract: An ability to understand and interpret changes in groundwater levels is essential for sound management of groundwater resources. Various statistical methods have been developed to explain hydrograph trends. Most of these operate on the assumption that groundwater trends are linear or best represented by short linear segments. However there is clear evidence that many hydrograph trends are non-linear. For example, as the groundwater level changes, the area of groundwater discharge may change, dynamically feeding back and altering the trend rate of change.

The long-term underlying trend of groundwater level over time may or may not be linear. Three types of long-term trends may be observed:

- We may observe a rising trend that reduces over time and is a common feature of local groundwater flow systems. In these cases, as groundwater level rise, the hydraulic gradient and the rate of flow (discharge) both increase. The result is that the rate of groundwater rise falls systematically over time.

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- There are cases where the long-term trend in groundwater level is linear. This is usually the case where aquifers are intermediate to regional, have relatively higher recharge to discharge ratios, very little hydraulic gradient to generate significant flow and groundwater levels are well-below the soil surface.

- Occasionally we may observe an increasing rate of groundwater rise. This may be observed where stagnant aquifers are segmented by obstacles (eg basement highs). In such cases each segment will rise until the area of discharge has increased or groundwater finds a convenient flow path to spill into the lower part of the aquifer. From that time, the lower segment, receiving water from another segment, will have an increasing rate of groundwater rise, at least for a period.

We present three models for statistically estimating non-linear trends in groundwater levels. The first model is an autoregressive model, in which a past moving average of the dependant variable is included as an explanatory variable. This approach is useful when regular and frequent water-level data is available, although it has a few shortcomings. The second model uses time-related spline functions in the GenStat statistics package. The third model includes a log time function to capture the non-linear trend.

Both, the spline and log time models are easy to use and produce realistic trend lines. The spline function is a subjective method as the number of splines needs to be selected. The advantage of the log time model over the spline method is that it is not subjective and does not need special software; the solver function of Microsoft Excel may be used to do the analysis. We provide detailed guidance on performing the spline and log time models.

Keywords: *Statistics, salinity, monitoring, sustainability indicators, nonlinear trend.*