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Bi-decadal groundwater level trends in a semi-arid south indian region: Declines, causes and management

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ABSTRACT

Study region: Three districts in crystalline aquifer region of semi-arid south India.
Study focus: India, world's largest groundwater user (250 billion $m^3\ yr^{-1}$) has been reported to experience declining groundwater levels. However, the statistical significance of the decline has not been analyzed to separate human effects from natural variability. Trends in groundwater levels in three administrative districts of south India were analyzed and explained through changes in irrigation, rainfall, and agricultural power subsidy.
New hydrological insights for the region: Contrary to common perception of widespread groundwater declines only 22–36% of the wells showed statistically significant declines. The use of well depth during dry well periods may slightly underestimate the number of declining wells (by 1%) and rate of decline. Increase in groundwater irrigated area combined with rainfall and power subsidy policy, were the main causative factors for the decline. Groundwater decline after implementation of free-electricity policy in 2004 confirmed the nexus between power subsidy and groundwater. These declines are likely to worsen due to future well drillings. Trends in other regions with similar hydro-geologic conditions need to be analyzed to verify groundwater declines and its linkages with power subsidy. Once established, reforms in power subsidy and well permit policy along with conversion to efficient micro–irrigation may be needed to maintain or enhance groundwater availability in the crystalline aquifer region of India (240 million ha).

1. Introduction

India, home to 17% of the world's population, is facing water scarcity. Ranked highest in groundwater use globally, its groundwater use is 250 billion m^3 per year (AQUASTAT, 2010; Shah et al., 2007). India uses 80% of its water for irrigation (Mall et al., 2006) and 65% of irrigation supply is provided by groundwater (Siebert et al., 2010). Such large-scale withdrawals are mainly due to an increase in the number of irrigation wells equipped with diesel or electric pumps; there has been a 130 fold increase in the irrigation wells from 0.15 million in 1960 to nearly 20 million by 2000 (Shah, 2009). This groundwater development has caused groundwater depletion and several other environmental problems in many regions of India (Ambast

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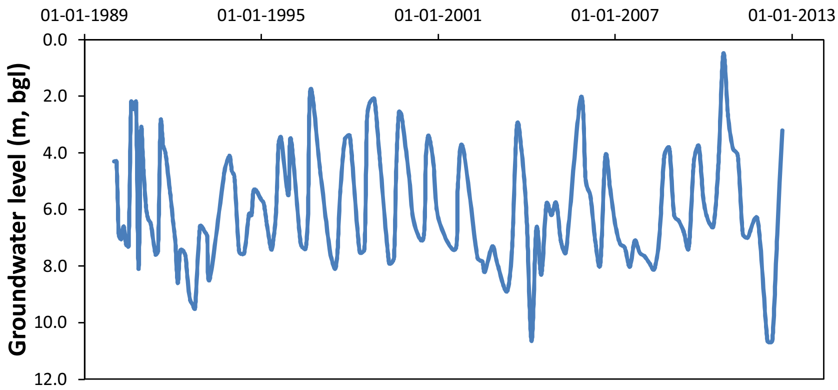

Fig. 1. Seasonal and annual groundwater level (below ground) fluctuations in a monitoring well in Rangareddy district, Telangana.

et al., 2006; CGWB, 2006; Rodell et al., 2009; Singh and Singh, 2002; Tiwari et al., 2009). Most of the states (e.g. Punjab and Telangana) where the groundwater depletion has been reported also provide free electricity to farmers. Free or subsidized electricity has frequently been cited as one of the main factors causing groundwater depletion in many regions of India (Shah et al., 2012). However, this qualitative assessment of relationship between subsidy and groundwater decline has not been field-verified.

Unlike other regions of India (e.g. eastern regions including Indo-Gangetic plains) which have plenty of surface water from Himalayan rivers, the semi-arid southern India mainly relies on ground water for irrigation. Northern and north western states (e.g. Punjab and Haryana) are located in alluvial aquifers while almost the entire region of southern India is underlain by hard crystalline rocks (CGWB, 2011). Deep alluvial aquifers found in Punjab and Haryana have higher specific yield and storage as compared to the shallow weathered fractured aquifers in southern India. While the declining water table may not affect the water availability, in a short run, for the farmers of Punjab (due to periodic well deepening) the groundwater declines are likely to deplete the shallow low storage aquifers of south India and limit the water availability (Fishman et al., 2011). While many studies have addressed the groundwater depletion in the north-west (Ambast et al., 2006; Rodell et al., 2009; Tiwari et al., 2009) and south (CGWB, 2011; Kumar et al., 2011; Massuel et al., 2007; Reddy and Reddy, 2010; World Bank 2010) India, none of these studies have tested the statistical significance of groundwater level trends in the semi-arid south Indian context. In addition, while the qualitative and some quantitative assessments have been made on the groundwater decline, it is not clear if these declines are due to groundwater withdrawals, power subsidy and/or rainfall. Systematic analysis of statistical significance of long-term trends in groundwater level change is needed to identify realistic groundwater management strategy in specific regions.

The former state of Andhra Pradesh, divided into two states namely Telangana and Andhra Pradesh on 2nd June 2014, officially implemented the free electricity policy for farmers in May 2004. Free or subsidized electricity causes wasteful use of groundwater as well as the electricity (Kumar et al., 2011). Use of automatic switches by the farmers turns the pumps on instantaneously as soon as the power comes, often causing the water to run unattended in the fields particularly at night. Although it has been argued that free electricity has triggered extensive well drillings in Telangana, it has also been reasoned that most of the well drillings already took place before 2004 and that free electricity didn't accelerated the drilling of wells (Fosli, 2014). Statistical analyses testing this cause-effect relationship (electric subsidy-groundwater declines) are lacking.

The groundwater system in the semi-arid crystalline aquifer regions of central and south India is highly dynamic where groundwater levels rise and decline quickly in response to recharge in the wet season (June-Oct) and pumping in the dry season (November–May) (Fig. 1). Seasonal and annual water level fluctuations in these fractured aquifers depend primarily on groundwater abstractions and recharge (Maréchal et al., 2006a, 2006b; Pavelic et al., 2012). Using six-year (2002–2008) GRACE satellite data and measured groundwater levels, Tiwari et al. (2011) examined temporal changes in groundwater storage in the semi-arid southern India including the former state of Andhra Pradesh. Both decline (1998–2004) and increase (2005–2008) were observed with overall increased groundwater storage in most parts of southern India. While they suggested that these changes in the groundwater storage are likely to be associated with inter-annual variability in rainfall, there were no statistical analyses to detect if these changes in groundwater storage or rainfall were significant. Fishman et al. (2011) argued that while there may be a short-term water stress due to low rainfall and increased withdrawals, the groundwater declines cannot continue in long-run because a good rainfall year can completely fill these shallow aquifers. With their simple groundwater budget model, Fishman et al. (2011) showed that groundwater levels in these weathered aquifers cannot keep declining in the long run because the levels rapidly approach the bottom of shallow aquifer and thus it becomes completely depleted. The dynamic nature of these aquifers and rainfall variability in the region requires statistical analyses of the long-term trends to differentiate natural or short term cyclic changes from anthropogenic or long term declines.

We used long-term (23 years) groundwater level data for the semi-arid south India to test if the groundwater level trends are significant and whether the observed trends are due to natural variability or anthropogenic factors. Specific objectives