Computers and Electronics in Agriculture 135 (2017) 143–153

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Groundwater monitoring and management: Status and options in Pakistan

Muhammad Tousif Bhatti *, Arif A. Anwar, Muhammad Aslam

International Water Management Institute, 12km Multan Road, Chowk Thokar Niaz Baig, Lahore 53700, Pakistan

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 11 December 2016
Accepted 19 December 2016
Available online 17 February 2017

Keywords:
Groundwater
Instrumentation
Inventory
Monitoring network
Observation-well

ABSTRACT

Due to extensive groundwater development in the recent past, Pakistan now faces enormous challenges of groundwater management as it struggles to ensure food security for its rapidly growing population. These management challenges require a re-balancing of surface and groundwater monitoring objectives and approaches in the country. This article presents the current status of the groundwater monitoring and management in Pakistan. A compelling case is presented for optimization of material resources in improving groundwater level and quality data by proposing to use farmer organizations as a source of crowd sourced groundwater information. The authors showcase new methods to collect groundwater data and demonstrate use of automatic recording instruments for groundwater monitoring in a tertiary canal command area in the Pakistan's Punjab. The results suggest that the potential for broader impact by engaging farmer organization and expanding monitoring networks is attractive. A common concern about long term deployment of automatic instruments is that the observation wells are not purged before extracting water quality samples. The authors address this concern through a field experiment by utilizing capabilities of automatic recording instruments.

1. Introduction

The Indo-Gangetic Basin comprises 25% of global groundwater withdrawals, sustaining agricultural productivity in Pakistan, India, Nepal and Bangladesh (MacDonald et al., 2016). Pakistan is the fourth largest user of groundwater among all countries (after India, USA and China). The agriculture sector is the largest consumer of groundwater within the Pakistan, and provides water for approximately one-half of the total crop water requirements (Qureshi et al., 2008). Mekonnen et al. (2016) suggest that the major drivers of groundwater use in Pakistan's agriculture are the variability and uncertainty associated with surface water delivery. However, there is little if at all any evidence of a unified or coordinated effort to manage or govern groundwater (van Steenbergen, 2006). Furthermore, in the populous province of Punjab, Pakistan, about 90% of the population depends on groundwater for domestic needs (Haq and Aslam, 2010).

The primary source of freshwater in Pakistan has been the flows from Indus and its tributary rivers. With the rapid increase in population, the water needed for food production, urban and industrial uses has increased which has resulted into more dependence on groundwater. The literature confirms a substantial growth in the number of private tube-wells installed in Pakistan since 1960s (PWP, 2001; GoP, 2000; Qureshi et al., 2008, 2010). There were around 20,000 private tube-wells in the country in 1960, currently there are more than one million tube-wells, largely for irrigation (Yu et al., 2013). Tube wells are concentrated in the Punjab Province which accounts for 93% of all private tube-wells in Pakistan. The ratio of groundwater recharge to discharge is 0.8 and as a result rapid decline in the water tables has been reported in many parts of the country (Planning and Development Board, 2007; Qureshi et al., 2010). This burden on Pakistan's groundwater aquifer suggests that the groundwater water supply will not be able to meet future demands and calls for regular monitoring and management of groundwater resource as a priority.

Pakistan lacks any institution that is responsible for groundwater management. Furthermore, there is no groundwater permitting system. Some federal and provincial organizations, in addition to water research institutions, are involved in groundwater monitoring however their effectiveness has eroded over time due to a number of factors e.g. financial constraints, over staffing (unskilled), a low priority in the national budget, duplication of efforts, and the lack of coordination and institutionalized arrangements to share information among institutions. Despite the reforms in the irrigated sector through the Provincial Irrigation and Drainage Act 1997 which envisaged a larger role for farmers

* Corresponding author.
E-mail addresses: tousif.bhatti@cgiar.org (M.T. Bhatti), a.anwar@cgiar.org (A.A. Anwar), muhammad.aslam@cgiar.org (M. Aslam).

http://dx.doi.org/10.1016/j.compag.2016.12.016
0168-1699/

and farmer institutions in the management of surface (canal) water, no role in groundwater monitoring or management was identified for these farmer institutions. In a slightly different context of involving stakeholders, Buytaert et al. (2014) has reviewed the state of citizen science in a hydrological context and explores the potential of citizen science to complement more traditional ways of scientific data collection and knowledge generation for hydrological sciences and water resources management. To collect high-resolution data sets, many agencies and organizations have started to incorporate the use of citizen scientists (Graham et al., 2011). While there are some drawbacks relating to the accuracy of citizen scientist data, the potential for broader impact by engaging citizens and expanding monitoring networks is attractive. Graham et al. (2011) has given examples of a Picture Post network (http://picturepost.unh.edu) that supports environmental monitoring by citizens, students, and community organizations through repeat digital photography and satellite imagery.

In most countries it is government agencies that maintain an inventory of private and public groundwater wells and monitor groundwater quantity and quality. This is a challenging task as even at places where wells permitting system is operative, drillers often flout the reporting rules. Wilson et al. (2013) has pointed out that the wells catalogue in Illinois does not represent all of the wells installed within the state in spite of the fact that permit system was introduced in Illinois back in 1960. In Pakistan where water users are free to drill with impunity, an updated inventory of wells is rarely available at any; national, provincial, or local scales. The Pakistan Bureau of Statistics (PBS) collects data on the number of private wells in the country. This data collection is done as a part of agricultural machinery census repeated every decade.

As for a systematic groundwater monitoring, there are very few operational programs in Pakistan. The Water and Sanitation Agency (WASA) of some major municipalities do undertake a degree of groundwater monitoring within urban centres but this does not extend to the rural/agricultural areas. In the Sindh, Khyber-Pakhtunkhwa (KPK) and Baluchistan provinces of Pakistan, groundwater is not monitored systematically. The Punjab province has more institutionalized and systematic monitoring program in place as of 2003, led by the Punjab Irrigation Department. This program covers monitoring of groundwater levels and water quality parameters (i.e. electrical conductivity, sodium adsorption ratio and residual sodium carbonate) through a network of piezometeric wells and a network of water quality sampling points, respectively. Table 1 compares the densities of groundwater level and quality monitoring networks in Punjab with some European countries. With the caveat that a straightforward comparison of the density of monitoring points between any two countries may be inappropriate due to difference in hydrogeology, stress to the aquifers, groundwater extraction patterns, etc., however, when compared with the densities of European countries, the monitoring network in the Punjab, Pakistan is higher than that of a number of European countries.

Table 1
Density of groundwater monitoring networks.

Region	Number per 1000 km^2[a]		Source
	GW level	GW quality	
Pakistan (Punjab Province)	1.11	1.53	DLR (2012)
Sweden	0.11	0.04	Jousma and Willems (1996)
Finland	0.02	0.02	
Denmark	0.15	0.26	
United Kingdom (England/Wales)	–	0.40	
Netherlands	10.70	1.07	
Belgium Flanders	1.61	1.61	
Germany/Bavaria	1.00	0.47	
Germany/New states		0.33	
Hungary	2.27	0.55	
Spain	1.95	0.22	

[a] Density figures based on total land area.

The International Groundwater Resources Assessment Centre (IGRAC) has prepared a global inventory on groundwater monitoring based on interviews been held with groundwater experts on the monitoring situation in several countries (Jousma and Roelofsen, 2004). Using a similar methodology, Table 2 provides a summary of the Punjab Irrigation Department's groundwater monitoring network.

There is a clear need for improved monitoring of groundwater quantity and quality in order to move towards better management of this resource. The research question that this paper addresses is how to do this in a cost-effective manner in the specific context of a Pakistan. In this research, data acquisition is tested through non-government actors (a derivative of the citizen scientist model), technologies to assemble an inventory of tube-wells, to monitor groundwater quantity and quality are explored along with IT technology for archiving and disseminating data and information.

2. Material and methods

2.1. The study area

The study area is located in the south-eastern part of the Punjab province, Pakistan (Fig. 1a). The climate is arid with large seasonal fluctuations in temperature and rainfall. Annual reference evapotranspiration is typically 2000 mm, and annual rainfall of about 250 mm. The Hakra Command Area shown in Fig. 1b is the area irrigated by the Hakra Branch Canal. The Hakra Branch Canal receives water from the Eastern Sadiqia Canal which originates from the River Sutlej. This is a typical run-of-the-river public irriga-

Table 2
Groundwater monitoring networks in Punjab, Pakistan.

Characteristics	Details
Type of groundwater bodies	Alluvial valley fills
Categories of groundwater use	Irrigation, Domestic/Public water supply
Groundwater problems encountered	GW table decline, Salinization
Monitoring GW levels	Secondary network-local
Objective of monitoring GW level	Reconnaissance of GW system, Planning/Pro-active management
Investigation of aquifer characteristics and parameters	No
Characterisation of the groundwater system	No
Quantifying effects of groundwater abstraction	No
Quantifying effects of surface water management	No
Quantifying effects of groundwater management measures	No
Monitoring transboundary effects	No
Techniques of observation	Manual recording
Frequency of observation	Twice a year
Storage and use of GW levels data	Data stored digitally, Ad hoc use
Monitoring GW discharge components	No
Monitoring GW quality	TDS, EC, RSC
Monitoring diffuse pollution	No
Specific Network for diffuse pollution	No
Storage and use of GW quality data	Data stored digitally, Ad hoc use