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Performance and impacts of managed aquifer recharge interventions for agricultural water security: A framework for evaluation

S. Prathapar[a], S. Dhar[a], G. Tamma Rao[a], B. Maheshwari[b,*]

[a] International Water Management Institute, New Delhi Office, NASC Complex, DPS Marg, Delhi 110012, India
[b] University of Western Sydney, Penrith, NSW, Australia

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ABSTRACT

To minimize and counter decline of groundwater levels and improve the availability of water for crop production, Managed Aquifer Recharge (MAR) interventions are widely adopted across India, often initiated or supported by, local communities, state and central governments to improve the availability of water for irrigation. While the literature on MAR in India is vast, the science of their construction is lacking. Furthermore, there is an absence of a structured approach to evaluate the performance and impact of MAR interventions. Often, performance and impacts of MAR have been commented upon together, without distinguishing the two.

In this article, we aim to propose that performance and impact are different from each other, and that the evaluation of MAR interventions should take into account such differences between them. A framework for performance and impact analysis, based on three levels, viz. primary, secondary and tertiary, is outlined. It is then applied to seven selected MAR interventions in India, Adarsha watershed – Andhra Pradesh, Gokulpura-Goverdhanpura watershed – Rajasthan, Kodangipalayam watershed – Tamil Nadu, Chikalgaon watershed – Maharashtra, Rajasamadhiyala watershed – Gujarat, Satlasana watershed – Gujarat and Sujalam Sufalam Yojana – Gujarat. Although, the evaluations of these case studies reported were not categorized into performance and impact, most of them have addressed both. However, none of them could explicitly demonstrate that reported impacts were uniquely related to MAR interventions. If impacts are used as a surrogate for performance, it must be shown that impacts are uniquely linked to MAR interventions.

1. Introduction

India is bestowed with substantial water resources-the total being 1780 BCM. Its groundwater resources are almost ten times its annual rainfall (Siebert et al., 2010). Despite the abundance of groundwater, only part of it is utilized due to physiographic, quality, and technological constraints. In India, where 15% of the global population lives, 55–60% of the Indian population is directly or indirectly dependent on groundwater for its livelihood (Villholth, 2006). As a direct result of the increased use of groundwater, millions of people have been lifted out of poverty (Kemper, 2007). In many parts of India especially in the arid- and semi-arid regions, due to vagaries of monsoon and scarcity of surface water, dependence on groundwater resource has increased greatly in recent years (Sakthivadivel, 2007).

However, while exponential groundwater use over the past few decades has improved stability in cropping and food production, there are increasingly serious issues with aquifer depletion, as groundwater tables are rapidly falling in a number of states (Rodell et al., 2009; Shah et al., 2007). In particular, states of Punjab, Rajasthan and Haryana witness more groundwater withdrawals than net recharge, resulting in groundwater level decline (Rodell et al., 2009).

In parts of India, groundwater decline has been so drastic, that it has resulted in dry dug wells and low yielding tube wells, especially in summer. The drinking water crisis prevalent in most of the villages in summer imposes serious health hazards for rural people due to toxic substances in deeper groundwater system (e.g., high level of fluorides) and is responsible for the loss of livestock population for want of drinking water and fodder (Adhikari et al., 2013). Decline in groundwater levels has also led to higher pumping costs (Machiwal et al., 2004), seawater intrusion in coastal aquifer systems (Srinivasamoorthy et al., 2013), and land subsidence (Ganguly, 2011) in various parts of India.

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* Corresponding author. Fax: +61 24570 1750.
E-mail address: b.maheshwari@uws.edu.au (B. Maheshwari).

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The severity of extreme events such as droughts and floods is predicted to increase over the next 20 years (Gupta and Deshpande, 2004; Pandey et al., 2005; Ramesh and Yadava, 2005). Groundwater aquifers are excellent for storage of excess water during wet years and serve as valuable reserves of water during dry years (Dillon et al., 2009).

To minimize decline of groundwater levels, Managed Aquifer Recharge (MAR) interventions are widely adopted across India, supported by local communities, State and Federal Governments. For example, the Government of India in its 2007 budget, allocated 450 m USD (Rs 1800 crore) to convert dry dug wells into recharge structures in 100 districts.

1.1. *Managed Aquifer Recharge*

Managed Aquifer Recharge, MAR, is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefits. MAR methods can be classified into two broad groups: direct methods and indirect methods. Direct methods can again be classified into surface spreading techniques and subsurface techniques (Dillon, 2009).

The most widely practiced methods of artificial recharge of groundwater employ different techniques of increasing the contact area and resident time of surface water with the soil, so that maximum quantity of water can infiltrate and augment the groundwater storage. Under the surface spreading techniques, the various methods employed are flooding, ditch and furrows, surface irrigation, stream modifications. Finally the most accepted and suitable for small community water supplies, are runoff conservation structures. Under the subsurface techniques, injection wells and gravity head recharge wells are the common ones. Indirect methods of artificial recharge uses pumping wells, collector wells and infiltration galleries, aquifer modifications and groundwater conservation structures, which require highly skilled manpower and other resources (Pyne, 2005).

While the literature on MAR in India is vast, the information on the science of their construction is scarce. Many have echoed this while reviewing the state of India's groundwater (COMMAN, 2005; Kulkarni et al., 2009). Contradictory conclusions have often been drawn that may be categorized under two camps: optimistic (e.g., Shah, 2009), and pessimistic (e.g., Kumar et al., 2008). On the optimistic side, researchers tend to have taken the overly simplistic view of water level rises and/or water quality benefits in the vicinity of recharge structures as undisputable proof of a positive net benefit (Muralidharan and Athavale, 1998 and references therein). Others have taken the pessimistic view after considering long-term maintenance issues, externalities, water pollution, or cost-benefit ratios (Kumar et al., 2008).

Invariably, these conclusions were arrived, without the application of a consistent framework for analysis of performance and impact of MAR interventions. Often, performance and impacts of MAR had been commented upon together, without distinguishing the two. There is a need to categorize the benefits of MAR with regards to their performance and impacts separately. In order to distinguish between the two, we must have clarity regarding the terms, performance and impact. Therefore, the main aim of this article is to propose and apply a framework for performance and impact analysis of MAR interventions using seven case studies from India.

2. Performance and impact analysis framework

Performance and impact are two separate aspects of MAR intervention and it is important to consider this difference in evaluating how useful a given intervention at local, regional and national levels.

2.1. *Performance and impacts of MAR*

We define performance as the accomplishment of a given task measured against pre-set known standards. In the pre-construction phase, the type of system to be designed for optimum performance depends entirely on local conditions of soil, hydrogeology, topography, water availability and climate (Bouwer, 1999). The potential standards during the pre-construction phase are design criteria such as: peak discharge, spillway capacity, storage capacity, and design infiltration rate. During the post-construction phase, standards may include percentage fill of total capacity and minimum damage to property from flooding. NRAA (2011) documents the performance of MAR recharge structures in terms of the incidence of clogging, damage occurred or maintenance required and the number of hours the intervention recharged during rainfall.

Hence, the indicators of performance are related to percentage fill of total capacity, the degree of damage to property from flooding and reduction in the infiltration rate due to clogging and siltation over time.

On the other hand we define impact as a sustainable change or outcome brought about by a given intervention. Impact can be related either to the specific objectives of the intervention or to unanticipated changes caused by the intervention; such unanticipated changes may also occur in the lives of people not belonging to the beneficiary group. Impact can be either positive or negative, the latter being equally important to be aware of.

The performance of MAR interventions influences impacts at different levels (Fig. 1), primary, secondary and tertiary level. The performance tends to be quantitative while the impacts can be both quantitative and qualitative and may take time (see impacts).

2.2. *Primary impacts of MAR*

When a MAR structure performs to its intended objective, its primary impact is on the groundwater resources – the groundwater level is expected to rise and its quality is expected to improve. Enabling factors affecting the extent of primary impacts are hydrogeological characteristics such as geological boundaries, inflow and outflow of regional groundwater flow, porosity; transmissivity, natural discharge of springs, lithology, thickness of the aquifer, and tectonic boundaries. The rise in groundwater level can be measured by piezometers and the perennial availability of water in recharge structures. Changes in water quality can be demonstrated by laboratory testing, potability of drinking water for community and livestock. Observation of the possible alteration of the chemical characteristics of the groundwater and chemical analysis could be carried out before and after the recharge application. A comprehensive review of primary impacts of MAR can be found in Glendenning, et al. (2012).

Invariably, there are negative primary impacts of MAR, often not monitored and reported. They include a reduction in water supply downstream, modification of environmental flow regimes, and reduced sediment and nutrient movement patterns along the water courses.

Consequently, it can be understood that, the potential indicators of primary impacts are groundwater level rise and change in ground water quality, which will depend on recharging water and hydrogeological parameters.

2.3. *Secondary impacts of MAR*

The secondary impact of MAR results from the use of additional groundwater available. This may improve potable water