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Paleochannels and their potential for artificial groundwater recharge in the western Ganga plains

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SUMMARY

Over the last few decades, a steep general decline in the groundwater table is being observed in the western Ganga Plains (India), the average rate being about 0.15 m/year. The area comprises of dominantly vast stretches of alluvial plains within which there occur three major paleochannels of the Ganga river, characterized by serpentine-meandering pattern and having an average width of almost 4–6 km and strike length of about 60–80 km. From the point of view of artificial recharge of groundwater, the paleochannels hold a distinct promise. The paleochannel-aquifer geometry has been delineated by integrating satellite sensor and well-litholog data. The first aquifer (≈25–30 m thick) in the alluvial plains is unconfined and consists of fine to medium sand whereas the second aquifer is confined. The paleochannel-aquifer is unconfined and is mainly composed of coarse sandy material along with boulder and pebbles beds and extends to a depth of about 65 m. The aquifer is well inter-connected with the adjacent alluvial aquifers. Analyses of soil samples from boreholes systematically sited on the paleochannel and its either flanks indicate that the value of hydraulic conductivity ranges from 30 to 75.3 m/day for samples falling in the paleochannel, and that between 13.5 and 22.3 m/day for the alluvial plain aquifers. The natural groundwater recharge rate due to precipitation, estimated using tritium tagging technique, is found to be 18.9–28.7% in the paleochannel area, and 6.3–8.9% in the alluvial plains. Data from stable isotopes of groundwater samples from the first unconfined aquifer indicates that the alluvial plains aquifer gets recharged by both rainfall and/or canal water, whereas rainfall is the dominant source for groundwater recharge in the paleochannel-aquifer. Monitoring of groundwater levels for 2 years (2006 and 2007), both during pre- and post-monsoon periods has been systematically carried out and it has been observed that groundwater flows away from the paleochannel in both pre- and post-monsoon periods, indicating that recharging of aquifers in alluvial plains is also through paleochannels. Thus, it may be inferred that such paleochannels can play a very important role in artificial recharge of groundwater.

1. Introduction

Groundwater is a precious natural resource of limited extent and volume. With the increasing use of groundwater for agricultural, municipal and industrial needs, the annual extraction of groundwater happens to be generally far in excess of its net average natural recharge. Additionally, interventions in hydrological regime and climate change have impact on natural recharge. Consequences of overexploitation of groundwater include alarming fall of water table all over the world, which has resulted in lower agricultural productivity, sea water intrusion in coastal aquifer, land subsidence, droughts, etc. (Clarke, 1991; Falkenmark and Lundqvist, 1997; de Villiers, 2000; Tsakiris, 2004).

Scientists, technocrats and planners have unanimously agreed and understood that replenishing the groundwater artificially is possibly the most important practical measure to arrest such aggressively falling groundwater tables. Therefore, artificial recharge or managed recharge of aquifer is becoming an important aspect of studies all over the world (Barksdae and Debuchanne, 1946; Beeby-Thompson, 1950; Todd, 1959; Wright and du Toit, 1996; Romani, 1998; CGWB, 2000; Bouwer, 2002; Asano and Cotruvo, 2004; Ong'or and Long-Cang, 2009).

Replenishment of groundwater by artificial recharge of aquifers in the arid and semi-arid regions of India is essential, as the intensity of normal rainfall is grossly inadequate to produce any moisture surplus under normal infiltration conditions. Although artificial groundwater recharge methods have been extensively used in the developed nations for several decades, their use in developing nations, like India, has occurred only recently. Techniques such as canal barriers, construction of percolation tanks

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and trenches along slopes and around hills have been used for some time, but have typically lacked a scientific basis (e.g., knowledge of the geological, hydrological and morphological features of the areas) for selecting the sites on which the recharge structures are located (Bhattacharya, 2010).

The Indo-Gangetic Plains, where this study has been carried out, is a land of fertile soil, moderate climate and generally abundant water. These factors have combined to make this a region of plenty for human settlement for centuries. Groundwater is a major source of water available for consumption in this area. However, over the years due to swelling population, increasing industrialization and intensive agriculture, the demand of water has increased manifold. Simultaneously, the available per-capita water resource has been reduced due to generally declining groundwater table (Joshi and Tyagi, 1994; Rodell et al., 2009). Hence, there is a urgent need to plan management strategies and take up augmentation measures for groundwater in this region.

1.1. Study area and scope

The study area is a part of Indo-Gangetic Plains falling between longitudes 77°30′E to 78°10′E and latitudes 29°10′N to 29°50′N and lies in the districts of Saharanpur and Muzaffarnagar of Uttar Pradesh (Fig. 1). Geologically, the Pleistocene to Recent alluvial deposits cover the area. Morphologically, four major landforms – piedmont, plains associated with river, interfluves and paleochannels have been recognized in the area (Kumar et al., 1996).

The study area has a moderate to sub-tropical monsoon climate. The rainy season (monsoon) extends from 15th June to 15th September. The average annual rainfall of the area is 1000 mm, of which about 85% is received during the monsoon season. From October to end of June next, generally dry conditions prevail except for a few showers received during the winter.

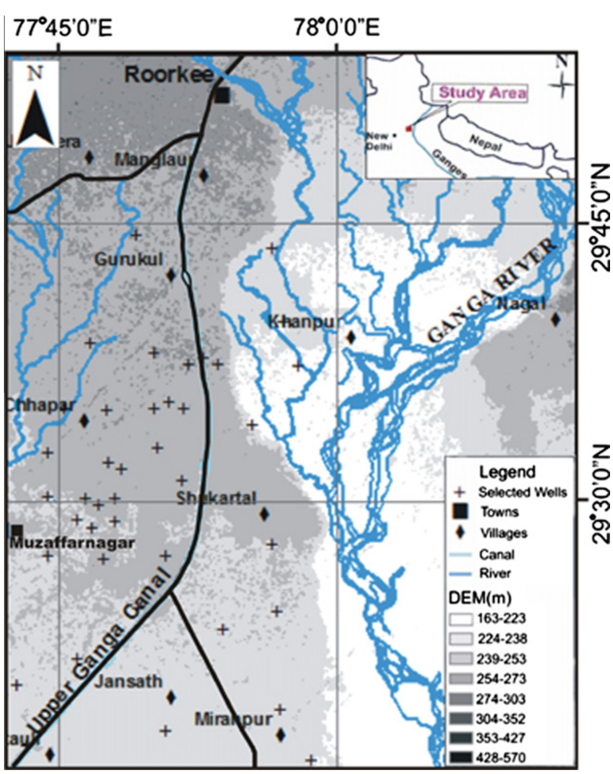

Fig. 1. Location map of the study area over the digital elevation model; note the terrain is nearly flat regionally sloping from north to south; selected well locations are also marked.

The Indo-Gangetic Plains are almost devoid of any significant relief features and are composed of unconsolidated alluvial deposits. The area slopes down gently from north to south, at an average gradient of less than 0.38 m per km. The physiography of the area is marked by the landforms that are characteristics of a river flood plain; viz. river channel, ox-bow lakes, and point bars. The drainage is a part of well integrated drainage system of the Ganga river, with almost all the streams flowing south-eastwards, concomitant with the regional slope. The Ganga is one of the important Himalayan river which carries sufficient water all round the year, though with seasonal fluctuations. Besides, the Upper Ganga Canal, which is more than 150 years old, forms an important irrigation system in the area.

Hydrogeologically, the Indo-Gangetic Plains comprise of extensive, multiple alluvial aquifer systems. The total thickness of the alluvium is not definitely known but may extend up-to about 7 km. Within the Indo-Gangetic Plains, the strata are found to exhibit variations, both vertically and horizontally, and this heterogeneity leads to variation of groundwater availability in the area (Taylor, 1959; Singhal and Gupta, 1966; Mithal et al., 1973). However, on a regional scale, the aquifers are inter-connected and hydraulically continuous almost throughout the Plains, the depth of water table varying from 3 to 18 m below ground level in the top unconfined aquifer.

The western Gangetic Plains form a region of high agricultural productivity with the prevalent two- to three-crop per annum system, accompanied by intensive use of groundwater for irrigation. The region forms the granary of India – a population of 1/5th of the world.

Due to large scale development of groundwater for agricultural, industrial and municipal use, the overall decline in groundwater levels has been observed in many parts of western Gangetic Plains (Fig. 2). Some wells have even dried up during the last few years. Thus, to sustain the livelihood, and local agricultural activity, artificial recharge of groundwater is urgently needed in the area.

In the present work, a systematic study has been taken up for developing a strategy for artificial recharge of groundwater. The main objectives of the research work include: (a) mapping of spatial distribution of porous and permeable stretches (which happen to be parts of paleochannels of the Ganga river) using remote sensing data and (b) evaluation of hydrogeological characteristics of paleochannel-aquifers and also the adjacent alluvial plains, from the point of view of artificial recharge.

2. Data sources and methodology overview

The data used in this study can be broadly categorized into three main groups – (a) remote sensing data, (b) ancillary data, and (c) field data.

Remote sensing data from Indian Remote Sensing (IRS) satellite mission (www.nrsa.gov.in) has been used in the present study. The data from IRS satellites is available in various resolution bands, i.e., LISS-II (36 m); LISS-III (23 m) and LISS-IV (5.8 m) but in identical spectral bands, viz., green (0.52–0.59 μm), red (0.62–0.69 μm), and near-infra-red (0.0.76–0.89 μm) bands. As the objective of the present study is to delineate paleochannels, which constitute regional/major geomorphological features, LISS-II, medium spatial resolution data (edge-enhanced with Laplacian isotropic filter) has been used. Specifications of the sensor are given in Table 1. The IRS LISS-II data have been widely used in recent times for a variety of applications – in geosciences, landuse/landcover mapping, hydrogeological mapping, urban planning, biodiversity characterization, disaster management, etc. (e.g., Navalgund, 2001; Gupta, 2003). In this study, the remote sensing LISS-II sensor data have been used