



Research papers

Regional scale groundwater modelling study for Ganga River basin

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ABSTRACT

Subsurface movement of water within the alluvial formations of Ganga Basin System of North and East India, extending over an area of 1 million km², was simulated using Visual MODFLOW based transient numerical model. The study incorporates historical groundwater developments as recorded by various concerned agencies and also accommodates the role of some of the major tributaries of River Ganga as geo-hydrological boundaries. Geo-stratigraphic structures, along with corresponding hydrological parameters, were obtained from Central Groundwater Board, India, and used in the study which was carried out over a time horizon of 4.5 years. The model parameters were fine tuned for calibration using Parameter Estimation (PEST) simulations.

Analyses of the stream aquifer interaction using Zone Budget has allowed demarcation of the losing and gaining stretches along the main stem of River Ganga as well as some of its principal tributaries. From a management perspective, and entirely consistent with general understanding, it is seen that unabated long term groundwater extraction within the study basin has induced a sharp decrease in critical dry weather base flow contributions. In view of a surge in demand for dry season irrigation water for agriculture in the area, numerical models can be a useful tool to generate not only an understanding of the underlying groundwater system but also facilitate development of basin-wide detailed impact scenarios as inputs for management and policy action.

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1. Introduction

A river basin is an integrated system where interaction between surface water, groundwater, water resources utilities and ecosystem are spatially widespread as well as incessant and it is understood that in this dynamic complex, health of groundwater systems have an important bearing on water management plans in a given river basin. Accordingly, in the latter context, regional or basin scale models have the potential to foster better understanding of the dynamics of the hydrological cycle and such an improved understanding, in the process, translates into a more rational basis for water resources management within the basin. Application of groundwater flow models to large scale aquifer system simulation started in 1978 with the Regional Aquifer System Analysis (RASA) program of U.S. Geological Survey (Sun and Johnson, 1994) in which typical regional aquifer system models covered an area of the order of tens of thousands km². In the past, regional models have also been used as decision support systems

(Bauer et al., 2005) as well as a tool to assess aquifer conditions under future climate change scenarios (Scibek et al., 2007; Maxwell and Kollet, 2008). Software engineering, computational speeds and memory infrastructure and wide use of Geographic Information Systems (GIS) have been significant advances that has made use of 3D groundwater flow models such as MODFLOW possible. On account of the latter's flexible modular structure, complete coverage of hydro-geological processes and its availability in the public domain has made the platform a global industry standard for groundwater modelling. Studies by Nishikawa (1998), Ting et al. (1998), Asghar et al. (2002), Faunt et al. (2004), Umar et al. (2008) and Wang et al. (2009) are some of the other successful applications of MODFLOW for groundwater modelling studies.

Recently, Hou and Zhang (2008) put together a modelling framework for the Cretaceous aquifer system in Ordos Basin while Shao et al., 2009, developed a transient groundwater flow model for the North China Plain having an area of 139,000 km² with a uniform grid of 4 km by 4 km. Wang et al. (2009), also developed a 3D transient groundwater flow model for the Beijing Plain in order to analyze groundwater flow systems within the integrated regional water balance.

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Ganga River basin is one of the largest alluvial systems in the world and over time, has witnessed extreme demands on its water resources on account of its soaring population along with its accompanying, and often competing, developmental aspirations. Additionally, Ganga waters occupy an iconic status amongst the collective Indian psyche owing to its religious and cultural importance and, understandably, environmental health of river Ganga has emerged as a socio-political concern. Outfall of industrial wastes and sewage into the river, over exploitation of its ground water resources, large scale dependence on irrigated agriculture and possibly, as is widely perceived, imprudent water management policies have, over the years, emerged as obdurate challenges.

This study was taken up as part of the Government of India initiative aimed at developing a comprehensive basin wide Water Resources Management Plan for Ganga Basin and the transient groundwater study was necessitated by the need to (i) study general ground water flow patterns in the region, (ii) identify hot spots of groundwater depletion, (iii) understand river-aquifer interaction to demarcate influent and effluent reaches and (iv) to investigate the effects of further groundwater development. It merits mention that this study is the first such attempt to model groundwater flow in the Ganga basin on such a scale as has been carried out and holds the promise of being a benchmark study for future studies.

2. Study area

Ganga basin extends over an area of 1,086,000 km² and lies in Tibet, Nepal, Bangladesh and India (at 8,61,452 km² constitutes nearly 26.2 percent of the total geographical area of India, Fig. 1). In India, Ganga basin also forms one of the largest multi-aquifer groundwater reservoirs with depths of 2000 m and more. The river originates as Bhagirathi from the Gangotri glaciers in the Himalayas at an elevation of about 7010 m in Uttarkashi district of Uttar Pradesh and flows for a total length of about 2525 km up to its outfall into the Bay of Bengal. Principal tributaries joining the river are the Yamuna, Ramganga, Ghaghra, Gandak, Kosi, Mahananda and Sone.

2.1. Physiography

Ganga Basin is flanked by Himalayas in the north and north-west, Aravali Ranges and East Rajasthan Uplands in west and south-west, Vindhyan Plateaux consisting Madhya Bharat Pathar, Malwa Plateau, Baghelkhand Plateau and Chota Nagpur Plateau in south and alluvial plains of Bangladesh in the East. Elevation levels range from 0 to 5 m amsl at Sundarbans to the high Himalayan peaks that include Mt. Everest, world's tallest at 8848 m amsl.

Physiographic features of the western part of the basin falling in Rajasthan state can be divided into three units: namely Aravalli hills, Eastern plains and the Vindhyan Scarpland and Deccan Lava Plateau.

The elevation of Aravali Hills ranges from 600 to 900 m amsl. The north eastern part of the hill is composed of rocks ranging in age from Archaean i.e. 2500 million years to Proterozoic i.e. 740 million years old. The hill ranges present an undulating topography with altitude of plains east of Aravali ranging from 150 m to 450 m amsl. The central part of Ganga Basin in the state of Uttar Pradesh can be divided into four physiographic units namely Himalayas, sub-Himalayas, alluvial plains and the southern plateaux. The Himalayan unit forms the northern most part of the state covering the districts of Uttarkashi, Tehri, Pauri, Chamoli, Pithoragarh, Almora and parts of Nainital and the zone is underlain by metamorphic and sedimentary rocks and form hill ranges with high relief, deep gorges and narrow deep valleys.

The Sub-Himalayan unit forms the region between the aforementioned Himalayan unit in the north and the alluvial plain to the south and comprises Doon Valley, river terraces and low relief hilly tracts of the Shivaliks.

The alluvial unit can further be sub-divided into the following zones:

- (i) **Bhabhar:** It is highly porous dry zone and forms the southern limit of the sub-Himalayan unit. Its width varies from 10 to 30 km along the foothills of Himalayas and extends from Uttar Pradesh and through to West Bengal.
- (ii) **Tarai:** This Zone lies between Bhabhar in the north and central Ganga plain in the south and has a variable width of 8–16 km and is characterized by change in surface slope.
- (iii) **Central alluvial tract:** The Vast alluvial tract south of Tarai belt and extending up to Yamuna river and Chota Nagpur plateau, Palamu plateau in the east, covers the largest, about 40–50% part of the basin and is highly cultivated throughout the area.
- (iv) **Marginal alluvial zone:** It occupies the southern fringe area of the Ganga plains lying south of Yamuna and close to the plateau region and slopes from south to north towards Ganga River.
- (v) **Southern Plateaux:** This unit occupies the extreme southern fringe of the basin and is characterized by the generally plain tableland of Vindhyas and residual conical hills in Bundelkhand region. The entire plateau region forms the cratonic part of Ganga basin.

2.2. Climate and rainfall

The normal minimum temperature for the month of January ranges from 2 °C in the north to 7.8 °C in the south west though at altitude in Himalayas, the temperature dips to below freezing during the winter months.

The water supply depends mainly on the rains brought by SW monsoons from July to September as well as the snowmelt beginning from March and lasting upto June and beyond. The average annual rainfall varies from 30 in. (760 mm) at the western end of the basin to more than 90 in. (2290 mm) at the eastern end. The delta region at the western end of the basin also experiences strong cyclonic storms both before the commencement of the monsoon season, from March to May, and at the end of it, from September to October. Understandably, rainfall is the main source of ground water recharge with nearly 90% of the annual totals being contributed by SW monsoon from June to September.

2.3. Drainage

Drainage in Ganga basin is governed mainly by rainfall, physiography and lithology. Drainage in mountains and hills are mainly dendritic and structurally controlled. On hill slopes drainage is mostly characterized by parallel to sub-parallel drainage, which persists in the Central Ganga plain and continues up to Bay of Bengal.

The Himalayan rivers are mainly rain-fed and snow-fed while rivers originating from Aravalli and Vindhyan mountains mainly rain-fed and ground water fed. The major drainage network of Ganga Basin is given in Fig. 2.

The main perennial drainage lines in the Basin are: the Ganga, Yamuna, Ramganga, Gandak, Kosi, Chambal, Sind, Betwa, Ken, Tons, and Son. In the northern and north-eastern parts of Rajasthan, the Banganga, Banas, Sota, Sahibi and Kantli rivers are of inland nature. These drainage lines become active only during the monsoon. The delta of the Ganga begins near Gaur. The main branch of the river in the delta portion flows in the south-east

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