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Delineation of groundwater potential zone for sustainable development: A case study from Ganga Alluvial Plain covering Hooghly district of India using remote sensing, geographic information system and analytic hierarchy process

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ABSTRACT

In the context of considerable change in the use of groundwater pattern, particularly with continuously increasing demand for groundwater due to growing population, expansion of area under irrigation and economic progress, the present paper makes an attempt to delineate groundwater potential zones using integrated remote sensing, geographic information system, and analytic hierarchy process techniques. Integration of geographic information system with analytic hierarchy process can exemplify as a process that transforms and harmonizes geographical data and weightage ranking to retrieve information for accurate decision-making. Accordingly, mapping and identification of groundwater potential zones are carried out in the Ganga Alluvial Plain of Hooghly district of India. Application of the same for Indo-Gangetic plain is made (new approach) to contribute the applicability Geographic Information System and Analytic Hierarchy Process for the delineation of groundwater potential zone. Predominant criteria (e.g., land use, land cover, soil type, geomorphology, geology, elevation, slope, rainfall, normalized difference vegetation index, drainage density, recharge rate, groundwater depth) were employed for computation of groundwater potential index. Overlay weighted sum method is applied to integrate all thematic criteria to generate groundwater potential zone map of the study area. The resulting groundwater potential index map has been classified into three groundwater potential zones, namely good, moderate and poor. Finally, groundwater potential zone map is validated using average groundwater level data from 32 wells scattered over the study area. The findings of the present paper have important implications for designing sustainable groundwater plan in the area.

1. Introduction

Generally groundwater is considered as one of the sources of quality fresh water and it is distributed ubiquitously in nature. Groundwater plays a lead role in maintaining ecological balance, human well-being and economic development (IPCC, 2001). The continuously-increasing demand for groundwater due to growing population size, expanding area of irrigated cultivation and economic progress with less importance to the environment has mounted huge stress on its cautious utilization (Mondal and Dalai, 2017). Globally, around 36%, 42% and 27% of the total groundwater withdrawal are used for domestic, agricultural and industrial purposes (Taylor et al., 2013a). In a country like India, 90% of rural population and 30% of urban people depend on groundwater to fulfil their basic requirements (Agarwal and Garg, 2016). Unfortunately, scarcity and rampant use of groundwater resources without appropriate scientific planning are very familiar scenario in India (Rodell et al., 2009). During the past twenty years, many parts of India experienced rapidly declining groundwater level due to increase in its extraction (CWC and CGWB, 2016). The present study focuses on part of the Indo-Gangetic Alluvial Plain as mentioned in Fig. 1. Groundwater has immense importance for socio-economic progress in the Ganga Plain. But, unplanned and unmanaged

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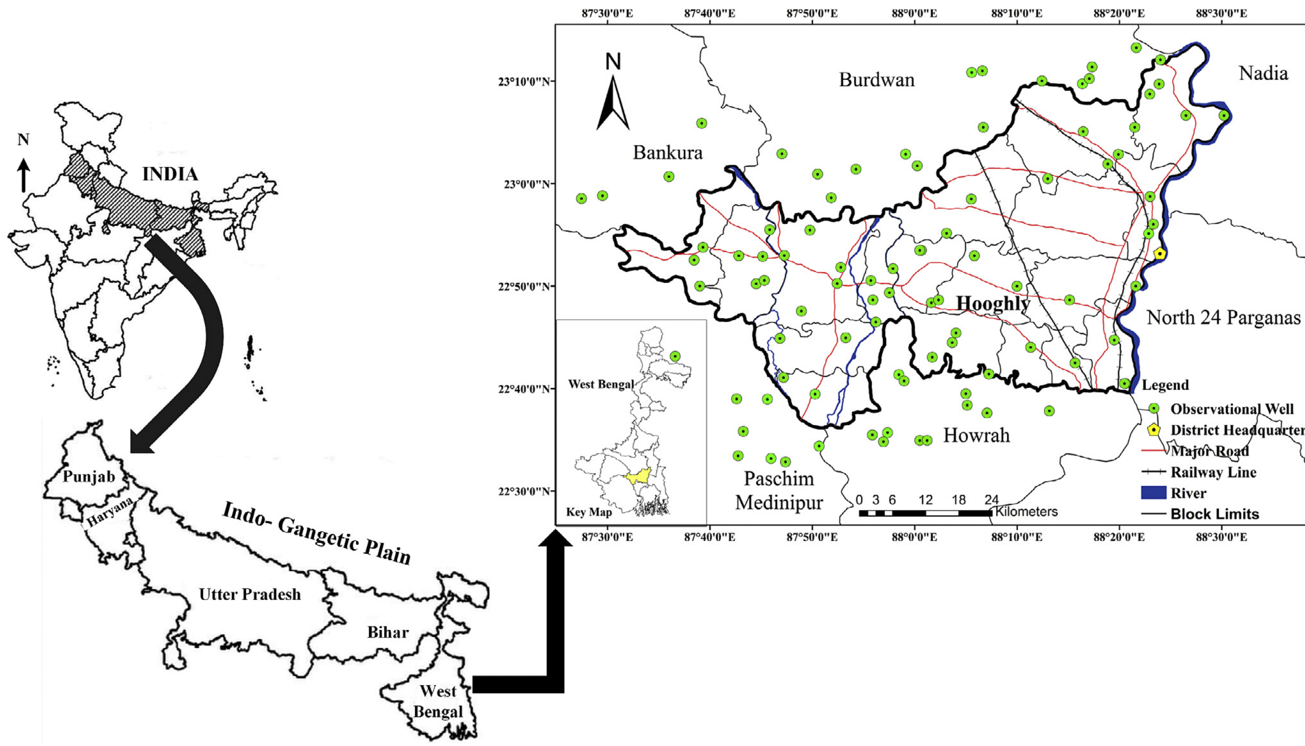

Fig. 1. Location of Indo-Gangetic Plain and Study area.

groundwater extraction in the area has resulted in aquifer-stress syndrome like falling groundwater water depth and deterioration of quality[1] (World Bank, 2011). Hence, identification of the critical parameters and their assessment are necessary for predicting groundwater potential and planning for this resource accordingly (Akinlalu et al., 2017). This is very important as its occurrence, origin, distribution and movement depend on geological formation, (i.e., lithology, thickness, structure and permeability of aquifers), climatic conditions, geomorphic features, texture of soil, ground slope, land use/land cover type, intensity of drainage and their interconnection with the hydrological attribute (Krishnamurthy and Srinivas, 1995; Greenbaum, 1992; Saraf and Choudhury, 1998; Schultz and Engman, 2012; Taylor et al., 2013b; Ebrahimi et al., 2016).

Groundwater is a hidden and precious natural resource and hence cannot be directly detected. Although a set of methods is used to explore groundwater resources, mapping of the same is a challenging task. Drilling test and stratigraphy investigation are the most widely used methods for determining the location of borehole and the thickness of the aquifereous materials to explore the groundwater resources (Jha et al., 2010). However, these methods are very cost effective and time consuming to find out availability of groundwater resources in a region (Roscoe Moss Company, 1990; Fetter, 1994). Furthermore, various techniques have been adopted by various researchers such as, decision-tree model (Lee and Lee, 2015), frequency ratio (Guru et al., 2017; Al-Abadi et al., 2016), weights-of-evidence (Ghorbani Nejad et al., 2017; Madani and Niyazi, 2015), artificial neural network (Lee et al., 2017), random forest model (Naghibi et al., 2016), logistic regression model (Pourtaghi and Pourghasemi, 2014), and evidential belief function (Nampak et al., 2014) etc. Most of these approaches are based on bivariate and multivariate statistical techniques with limitations in making assumptions prior to investigation and sensitivity of findings (Thapa et al., 2017). In this context, analytic hierarchy process (AHP) is considered as a simple, transparent, effective, and reliable technique (Machiwal et al., 2011; Ishizaka and Labib, 2011), and hence can be used for delineating groundwater potential zones. As groundwater is dynamic in nature, integration of remote sensing (RS) data in the geographical information system (GIS) is very convenient to identify the groundwater potential zones (GWPZ) (Agarwal and Garg, 2016) in a useful fashion (Aluko and Igwe, 2017). The RS technique offers a repetitive coverage of an area in a systematic, synoptic and rapid way with the combination of different ranges of the electromagnetic spectrum radiated from various earths' features. As an outcome, it offers a useful device for obtaining spatiotemporal data of sizable areas in a short time of interval. Satellite data produce quick and suitable guideline and information about diversified factors governing directly or indirectly the occurrences and movements of groundwater (Aluko and Igwe, 2017). In addition, GIS contributes a distinguished work environment to deal extensive and complex spatio-temporal data efficiently (Wieland and Pittore, 2017). Many of the existing studies (Jasrotia et al., 2016; Mallick et al., 2015; Gumma and Pavelic, 2013; Chenini et al., 2010; Madrucci et al., 2008; Srivastava and Bhattacharya, 2006; Sikdar et al., 2004; Krishnamurthy et al., 1996) have widely applied RS and GIS techniques for the assessment of GWPZ. However, thematic layers used for identifying GWPZ differ across the studies, and the selection of attribute layer is arbitrary (Table 1). The assignment of weights to various thematic layers and their classes are decided on the basis of experts' opinion and site specific conditions. In the present study, analytic hierarchy process propounded by Saaty (1980) is used in combination with RS-GIS technique for delineation of GWPZ. The AHP is a powerful

[1] According to "Dynamic Ground Water Resources of India (2011)" report published by Central Ground Water Board (CGWB), 29 percent of the groundwater assessment blocks in the country cumulatively fall under the semi-critical, critical, and overexploited categories where the situation become more worsen day by day (World Bank, 2011).