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Quantification of Groundwater Recharge and Pumping from Different Land Uses in Kanpur District (Uttar Pradesh), India

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Abstract

Groundwater has been recognized as an essential water source due to its low pollution susceptibility and large storage capacity. In comparison to surface water, groundwater is relatively safe and reliable. Therefore, it is essential to evaluate groundwater use and its availability for long-term sustainable water management planning. The most important aspects for sustainable water management are estimation of groundwater recharge and water supply schemes. A study was carried out in the Kanpur district to estimate groundwater pumping (GP) and groundwater recharge (GR) from different land cover used in the last 10 years (2009-2019). Assessment of GP and GR were done as per the guidelines of the Ground Water Resource Estimation Methodology–1997 (GEC-97). The results indicated that groundwater is utilized highest as agricultural water consumption then for urban land requirements. Groundwater recharge varied from 30974 ha-m to 39577 ha-m and pumping varied between 12584 ha-m and 47054 ha-m. Since groundwater recharge is higher than its pumping in the study area, it determines that the area is lying under the safe category.

Keywords

Groundwater level, Groundwater pumping, Groundwater recharge, Landuse

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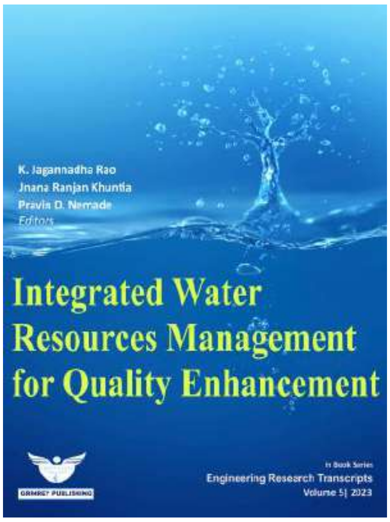

1. Introduction

Among the different sources available across the globe, groundwater is a vital natural water system because of its quality assurance [1]. Groundwater, which is unquestionably the most suitable form of water for domestic, agricultural, and industrial use, has become a major concern across the globe as a result of the increased demand for water [2][3][4]. The excessive withdrawal of groundwater and insufficient recharge lead to the reduction of quantity and quality of groundwater [1]. The ever-increasing rate of urbanization is one of the major reasons for depleting groundwater levels and degrading its quality as well [5]. Characterizing the aquifer and performing ambient spatiotemporal groundwater monitoring is necessary for the development of an effective groundwater management plan [6].

For the effective management of groundwater resources, it is essential to estimate pumping rates by combining groundwater recharge, discharge, and aquifer storage [7] [8]. Natural characteristics such as climate, land cover, geology, morphology, rainfall frequency, etc., and artificial topographic changes such as land use, land cover, etc., are responsible for groundwater recharge [9]. Sand, gravel, fault zones, fissures in hard rocks, and the absence of obstacles such as impermeable strata, etc., are sedimentary formations that are extremely important for groundwater recharge. Recharge varies greatly depending on the type of land use, such as agricultural land, grassland, and urban land covered with concrete pavements, etc. [10]. In addition to these, irrigation and irrigation return flow may contribute significantly to the recharging of aquifers in regions where agriculture predominates. Effective groundwater management needs a detailed knowledge of the aquifer system and an analysis of its responses to various input and outflow parameters [7].

The Ground Water Resource Estimation Methodology-1997 (GEC-97) suggested a specific scientific standard method for the estimation of various parameters of Groundwater Recharge (GR) and Groundwater Pumping (GP) [11]. Since natural recharge and discharge patterns of groundwater change over time, it is a continuous process [12] [13]. Several researchers studied rainfall in the basin of the Ganga (India) and came up with empirical methodologies to estimate the natural recharge of groundwater [14].

Here, an attempt has been made to calculate the GR and GP of Kanpur city (India). This can help decision-makers to develop groundwater sustainability management plans. To understand groundwater behavior, spatial as well as temporal analysis of groundwater was also carried out. In addition, groundwater recharge and pumping would be calculated from different land uses by standard methodology.

2. Material and methods

2.1 Details of the area under study

Kanpur Nagar is one of the districts of Uttar Pradesh (India), geographically situated in the central part of the river Ganga Basin, covering a total geographical area of about 3,155 sq km (North latitude: 25°26′ to 26°58′, East longitudes: 79° to 80°34′) [15]. It comprises three tehsils and ten blocks, namely Kalyanpur, Sarsaul, Bilahaur, Kakawan, Chaubepur, Patara, Bidhnu, Bhitrgaon, Sivrajpur, and Ghatampur. The major part of this area is almost flat and plain with some minor undulations. It is also situated on the bank of the Ganga and the city is well known for its industrial development [16]. Its subsurface is mainly composed of alternate layers of coarse and fine soil [17].

GIS platform is used to present the area of Kanpur Nagar (Fig. 1). Domestic and irrigation data have been collected by the Statistical Diary of Uttar Pradesh, Government of Uttar Pradesh (India). Meteorological data such as solar radiation, wind speed, temperature, precipitation, and relative humidity have been collected from the Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur (U.P.). The water level data was obtained from the State Groundwater Board.

Furthermore, based on the collected data from a different organization, an attempt has been made to estimate the GR and GP for the Kanpur Nagar district.

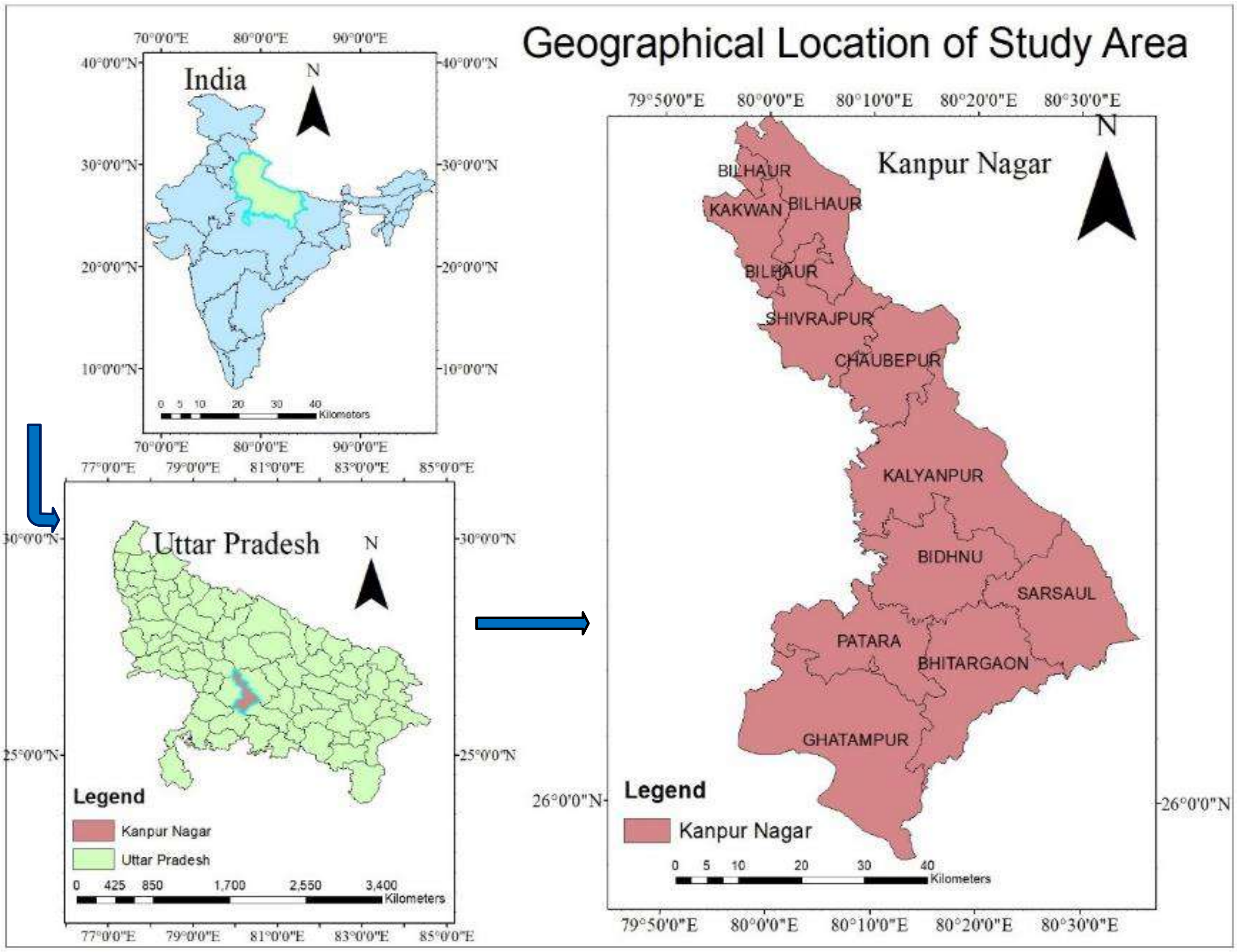

Fig. 1. Study area showing block locations

2.2 Estimation of groundwater recharge

Groundwater recharge is an essential component of groundwater hydrology that affects groundwater fluctuation. There are various methods for estimating groundwater recharge, such as:

- Soil water balance models
- Water table fluctuation method
- Water budget method
- Darcy's law
- Groundwater model

The soil water balance model requires extensive data, so it cannot be applied in every location or anywhere. An empirical model can be a good option where data is limited [19]. Different empirical methods have been used in previous studies. The most widely used method is based on the recommendations of the GEC-1997.

In this study, groundwater recharge was assessed through three different sectors: irrigation land, urban land, and other land. The forest sector was excluded from this assessment process, as per the guidelines of the GEC-1997. The GEC-1997 guidelines were followed for the calculation of groundwater recharge. The groundwater recharge was calculated using equations (1) and (2) for the irrigated land and other lands, respectively.

$$\textit{Total cropland recharge} = \sum (\textit{Crop area} \times \textit{Return flow}) \tag{1}$$

$$\textit{Return flow} = 10\% \times (\textit{Rainfall} + \textit{GIR}) \tag{2}$$

Where, GIR = gross irrigation requirement. GIR is calculated from evapotranspiration and rainfall data. Groundwater recharge from urban land and other land was calculated by 10 % of rainfall x area [14] [19].

2.3 Estimation of groundwater pumping

Due to their increasing use in domestic, industrial, and agricultural sectors, groundwater resources are under greater demand in arid and semi-arid areas. Groundwater pumping measurement is a tedious job. However, estimation of groundwater pumping is essential for availability and to ensure long-term groundwater sustainability [14]. There are some indirect approaches for measuring groundwater pumping (such as crop water demands, satellite data-based approach, groundwater modeling approach, and AI-based methods, etc.) [20]. In this study, groundwater pumping was assessed through three different sectors: irrigation land, urban land, and forest land. Other land was excluded from this assessment process, as per the guidelines of the GEC-1997. The gross amount of water required for a particular crop can be calculated by multiplying the amount of water required in a year by the area in which that crop was harvested [21]. The amount of water needed by each type of crop is calculated by evapotranspiration, monthly precipitation data, and the water available in the plant soil for each variety of crop [3]. A theoretical evapotranspiration map was created using temperature and solar radiation data from the study area for this purpose. The value of the crop coefficient of different crops was taken from the GEC-1997 [11][22]. In the case of pumping in urban land, consumption of water demand per head can be measured by multiplying the total population and per capita water demand per day.

3. Results and Discussions

In this study, different spatio-temporal maps were generated for the groundwater level of the years 2009 and 2019 using ArcGIS in the pre-monsoon and post-monsoon seasons. From Figures 2 and 3, it can be observed that the groundwater depth level ranges from ~2.41 to ~25.19 meters below ground level (mbgl) during the pre-monsoon season and from ~1.62 to ~27.43 mbgl during the post-monsoon season of 2009. Furthermore, Figures 4 and 5 show that the groundwater depth level ranges from ~1.28 to ~32.12 mbgl during the pre-monsoon season and from ~0.62 to ~31.91 mbgl during the post-monsoon season of 2019.

Groundwater recharge was also considered through three different sectors: irrigation land, urban land, and other land. The assessment of pumping volume was done considering irrigation land, urban land, and forest land. The detailed values obtained from these sectors are shown in Figures 6 and 7. For better comparison, the average values of groundwater recharge and pumping for the study period were used. It was observed that groundwater pumping was higher from crop land (16,169.5 ha-m), followed by urban land (10,376.48 ha-m) and forest land (1,467.73 ha-m). Similarly, higher groundwater recharge was estimated from crop land (20,506.14 ha-m), followed by other land (7,171 ha-m) and urban land (5,950 ha-m).

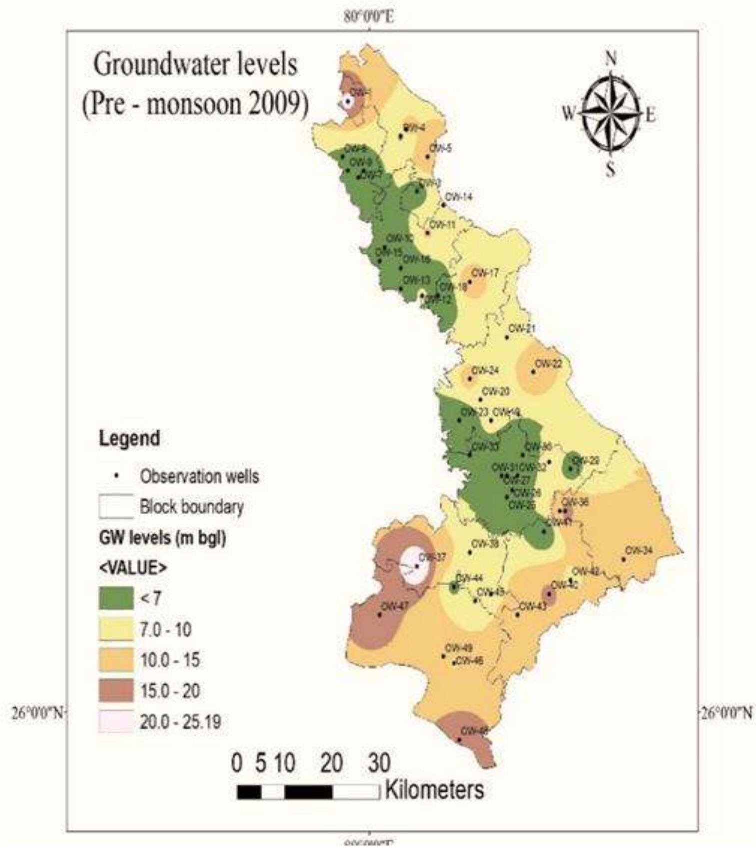

Fig. 2. Pre-monsoon water level in 2009

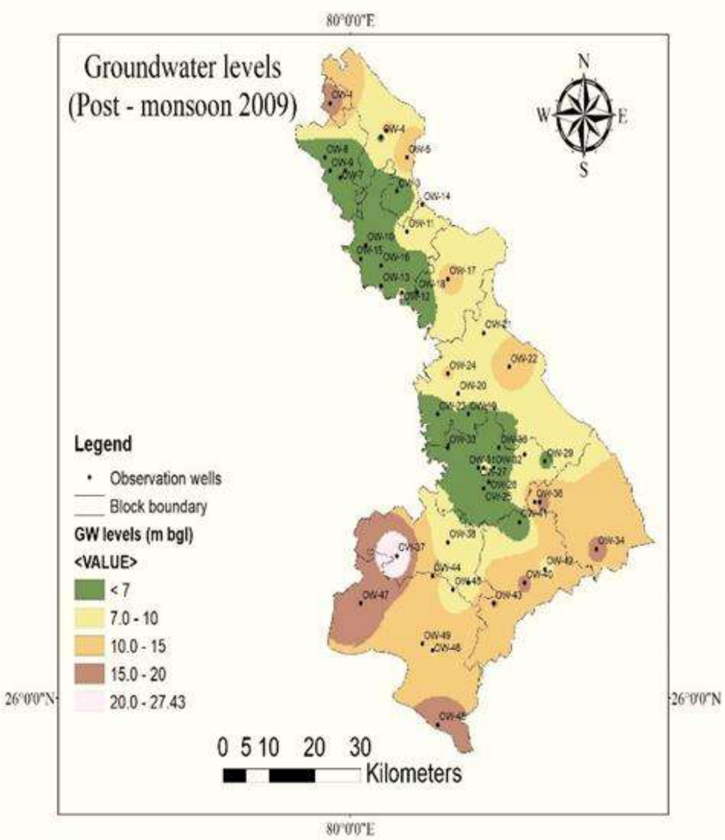

Fig. 3. Post-monsoon water level in 2009

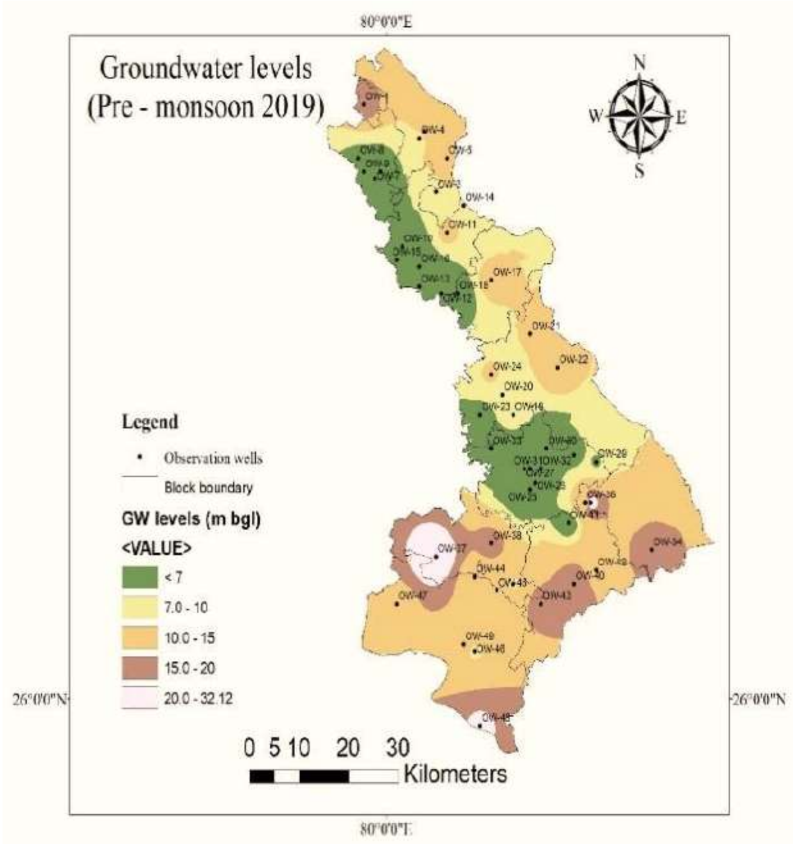

Fig. 4. Pre-monsoon water level in 2019

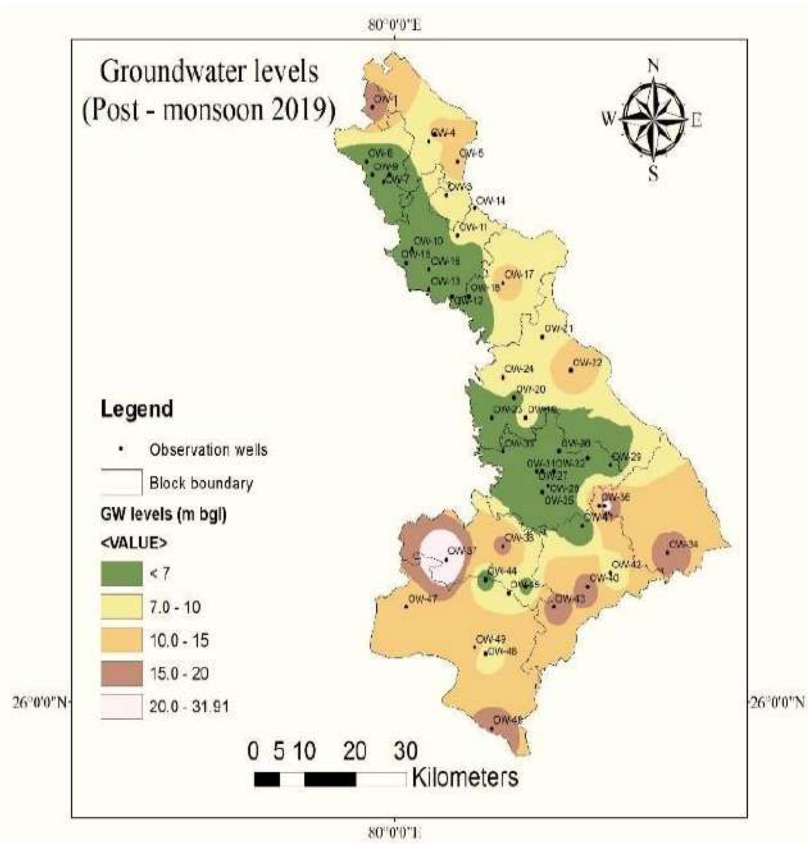

Fig. 5. Post-monsoon water level in 2019

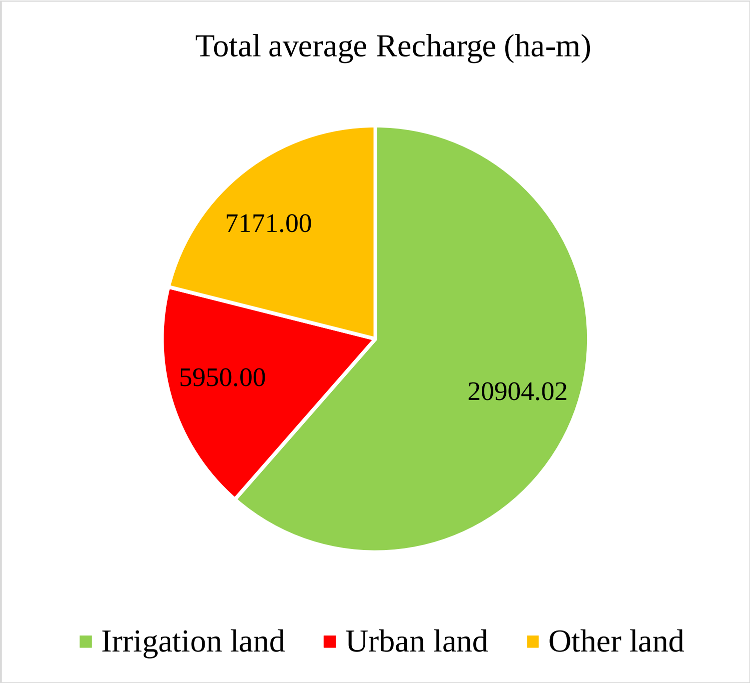

Fig. 6. Total average Recharge from different sectors in the study period (2009-2019)

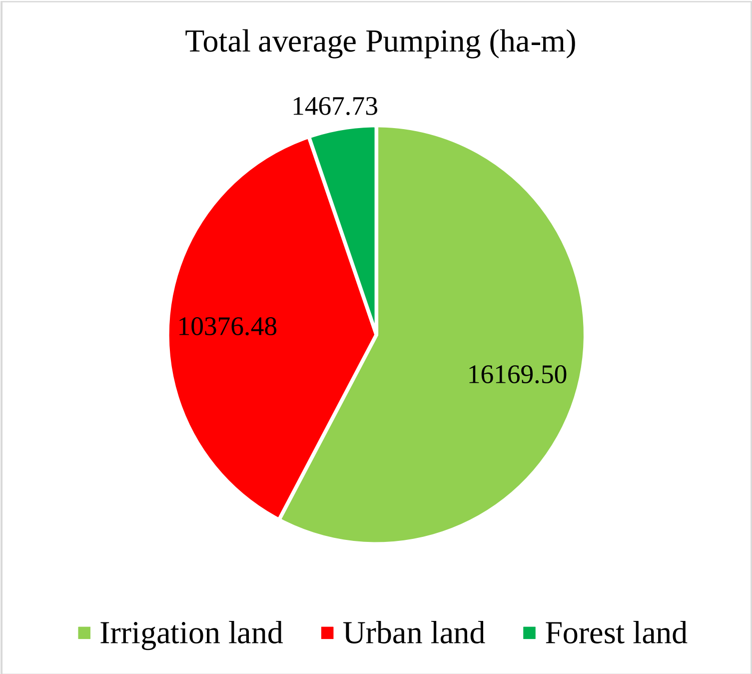

Fig. 7. Total average Pumping from different sectors in the study period (2009-2019)

As shown in Figures 6 and 7, the contribution of irrigation land to groundwater recharge (20,904.02 ha-m) is higher than its contribution to pumping (16,169.50 ha-m). Figure 8 shows the year-wise variation in groundwater recharge (ha-m) and pumping (ha-m) through irrigation land. It is clear from Figure 8 that the water required for irrigation land pumping was low in the years 2013-14, 2018-19, and 2019-20, with values of 82.26 ha-m, 2,619.99 ha-m, and 2,186.3 ha-m, respectively. This can be attributed to the high rainfall of 1,133.7 mm, 654.5 mm, and 1,874.9 mm received during those periods. However, groundwater recharge values were high in those years, with values of 22,410.15 ha-m, 2,645.42 ha-m, and 24,882.88 ha-m, respectively, in the years 2013-14, 2018-19, and 2019-20. This led to an increase in the water table. The high rainfall input enhanced the groundwater recharge.

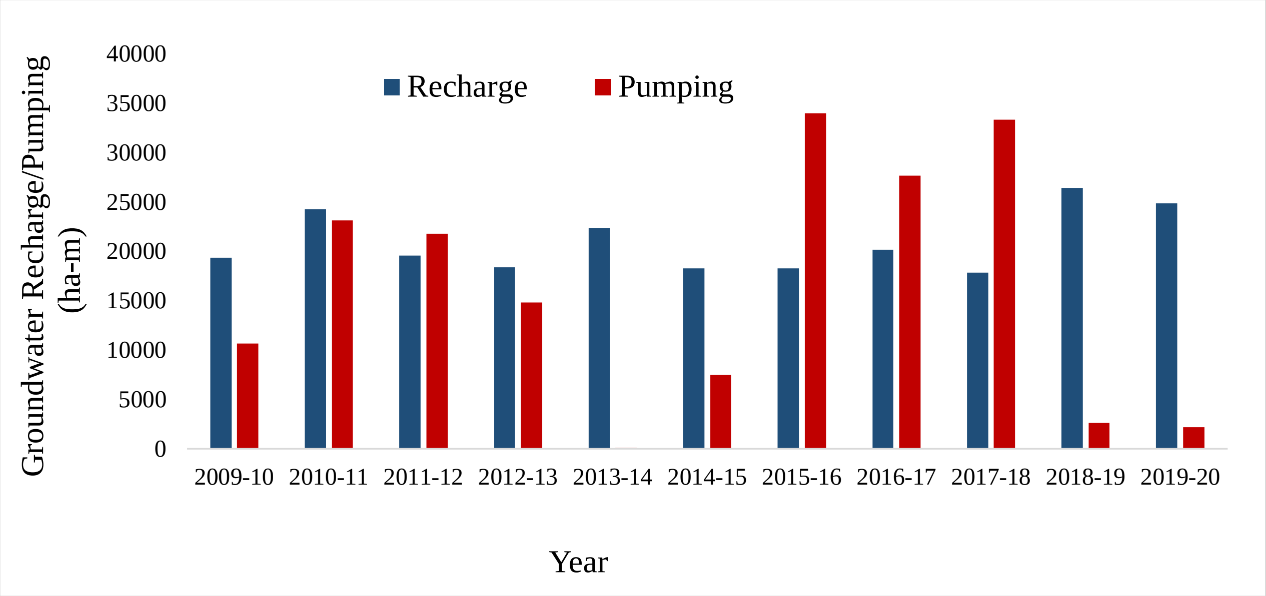

Fig. 8. Trends of groundwater recharge and pumping through irrigation land, 2009-2019.

Total recharge or pumping is associated with the sectors of agriculture, urban, forest, and other land. Figure 9 shows the cumulative recharge and pumping as total recharge (ha-m) and total pumping (ha-m). It can be noted from Figure 9 that the total recharge is high in the assessment years 2013-14, 2018-19, and 2019-20, with values of 35,531.15 ha-m, 39,577.42 ha-m, and 38,003.88 ha-m, respectively. This is compared to the total pumping in the years 2013-14, 2018-19, and 2019-20, with values of 13,122.71 ha-m, 12,996.47 ha-m, and 12,562.78 ha-m, respectively. Figure 9 indicates that the total groundwater recharge was comparably higher than its pumping in most of the times, except in 2011-12, 2015-16, 2016-17, and 2017-18. This was due to the low rainfall in those years. This determines that the study area is lying under the safe category.

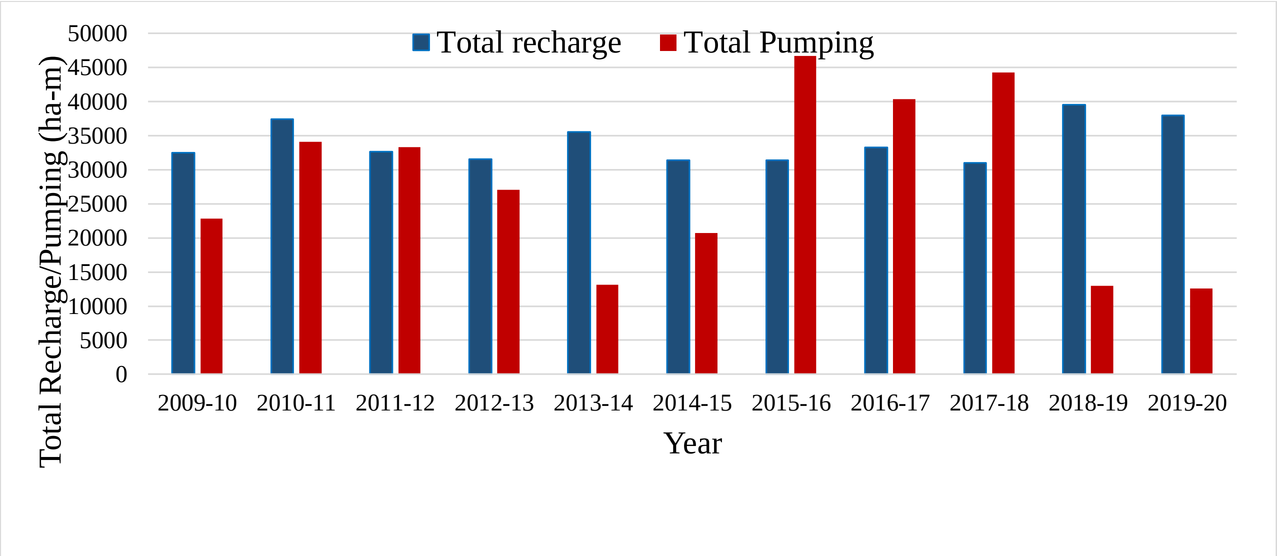

Fig. 9. Trends of total recharge and pumping through different land uses 2009-2019.

4. Conclusions

The assessment of groundwater behavior and its quantification is essential for long-term groundwater management planning. During the assessment period, groundwater recharge increased due to heavy rainfall in the study area. Moreover, a significant amount of groundwater recharge infiltrated and returned to the aquifer. During the year 2015-16, a maximum groundwater extraction of about 470,554 ha-m was observed. This study showed that 2018-19 was the year for maximum groundwater recharge, and this came from irrigation return flow. The groundwater recharge being comparably higher than its pumping in the study determines that it is lying under the safe category.

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