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Assessment of Groundwater Potential Using Water Balance Approach in Pindra Block Varanasi

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Abstract: Groundwater is an important source of irrigation in rural areas. Groundwater potential of Pindra block of Varanasi district was assessed using water balance approach during monsoon (June to October) and non-monsoon (November to May) season. Its various inflow and outflow parameters of groundwater balance equation were calculated such as recharge from rainfall, canal seepage, pond seepage, field irrigation, sub-surface inflow-outflow, groundwater discharge from tubewells, evapotranspiration and groundwater storage change. The results of the study reveal that various inflow parameters i.e. recharge from rainfall, canal seepage, pond seepage, field irrigation and sub-surface inflow during monsoon season were estimated 6501.41 ha m, 417.49 ha m, 9.56 ha m 1283.02 ha m and 405.98 ha m respectively. During non-monsoon period these inflow parameters were estimated 154.01 ha m, 471.40 ha m, 3.83 ha m, 3822.61 ha m and 149.57 ha m respectively. Groundwater outflow parameters i.e. sub-surface outflow, discharge from tubewells and change in storage during monsoon season were estimated 123.35 ha m, 4587.18 ha m and 0.87 ha m. These outflow parameters during non-monsoon season were estimated 561.81 ha m, 10498.33ha m and 3.95 ha m. Average recharge coefficient was calculated 47.76%. Conducting the water balance study it was found that the declining trend of the water level due to lack of surface irrigation sources and sustained groundwater pumping.

Keywords: Water balance, groundwater recharge, recharge coefficient.

I. INTRODUCTION

Water is a significant part of life which plays an important role in development ofnation economy of the country like India which is mainly agriculture dependent economy (Kumar and Srinivas, 2009)**.** The global water resource is 1.37×10^8 million ha-m. Out of total global water resource,97.2% water is available as salt water mainly in oceans and remaining 2.8% available as fresh water. Out of this 2.8% of fresh water about 2.2% available as fresh water and remaining 0.6% available as groundwater (Ahmeduzzman*et al*., 2012). It being a dynamic and replenishable natural resource is generally assessed on the basis of components of annual groundwater recharge. Assessment of the rate of natural groundwater recharge is important for efficient management of groundwater resource. Many techniques are used to assess the rate of groundwater recharge i.e. Darcian approach, soil water balance approach and groundwater level fluctuation approach(Kumar, 2012). Assessment of groundwater recharge from rainfall is an integral part of hydrology and hydrogeology. Groundwater balance equation is Important to estimate groundwater recharge. Estimation of groundwater recharge volume is important to predict the present condition of groundwater and its effect on future (Ahmeduzzman*et al*., 2012). Estimation of groundwater balance of an area requires estimation of all individual inflows to and outflows from a groundwater system and change in groundwater storage over a given period of time (Kumar, 2012).

II. STUDY AREA

The area is located in south-west part of Uttar Pradesh in Pindra block of district Varanasi. It has lies between 25°23’40’’ and 25°33’33’’N latitude and 82°50’01’’ and 82°53’10’’E longitude. Pindra block having an area of 22482 ha in which net cultivable area is 16269 ha, area other than agriculture is 2825 ha, barren land 2405, horticultural area 323 ha, usher land (non suitable for agriculture) 334 ha, usher land (suitable for agriculture) 320 ha and forest area 6 ha. Alluvial formations and plain topographic features were found in present study area. Confined to semi-confined aquifer system were found depending upon the availability of clay beds and the duration of pumping. The average rainfall in this region is 864 mm annually. The average annual temperature varies from 14.15°C to 39.8°C.

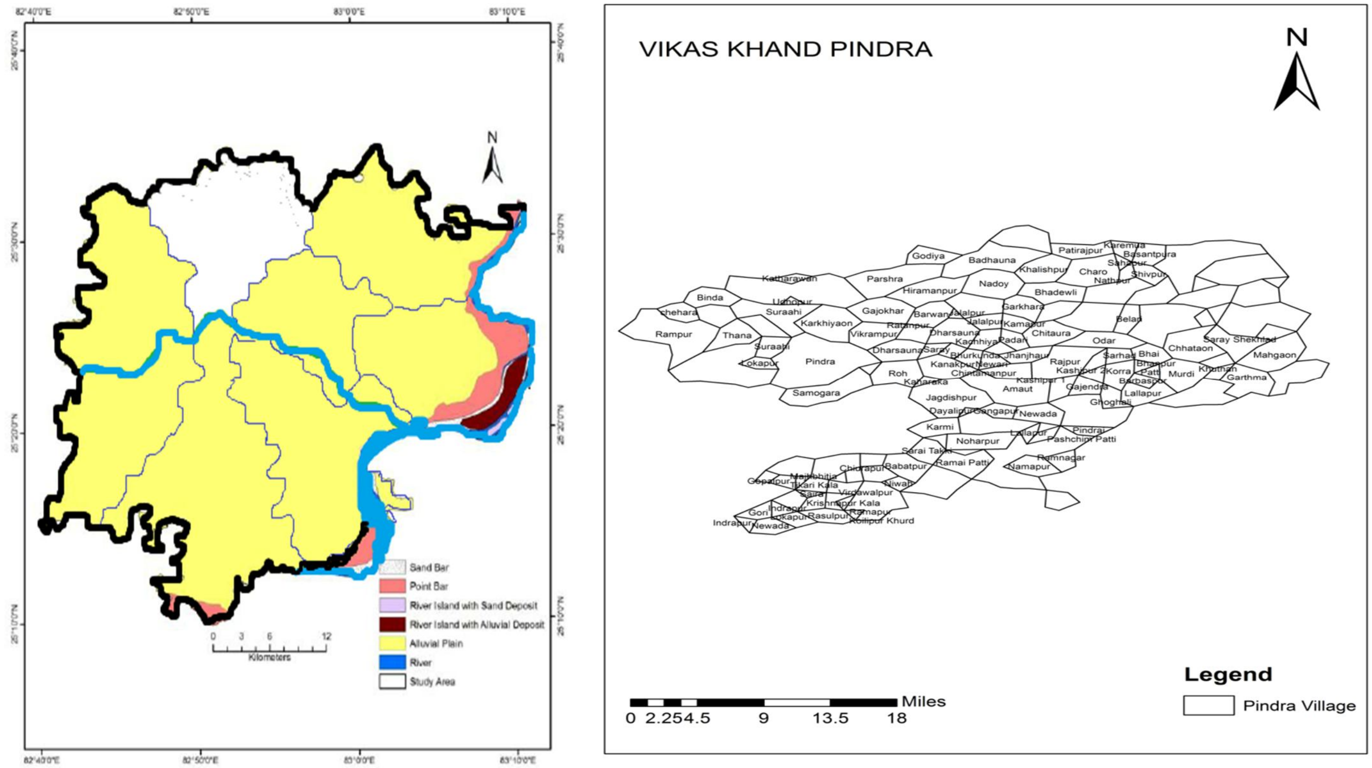

Fig. 1: Map of study area (Pindra block, Varanasi)

A. Objectives of Study

To estimate the inflow and outflow parameters of the groundwater balance equation & to estimate the groundwater recharge based on groundwater based on groundwater balance equation and to estimate recharge coefficient for Pindra block, Varanasi.

B. Techniques

1) Groundwater balance
2) Groundwater recharge
3) Recharge coefficient

C. Data Collection

1) Climatological data- rainfall, humidity maximum and minimum temperature and wind speed data were collected from "*GLOBAL WEATHER*". These data were collected on daily basis from the year 2004 to 2013.
2) Lithological data- specific yield and transmissibility were taken based on the standard lithological values of study area using "Groundwater Brochure of Varanasi District U. P".
3) Canal data- length, width, depth of water in canal along with running days data were collected from "Divisional Office of Irrigation Department Varanasi".
4) Groundwater data- pre-monsoon and post monsoon groundwater level data were collected from "Regional Groundwater Board, BhujalBhawan, Lucknow".
5) Pond data- conducting the sample survey it was found that one pond per two Gram Panchayats, being 103 Gram Panchayats in the present study area 51 ponds were assumedin the current study.
6) Discharge from tubewells- number of government and private tubewells along with running hours in each month was collected from "Tubewell Division, Irrigation Department, Varanasi".

D. Study period

Water balance study is desirable to conduct part of year basis covering one cycle of a dry and a wet year i.e. monsoon and non-monsoon. Monsoon period was taken as June to October and non-monsoon period was taken as November to May.

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III. METHODOLOGY

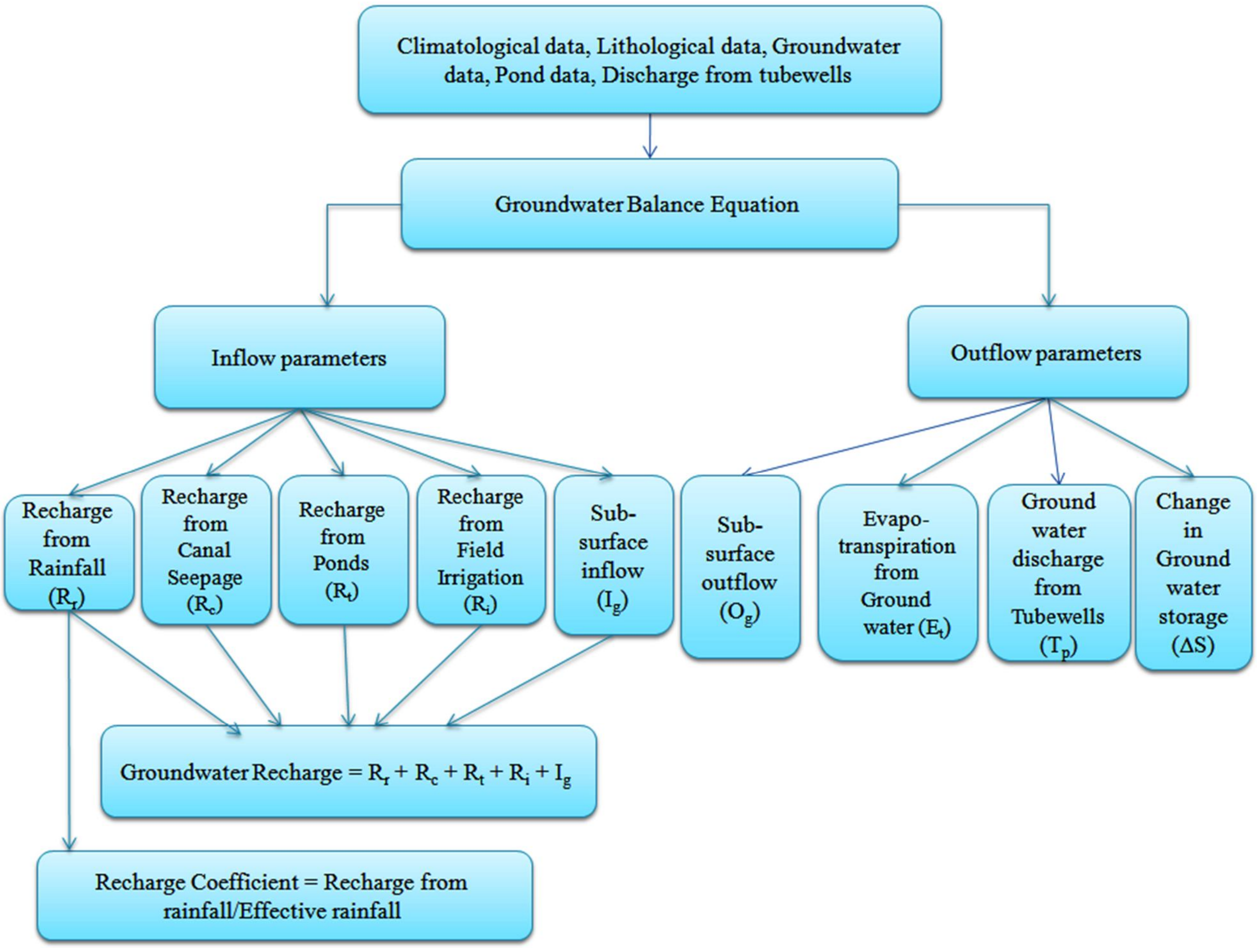


Fig. 2: Flow chart for estimation of groundwater potential & recharge coefficient

E. Process & Techniques

The Groundwater balance equation (Chandra and Saxena, 1975) was used for assessment of groundwater potential. It is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specified period. With the water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system. The basic concept of water balance is changing in storage of the system is equal to the difference between input to the system and outflow from the system over a period of time. The equation can be written as follows:

$$R_r + R_c + R_t + R_i + I_g = O_g + Et + T_p + \Delta S \qquad (1)$$

Where,

R_r, R_c, R_i, & R_t = Recharge from rainfall, canal, irrigation water and pond respectively

I_g, O_g= Sub-surface inflow & outflow

Et = Evapotranspiration from groundwater

T_p= Discharge fromtubewells

ΔS = Change in groundwater storage

In the present study influent and effluent seepage from rivers was found negligible so that influent and effluent seepage was omitted from the groundwater balance equation.

1) Recharge from Rainfall (R_r): Recharge from rainfall is an important component of groundwater potential which mainly depends on soil characteristics, rainfall intensity, depth of water level and topography of the area. Recharge from rainfall was estimated by using empirical formula (Chandra and Saxena, 1975):

$$R_r = 3.984\,(P - 40.64)^{0.5} \quad (2)$$

Where, R_r is rainfall recharge (cm), P is annual precipitation (cm).

In present study rainfall recharge was estimated by using average annual rainfall data from 2004 to 2013 and rechargeable area was considered as cultivable area.

2) Recharge from Canal Seepage (R_c): Seepage from canals is an integral part of total groundwater recharge, hence it is important to properly estimate seepage losses to assess the contribution of canal seepage in groundwater recharge. In present study recharge from canal seepage was estimated by using empiricalformula (Kumar, 2012):

$$R_c = \frac{C}{200}\,(B + D)^{2/3} \quad (3)$$

where, R_c is recharge from canal seepage (cumecs/km), B and D are the bed width and depth of the canal (meters), C is a constant, being 1.0 for intermittent running canal and 0.75 for constant running canal. Being intermittent running canal in the study area C was taken as 1.

3) Recharge from Ponds (R_t): As per Kumar (2012), seepage from ponds varies from 9 to 20 percent of their storage capacity. It was found that average surface area of each pond was 2500 m², depth of water in pond for monsoon season was assumed 5 m and for non-monsoon season 2 m.

4) Recharge from Field Irrigation (R_i): Recharge from field irrigation was estimated considering the norms of Central Groundwater Estimation Committee, 2009 as given below:

Table 1: Percentage of Gross Irrigation Depth Contributing Recharge from Field Irrigation

Source of Irrigation	Paddy crop	Non-paddy crop
Surface water	40%	35%
Groundwater	35%	30%

In the present study crop water requirement was estimated on daily basis by using following formula:

$$ET_c = ET_o \times Kc \quad (4)$$

Where,

ET_c = Crop evapotranspiration [mm/day]

ET_o= Potential evapotranspiration [mm/day]

K_c = Crop coefficient.

Potential evapotranspiration was calculated by using Penman-Montieth (FAO 56) equation:

$$ET_o = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}\,u2(es - ea)}{\Delta + \gamma(1 + 0.34\,u2)} \quad (5)$$

Where,

ET_o = potential evapotranspiration [mm day^{-1}]

Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}]

G = soil heat flux density [MJ m^{-2} day^{-1}]

T = air temperature at 2 m height [°C]

u_2 = wind speed at 2 m height [m s^{-1}]

e_s = saturation vapour pressure [kPa]

e_a= actual vapour pressure [kPa]

e_s-e_a= saturation vapour pressure deficit [kPa]

Δ = slope of vapour pressure curve [kPa °C^{-1}]

γ = psychrometric constant [kPa °C^{-1}]

Net irrigation depth and gross irrigation depth was calculated by using following formula:

$$\text{Net irrigation depth} = \text{Crop water requirement} - \text{Effective rainfall} \quad (6)$$

$$\text{Gross irrigation depth} = \frac{\text{Net irrigation depth}}{\text{Application efficiency}} \quad (7)$$

5) Sub-surface inflow and outflow ($I_g$andO_g): Sub-surface inflow-outflow was estimated by using pre-monsoon & post-monsoon water level. Darcy's law was used for the estimation of sub-surface inflow and outflow:

$$Q = T\,I\,L \quad (8)$$

Where,
Q = Rate of flow through a cross-section of aquifer (m^3/day)
T = Transmissibility (m^2/day)
I = Hydraulic gradient (m/km)
L = Length of flow path (km)

6) Evapotranspiration from Groundwater (E_t): Evapotranspiration from groundwater occurs in waterlogged areas or where water level exists 2 meters below ground level (Kumar, 2012). Water level being more than 2 meters below ground level in the present study area evapotranspiration from groundwater was found negligible.

7) Groundwater discharge from Tubewells (T_p): Groundwater discharge from tubewells during monsoon and non-monsoon was estimated by using formula:

$$T_p = \text{No. of running days} \times \text{average no. of daily running hours} \times \text{discharge } (m^3/hr) \quad (9)$$

8) Change in Groundwater storage (Δs): Change in groundwater storage between beginning and end of non-monsoon season indicates the total amount of water extracted from groundwater storage but the beginning of monsoon and end of monsoon season indicates the amount of water that contributes in groundwater recharge. During monsoon non-monsoon season, the recharge may or may not be more than extraction it depends upon rainfall and other components of groundwater recharge.

To assess the change in groundwater storage during monsoon and non-monsoon season, the water level was observed through observation wells spread within the study area. The following empirical formula was used for estimation of change in groundwater storage:

$$\Delta S = \Delta h A S_y \qquad (10)$$

Where,
Δh = change in water level
A = area influenced by the well
S_y = specific yield

9) Groundwater Recharge:The groundwater recharge was estimated by adding all the inflow parameters of groundwater balance equation i.e. recharge from rainfall, canal seepage, pond seepage, field irrigation and sub-surface inflow.

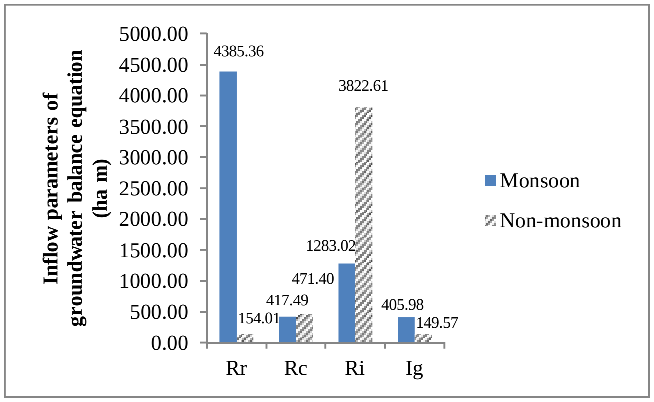
10) Recharge coefficient: Recharge coefficient is defined as the ratio between rainfall recharge and effective rainfall and is expressed in percentage. Recharge coefficient was estimated using empirical formula (Adeleke*et al.*, 2015):

$$R_{coefficient}(\%) = \frac{R}{Pe} \times 100 \qquad (11)$$

Where, R is Recharge from rainfall (mm) and P_e= Effective rainfall (mm).

IV. EXPERIMENTAL RESULTS

Inflow parameters (recharge from rainfall, canal seepage, field irrigation and subsurface inflow) in monsoon and non-monsoon season were presented in figure 3. Recharge from rainfall during monsoon season was estimated 4385.36 ha m and during non-monsoon season was estimated 154.01 ha m. From last ten years data it was observed that during the month of July Antecedent Moisture Content was on stage III. Therefore, canal seepage during that time was considered negligible. It was estimated 417.49 and 471.40 ha m during monsoon and non-monsoon season respectively. Recharge from field irrigation was estimated 1283.02 and 3822.61 ha m during monsoon and non-monsoon season. It was estimated three times higher recharge from field irrigation during non-monsoon season due to higher cropped area. Sub-surface inflow was estimated during monsoon season 405.98 ha m and during non-monsoon season it was estimated 149.57 ha m.In this region, sub-surface inflow was observed from Baragaon Block. Recharge from pond seepage is presented in figure 4. It was estimated to be 9.56 ha and 3.83 ha mduring monsoon and non-monsoon season, respectively. Outflow parameters (sub-surface outflow and discharge from tubewells) in monsoon and non-monsoon season were presented in figure 5. Sub-surface outflow was estimated during monsoon season and non-monsoon season are 123.35 and 561.81 ha m. In this region, sub-surface outflow observed from Cholapur block. Discharge from tubewells during the monsoon and the non-monsoon season was estimated 4587.18 and 10498.33 ha m, respectively. In this region change in groundwater storage was estimated 0.8 ha m and 3.95 ha m during monsoon and non-monsoon season, respectively (Figure 6). Groundwater recharge during monsoon and non-monsoon season was presented in figure 7. It was estimated 6501.11 and 4601.42 ha m during monsoon and non-monsoon season respectively. Groundwater recharge and discharge during monsoon and non-monsoon season are presented in figure 8. Groundwater recharge was estimated 1790.48 ha m higher during monsoon season and during non-monsoon season groundwater discharge was estimated 6458.72 ha m higher than monsoon season.The average recharge coefficient was estimated 47.76%.



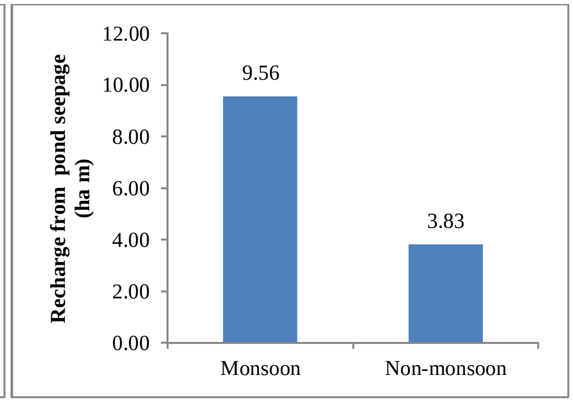
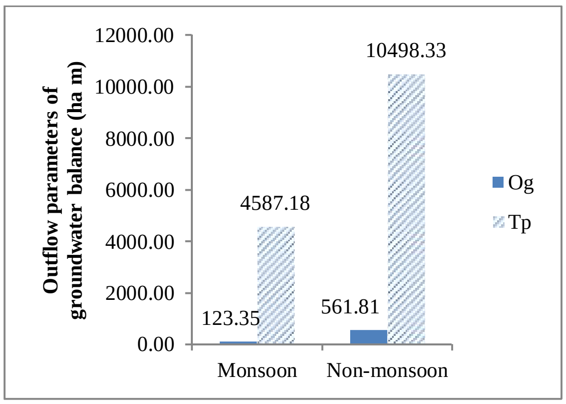


Fig. 3:Inflow parameters during monsoon & non-monsoon seasonFig. 4. Recharge from pond seepage during monsoon &nonmonsoon season



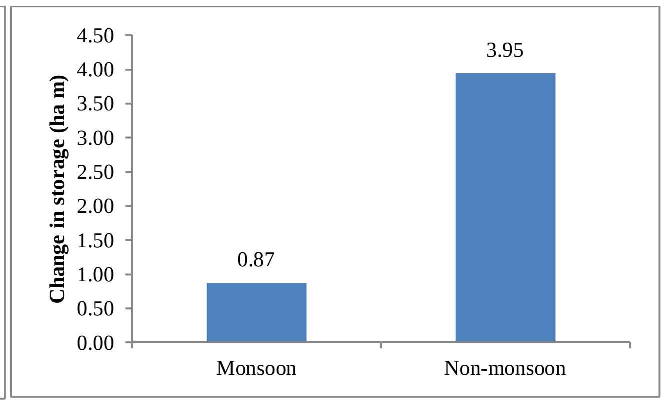
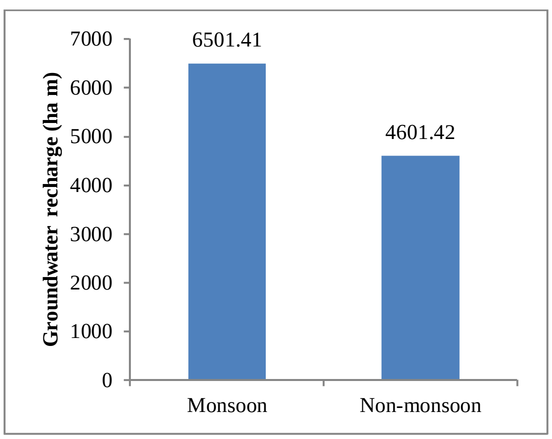


Fig. 5.Outflow parameters during monsoon & non-monsoon seasonFig. 6. Change in storage during monsoon & non-monsoon season



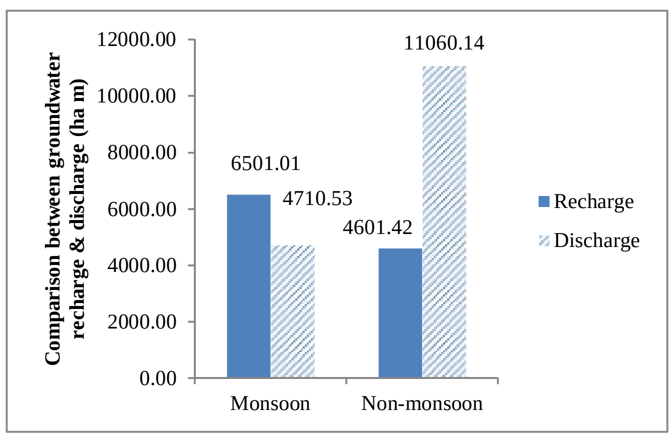


Fig. 7. Groundwater recharge during monsoon & non-monsoon season Fig. 8. Comparison between groundwater recharge & discharge

V. CONCLUSION

The groundwater potential of Pindra block, Varanasi has been carried out using water balance approach. The net recharge to groundwater from different sources was quantified to determine the available groundwater potential in the area. The available groundwater recharge was estimated 11102.83 ha m annually.Overall reduction in groundwater storage was estimated 4667.84 ha m. Groundwater development stage of Pindra was found under over exploited condition which is mainly caused by sustained groundwater pumping.There is an urgent need of artificial groundwater recharge techniques at appropriate locations and proper management techniques to check the declining trend of groundwater level. Declining trend of water level can be checked by developing surface irrigation sources, by reducing excess pumping and proper utilization of rainwater using rainwater harvesting techniques.

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