



Exploring available water resources in Bahraich district of Uttar Pradesh: A comprehensive study

SHIV SHANKER CHAUDHARI¹, SUSAMA SUDHISHRI^{1*}, ANCHAL DASS¹, MANOJ KHANNA¹,
PRAMOD KUMAR¹, VINAY KUMAR SEHGHAL¹, RABINDRA PADARIA¹,
BLESSY V A² and LOVE KUMAR³

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 08 October 2023; Accepted: 29 January 2024

ABSTRACT

Present study was carried out during 2018–22 at Bahraich, Uttar Pradesh focusing on groundwater, runoff, and canal water suggesting that a sizable database is essential for effectively managing water resources. Groundwater quantity was estimated using water level fluctuation (WLF), runoff using GIS coupled with curve number and canal water volume using equivalent length factor methods. This study revealed that the contribution of groundwater was more than 52.5%, whereas runoff (45.61%) and canal water (1.89%). Higher amounts of total available water observed in Mihipurwa (305.3 million cubic meter, MCM), Mahsi (211.6 MCM), Chittaura (189.3 MCM) and Nawabganj (184.4 MCM) blocks due to denser vegetation cover and moderate to low curve number values, while Risia (96.5 MCM) had the lowest amounts of available water in juxtaposition with the other blocks due to high industrial draft, higher drop down in the depth of post-monsoon groundwater level and minimal canal water irrigation. The sandy soil predominant in Jarwal had the lowest annual runoff (117.54 mm) while Nawabganj had the highest (359.84 mm) followed by Balha and Huzoorpur due to having a higher elevation over the other blocks. The runoff ratio was found to be larger in Nawabganj (27.74%), followed by Balha (23.06%) and lowest in Mihipurwa (14.89%) followed by Chittaurah (14.91%). Kaisarganj (11.6 MCM) had the highest amount of canal water resources accessible, followed by Mahsi (6.8 MCM) and Huzoorpur (6.1 MCM), while Balha and Nawabganj had the lowest amounts of canal water resources at 0.1 MCM.

Keywords: Canal water, Curve number, Ground water, Water resource management

In the Indo-Gangetic Plains and north-west Indian farmers struggle with low irrigation efficiency, under-utilization of irrigation water potentials, rising production and pumping costs, declining farm profits, ineffective water management, and declining groundwater (GW) tables (Chaudhari *et al.* 2020, Scanlon *et al.* 2023). Extensive river system and groundwater resources in the state face significant challenges due to over-exploitation, erratic rainfall, water contamination, and reduced ecological flows. The state currently has an irrigated area of 88%, compared to the national average of 49% (Sinha 2021), 70% of irrigated agriculture is GW dependent (Kishore *et al.* 2022). Rainfall and runoff are the significant contributors to the recharge of GW (Kumar *et al.* 2017). Population growth, intensive agriculture and industrialization impacted long-term GW

recharge of an aquifer, necessitating accurate estimation of surface runoff for effective GW management (Karunanidhi *et al.* 2020).

Surface water (SW) consisting of runoff and canal water is an important resource for crop production, socio-economic development, and ecosystem services (Pekel *et al.* 2016). The Natural Resource Conservation Service-Curve Number method is a reliable and predictable method for estimating direct runoff based on storm rainfall (Liu and Li 2008). The monsoon climate has significantly impacted India's canal irrigation, leading to a rapid decrease in water distribution due to poor performance of surface irrigation systems (Bjornlund *et al.* 2020). The Saryu canal network in Bahraich, located on the left bank of the Ghagra river, has increased crop yield and net income, but has also faced challenges in recent years (Ray *et al.* 2002).

The water resource can only be used and perpetuated in the best possible way after being assessed for quantity and quality. The Bahraich, a predominantly agrarian economy, faces pressure on land and water resources due to natural calamities like floods and droughts. The study aims to assess the annual available water resources, both surface

¹ICAR-Indian Agricultural Research Institute, New Delhi;

²ICAR-Indian Institute of Soil and Water Conservation, Regional Centre, Udahgamandalam, Tamil Nadu; ³Bihar Agriculture University, Sabour, Bihar. *Corresponding author email: susama.sudhishri2023@gmail.com

and groundwater, at the district's 14 blocks endowed with diverse natural resources.

MATERIALS AND METHODS

A study was carried out during 2018–22 at Bahraich (27° 02' to 28° 30' N latitude and 81° 04' to 81° 42' E longitude), Uttar Pradesh. Administratively, the district is divided into 6 tehsils and 14 developmental blocks. The detailed study on available water resources was carried out for this district after collection of data and analysis as per the methodologies and methods.

Climate and weather: Annual rainfall in the district gradually declined over the normal rainfall (1036.2 mm) during last 30 years (1987–2016), whereas, average maximum temperature, minimum temperature and total average temperature increased over normal 31.1°C, 18.08°C and 24.6°C, respectively. The district experiences sub-humid climate and three distinct seasons, viz. summer, rainy and winter. The hottest month is May with average mean daily temperature of 39.8°C. The coldest month is January with average mean daily temperature of 22.6°C.

Soil type and drainage: The soil data were taken from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), New Delhi. The district has 3 distinct soil types, sandy in the belt of Ghagra river, sandy-loam in the middle, and loam in few pockets. Ghaghara and Saryu are the main rivers of the district. All the rivers are effectively perennial since these maintain the flow for most part of the year.

Groundwater (GW) resources: GW occurs in unconsolidated alluvial material, with shallow tubewells tapping water from kankar and sandy horizons. Bahraich's alluvial tract is underlain by sands, gravels, silt, and clay. The variation in the water table is closely related to the quantity of precipitation (Halder *et al.* 2020). Broadly the district can be considered to be a flat country with a gentle slope towards south. The method used for estimation of GW is as follows (Bhanja *et al.* 2016).

$$\text{Potential ground water resource } (\Delta S) = \text{Area of water level zone (A)} \times \text{Depth to water level of pre-monsoon below cut-off level (H)} \times \text{Specific yield (Sy)} \quad (1)$$

The value of specific yield was taken as 0.025 in case of Bahraich. If, non-monsoon season rainfall less than 10% of annual rainfall then rainfall is considered zero and monsoonal recharge is estimated using the water level fluctuation method.

Surface Water Resources

Runoff: Surface runoff for different blocks was estimated by using NRCS curve number method. It is based on the concept that the ratio of actual amount of runoff to maximum potential runoff is equal to the ratio of actual infiltration to the potential maximum retention. In Indian condition, initial abstraction (Ia) is equal to 0.3 times of surface retention. The following steps were taken for calculation of CN;

Step I: The study area's size, soil type, soil hydrologic groups and land use/land cover information were analyzed using satellite imagery (using Sentinel) and GIS models. Analysis of Land use/Land cover map area and determination of percentage area under various soil hydrologic groups.

Step II: The hydrologic cover complex and curve numbers were determined through interpolation using standard tables.

Step III: Determined of appropriate weightage for different land uses by using weighted curve numbers.

Step IV: Analysis of potential maximum retentions and depth of runoff.

Surface retention, depends on antecedent moisture conditions (AMC) can be as:

$$S = \frac{25400}{CN} - 254 \quad (2)$$

The following equations were used in the cases of AMC-I and AMC-III (Chow 2002):

CN for AMC I:

$$CN_I = \frac{CN_{II}}{2.281 - 0.011281 CN_{II}} \quad (3)$$

CN for AMC III:

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573 CN_{II}} \quad (4)$$

The curve number is a purpose of the ability of soils to allow infiltration of water with respect to land use land cover (LULC) and AMC (Amutha and Porchelvan 2009, Bansode *et al.* 2014). The four hydrologic soil groups (HSGs) A, B, C, and D have been found based on the infiltration rate, soil texture, depth, drainage situation, and water transmission capacity of the soils. AMC was determined as per Chow (2002) criteria and curve number under AMC II condition for the study area (Table 1).

Area weighted composite CN for various conditions of land use and hydrologic soil conditions are computed as:

$$CN_w = [(CN_1 \times A_1) + (CN_2 \times A_2) + \dots + (CN_6 \times A_6)] / (\sum A_i) \quad (5)$$

where CN_w , Weighted curve number; A_i , Area with CN_i ; (where $i = 1-6$)

Table 1 Curve number for hydrological soil cover complexes

Class name	HSGs			
	A	B	C	D
Forest	26	40	58	61
Agriculture land	72	81	88	91
Settlement	57	72	86	91
Tree cover/Orchard	41	55	69	73
Water body	97	97	97	97
Wasteland	71	80	85	88
Shrub and scrub	33	47	64	67

Step V: Depth of runoff was estimated by following relation (USDA 1972)

$$Q = \frac{(P-0.3S)^2}{P + 0.7S} \text{ if rainfall} > 0.3S \quad (6)$$

$$Q = 0 \text{ rainfall} \leq 0.3S \quad (7)$$

where Q, Runoff (mm); P, Amount of precipitation (mm); S, Surface retention (mm)

Canal water: The data regarding canal roster was taken from irrigation department of the district for the period 2007–2017 and on the basis of daily discharges, season-wise discharges were computed for the Saryu canal system. The volume of water going out of the study area was subtracted in order to get the net amount of water utilized. The canal water availability was estimated block-wise by considering the length of branches and distributaries (Table 2). The canal network map of Bahraich was superimposed using supervised classification in GIS environment. The total discharge of each branches/distributaries in block was calculated as (Kaur *et al.* 2009):

$$\text{Total volume (ha-m)} = \frac{\text{Average discharge (cusecs)} \times \text{Length factor} \times 0.245 \times \text{No. of days of operation}}{\text{Length factor}} \quad (8)$$

$$\text{Length factor} = \frac{\text{Blockwise length of each branch/distributary}}{\text{Total length of branch/distributary in district}} \quad (9)$$

The total available water resource (TAWR) in each block was computed by adding the groundwater available

in each block and surface water (canal flow and runoff from rainfall).

RESULTS AND DISCUSSION

It was observed that around 43.1, 1195.1 and 1038.9 MCM of average annual canal water, ground water and runoff, respectively in Bahraich district (Table 3). Similar study on total water resource was conducted by Kaur *et al.* (2009) for Ludhiana district of Punjab. Block-wise pre- and post-monsoon below ground water level data (bgl in meter) showed a maximum difference of pre and post-monsoon GW level was found for Mihipurwa (8.2 mbgl). It might be due to land slope and ground water outflow. The net GW availability has been computed after deducting the natural discharge from the replenishable GW resources as per GEC norm. The average value of specific yield was taken as 0.025 as most of aquifers are unconsolidated alluvium and it was found that Chittaura (120.1 MCM), Mahsi (120 MCM), Payagpur (101.8 MCM) and Bisheswarganj (101 MCM) have higher amount of GW resources due to higher amount of annual GW recharge due to high natural as well as man-made depression area while Risia (51 MCM) has lowest amount of GW resource among all other blocks due to lower annual ground water recharge and 65% level of exploitation of GW resources which are in concomitance with UP GW development report 2018.

Daily runoff was estimated using NRCS-CN method as for the period of 2007–2017. The land use and soil maps were processed using GIS techniques for the selection of

Table 2 List of branches and distributaries flowing through block

Block	Branches and minors (length, km) (as per 2015)
Balaha	Nevada (4.4)
Bisheswarganj	Sultana (6.6), Kaluapur (3.61), Badagaon (5.5)
Chittaura	Dharsawa (4.2), Kusaur (4.2), Kaimee (8.31) Govindapur (4.1), Jagdishpur (6.2), Janijyot (1.5), Duhru (9), Dharmanpur (4.7), Baldipurwa (2.4) Barwabhadauli (3.4), Bhagwanpur (3.87), Badagaon (3), Soharwa (3.4), Damaodarjyot (2.65), Sahpur (3), Bichudi (9.6), Gambhirwa (11.6), Mahammad Nagar (4.4)
Fakherpur	Maraucha (4.4), Takhwa (3.8), Majhaura (3.3), Kandausa (4.95), Ajeejpur (7.2), Bedaura (2.6), Patti Kamalpur (5.05)
Huzoorpur	Siraula (2.31), Bhatikunda (2.31), Padampichaura (4.87), Katghara khurd (14.3), Shekhapur (3.15), Shivnaha (6.2), Sarkhana (3.1), Vasantpur (9.185), katghara (14.3), Sarwa (3.6)
Jarwal	Jarwal Rajwaha (15)
Kaisarganj	Parsendi (16.1), Narendrapur (5.19), Umri (19.75), Kundasar (5.75), Sutaui (7.4), Idnapur (5), Rasoolpur (2), Sirauli (13), Mahammadpur (9), Patupur (3.4)
Mahsi	Hardi (18.2), Siphya Puli (6.5), Sadhwapur (3.7), Rehwa (7.5), Masadeeh (5.42), Gadamarkhurd (4), Ramwapur (5), Makrandpur (7.8), Nautala (15.85), Devrai Pur (2.6), Bekuntha (4.8), Kapurpur (13.197), Chattarpur (5.6), Gadwa (3.87), Mahrajganj (2.2)
Mhipurwa	Suajuli minor (5.4), Bojhya minor (2.5), Madhavapur (3), Urra (7), Harkhapur (3.5), Kyura (5.2)
Nawabganj	Madhopur (3)
Payagpur	Hasuapura (3), Lahraura (4), Belkhada (12.7), Sarsa (3.735), Khutena (6.8), Chausar (4), Parsia (13.3), Bainee (4.8), Rajapur (7.64)
Risia	Bhagwanpur (3)
Shivpur	Patharkala (7.7), Patharkhurd (3.8), Kotwa (1.5), Chandela (10.6), Semarya (2.15), Sankalpa (2.8), Piprimafi (4.1), Chalar (2.95), Narottampur (2.8)
Tejwapur	Unchgaon (7.5), Khaira (2.5) Gajpatipur (4.5), Chaukaria (5), Nevada (2.8), Behta (2.8), Jumrajyot (9.07), Maigla (13.5), Ramgaon (5.2), Narhargaud (6.3)

runoff CN (Soulis and Valiantzas 2012). It was found that area under agriculture, deciduous forest, built up lands and water bodies cover 59, 14.90, 20.40 and 3.50%, respectively. Remote sensing and GIS have proved to be powerful and cost effective method for determining block-wise runoff generation of district Bahraich (Waikar and Nilawar 2014).

In general, northern part of the district is covered with hydrologic soil group C while southern part is covered with group D; however, western parts are covered with fragmented patches of B types of HSG whereas A group of HSG are found in fragmented patches of Jarwal, Kaisarganj, Fakherpur and Mahsi. Except some part of Mihipurwa and Balha most of the area is under high range of curve number. For various curve numbers, the runoff was estimated for different AMC conditions. The individual composite curve number was computed for study area of AMC II condition. Using equation (6) the block-wise daily runoff depth were computed.

From the daily runoff, monthly and annual values were derived. The runoff depths computed for each rainfall event for the years 2007–2017. The spatial variability map of annual runoff is shown in Fig. 1. For those rainfall events whose intensity is less than 0.3 sec, the runoff depth is taken as zero. The lowest amount of annual average runoff was found for Mihipurwa (14.9%) and Chittaura (14.9%) while maximum for Nawabganj (27.7%) followed by Balha (23.1%). Block-wise average decadal variation of runoff was calculated for the last 10 years i.e. 2007–2017.

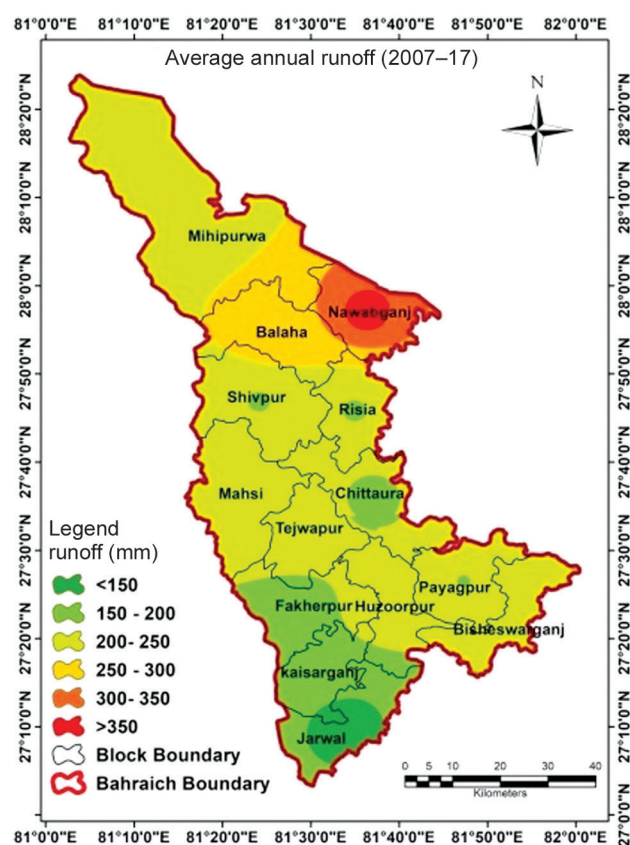


Fig. 1 Spatial variability map of annual runoff in Bahraich district.

In all the year, lowest annual runoff was found for Jarwal 117.5 mm because of predominance of sandy soil while it was highest for Nawabganj i.e., 359.8 mm followed Balha i.e. 259.7 mm and Huzoorpur i.e., 222.6 mm due to higher elevation compared to other blocks. There was no temporal relationship found for runoff in either increasing or decreasing trends. The CN methods and the extension proposed by Bartlett *et al.* (2016) promote a “one-size fits all” mentality that gives the impression that just adding one or two more parameters will solve the problem of hydrological predictability. The lowest amount of runoff in Mihipurwa was due to higher percentage of vegetation cover to its total geographical area i.e. 46 % of its total geographical area while in Chittaura block it might be due to large number of water bodies. However, higher percentage of runoff was found in Nawabganj followed by Balha due to topographical factor.

Canal Index Map (2015) was obtained from Irrigation Department of Bahraich and digitized in ArcGIS (Fig. 2). Three main distributaries were found feeding the different minors namely Saryu Link Channel (SLC) with average discharge equivalent to 360 cumecs, Saryu Main Canal (SMC) with average discharge equivalent to 360 cumecs and lastly Rapti Link Channel (RLC) average discharge equivalent to 95 cumecs. SLC is Left Bank Canal of Ghagra river taking source from Girja barrage. RLC were added in to SLC to divert excess flood water of river Rapti flowing across Shrawasti district. As of 2018 all the blocks have

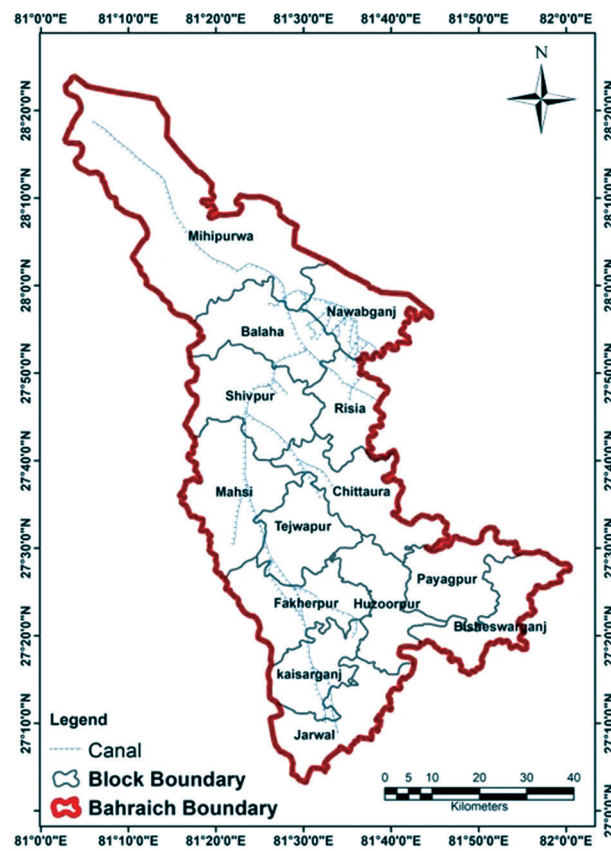


Fig. 2 Canal index map of Bahraich.

Table 3 Block-wise total available water resource of district Bahraich

Block	Ground water (MCM)	Surface water (MCM)		Total available water (MCM)
		Runoff	Canal	
Balha	75.3	96.4	0.1	171.8
Bisheshwarganj	101.0	55.7	0.4	157.1
Chittaura	120.1	64.8	4.5	189.3
Huzurpur	70.5	57.6	6.1	134.2
Jarwal	78.2	34.0	0.6	112.7
Kaisarganj	89.1	45.2	11.6	146.0
Mahsi	120.0	84.7	6.8	211.6
Mihipurwa	90.9	212.9	1.5	305.3
Nawabganj	88.2	96.1	0.1	184.4
Payagpur	101.8	55.3	3.9	161.0
Phakarpur	64.8	61.7	0.7	127.2
Risia	51.0	44.1	1.4	96.5
Shivpur	87.7	75.8	2.1	165.6
Tejwapur	56.6	54.6	3.3	114.6

one or more functional minors. Chittaura block have highest number of functional minor followed by Mahsi, Huzoorpur and Tejwapur.

However, Risia, Balha, Nawabganj and Jarwal blocks have only one minor or Rajwaha (Table 2). Available water resource from canal were found to be higher in Kaisarganj (11.6 MCM) followed by Mahsi (6.8 MCM), Huzoorpur (6.1 MCM) while Balha and Nawabganj have lowest available canal water resources i.e. 0.1 MCM. Canal water may be regulated so as to implement the conjunctive use of surface and ground water effectively.

In terms of total available water resources Mihipurwa block has the highest quantum of total available water resources followed by Mahsi and Chittaura i.e. 305.3, 211.6 and 189.0 MCM, respectively. However, Risia has lowest amount total amount of available water resources (96.5 MCM) followed by Jarwal (112.7 MCM) and Tejwapur (114.6 MCM). In all the blocks except Mihipurwa, Nawabganj and Balha, all the blocks have higher amount of groundwater resources compared to runoff. Overall, canal water resources have least amount of available water resource among others (Table 3). Ground water contributes 52.5%, rainfall and runoff contributed 45.61% whereas canal water contributed 1.89% (Table 3). However, UP as a whole as per Statistical Diary, Uttar Pradesh 2018, in 2014–15 the contribution of ground water (GW) by government tubewell and private tubewell was stand at 3% and 67.7%, respectively. However, canal irrigation was found to be 17.3% of total irrigation.

Overall, groundwater contribution in total available water resource was found to be highest followed by runoff whereas canal water contribution was found to be least. Among all 14 blocks, Mihipurwa have highest quantity of

WRs i.e., 305.3 MCM whereas Risia had lowest available WRs i.e. 96.5 MCM. GW is a major source of irrigation in Bahraich. Total amount of runoff generation was found to be highest in Mihipurwa contrast to having highest vegetation area. The average decadal runoff for the blocks was found between 15–18%. But proportions of canal irrigated area are less compared to groundwater. Various minors were found to be non-functional. Breaches in canal minors due to anthropogenic activity were predominant feature. Therefore, a comprehensive water resource management plan is required for the aspirational district to enhance water security.

ACKNOWLEDGEMENT

Authors are grateful to the ICAR-Indian Agricultural Research Institute, New Delhi for providing technical and financial assistance for undertaking this study.

REFERENCES

- Amutha R and Porchelvan P. 2009. Estimation of surface runoff in Malattar sub-watershed using SCS-CN method. *Journal of The Indian Society of Remote Sensing* **37**: 291–304.
- Bansode A and Patil K A. 2014. Estimation of runoff by using SCS curve number method and ArcGIS. *International Journal of Science and Engineering Research* **5**(7): 1283–287.
- Bartlett M S, Parolari A J, Mc Donnell J J and Porporato A. 2016. Beyond the SCS-CN method: A theoretical framework for spatially lumped rainfall-runoff response. *Water Resource Research* **52**: 4608–627.
- Bhanja S N, Mukherjee A, Saha D, Velicogna I and Famiglietti J S. 2016. Validation of GRACE-based groundwater storage anomaly using *in situ* groundwater level measurements in India. *Journal of Hydrology* **543**: 729–38.
- Bjornlund V, Bjornlund H and Rooyen A F. 2020. Exploring the factors causing the poor performance of most irrigation schemes in post-independence sub-Saharan Africa. *International Journal of Water Resources Development* **36**: 54–101.
- Chaudhari S S, Sudhishri S, Khanna M, Dass A, Rosin K G, Bhattacharya R and Maurya R. 2020. Water budgeting in major *rabi* crops under surface irrigation in Western Indo-Gangetic Plains. *The Indian Journal of Agricultural Sciences* **90**(11): 2185–91.
- Chow V T, Maidment D K and Mays L W. 2002. *Applied Hydrology*. McGraw-Hill Book Company, New York, USA.
- Halder S, Roy M B and Roy P K. 2020. Analysis of groundwater level trend and groundwater drought using standard groundwater level index: A case study of an eastern river basin of West Bengal, India. *Applied Sciences* **2**: 1–24.
- Karunanidhi D, Anand B, Subramani T and Srinivasa Moorthy K. 2020. Rainfall surface runoff estimation for the Lower Bhavani basin in south India using SCS-CN model and geospatial techniques. *Environmental Earth Sciences* **79**(13): 1–19.
- Kaur S, Agarwal R and Kumar S T M. 2009. A micro level assessment of water resources: A case study. *Journal of Indian Water Resource Society* **29**(1): 17–21.
- Kishore P, Chand S and Srivastava S K. 2022. Potential area of micro-irrigation and its outreach across Indian states. *The Indian Journal of Agricultural Sciences* **92**(9): 1056–060.
- Kumar S, Venkateswaran S and Kannan R. 2017. Rainfall-runoff estimation using SCS-CN and GIS approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India.

- Modeling Earth Systems and Environment* **3**: 1–8.
- Liu X and Li J. 2008. Application of SCS model in estimation of runoff from small watershed in loess plateau of China. *Chinese Geographical Science* **18**: 235–41.
- Pekel J F, Cottam A, Gorelick N and Belward A S. 2016. High-resolution mapping of global surface water and its long-term changes. *Nature* **540**: 418–22.
- Ray S S, Dadhwal V K and Navalgund R R. 2002. Performance evaluation of an irrigation command area using remote sensing: A case study of Mahi command, Gujarat, India. *Agricultural Water Management* **56**(2): 81–91.
- Scanlon B R, Fakhreddine S, Rateb A, de Graaf I, Famiglietti J, Gleeson T and Zheng C. 2023. Global water resources and the role of groundwater in a resilient water future. *Nature Reviews Earth and Environment* **4**(2): 87–101.
- Sinha R S. 2021. State of groundwater in Uttar Pradesh. A situation analysis with critical overview and sustainable solutions ground water action group, Water Aid. Available online: <https://cdn.cseindia.org/gic/state-of-ground-water> (Accessed on 15 February 2022)
- Soulis K X and Valiantzas J D. 2012. SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds—the two-CN system approach. *Hydrology and Earth System Sciences* **16** (3): 1001–015.
- USDA C S. 1972. *National Engineering Handbook, Hydrology Section 4*: 4–10.
- Waikar M L and Nilawar A P. 2014. Identification of groundwater potential zone using remote sensing and GIS technique. *International Journal of Innovative Research in Science Engineering and Technology* **3**(5): 12163–74.