International Journal of Environment and Climate Change

Volume 13, Issue 8, Page 1662-1672, 2023; Article no.IJECC.100378
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Land Use Planning and Management in Jamrani Dam Command

R. K. Singh [a++*] and H. C. Sharma [b#]

[a] *College of Agricultural Engineering and Technology, Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India.*
[b] *College of Technology, GBPUA&T, Pantnagar (Uttrakhand), India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i82118

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/100378

Original Research Article

Received: 04/04/2023
Accepted: 08/06/2023
Published: 15/06/2023

ABSTRACT

The Present study was conducted to assess the groundwater inventory in Jamrani Dam Command situated in Uttrakhand and Uttar Pradesh, India. Groundwater inventory was prepared for different blocks of Udhamsingh Nagar, Rampur, and Bareilly districts in Jamrani Dam Command from 1988 to 2010 at an interval of five years. Over-exploitation of groundwater has created an alarming situation in a few blocks of Rampur and Bareilly districts in Jamrani Dam Command. In the year 2010, the Bilaspur, Baheri, Gadarpur, and Rudrapur blocks of the study area were found under the safe category; Swar and Meerganj blocks were found under the critical category whereas Milak and Shergarh blocks were found under the over-exploited category. The maximum and minimum stages of development were found at 109.08% and 59.31% at Shergarh and Rudrarpur blocks, respectively. The overall stage of development for the study area was 68.44% and the area as a whole may be put under the semi-critical category for the year 2010. In the present study, the physical-chemical properties of groundwater in shallow aquifers and their suitability for drinking, irrigation, and industrial uses were studied. The physical-chemical properties of the groundwater of the study area were determined using standard methods of water quality analysis. A

[++] *Senior Tech. Officer, SWE;*
[#] *Ex. Dean;*
**Corresponding author: E-mail: singhraj37048@gmail.com;*

comprehensive and proper groundwater recharge plan for the identified landforms with their prevailing geomorphic features in the study area has been suggested to maintain the groundwater at a safe and desired level in the future in the Jamrani Dam Command. Various water recharging structures namely: a series of check dams, percolation tanks, farm ponds and nallah bunds are most possible techniques for recharging groundwater aquifers by utilizing excess water available during monsoon season in the form of runoff obtained from the land surface. Geographic information Systems (GIS) and Remote Sensing were applied to the study area to delineate different land uses from the satellite imageries (IRS-1D). The study area delineated from the S.O.I. toposheets was also classified into nine land use classes i.e. agricultural land, grassland, water body, scrubland, and forest etc.

Keywords: Groundwater; recharge; check dam; percolation tank; GIS.

1. INTRODUCTION

"Land and water are two finite natural resources, and these are degrading rapidly due to unscrupulous and indiscriminate utilization. Immense pressure on these resources can be gauged from the fact that India shares 2.45% geographical area of the world but it supports 16% population and 18% livestock of the World" [1]. "It has been estimated that renewable water resources of the country account for about 4 % of global water availability. Leading experts on water resources are warning that the world is fast heading towards "a water shock" which even dwarfs the oil crisis. They also fear that the shortage of water and disputes relating to sharing of water resources among various countries may lead to the next world war. Today about 80 countries comprising 40% of the World's population suffers from serious water shortages" [2].

"As per UN standards, the countries with annual per capita water availability of less than 1700 m^3 are considered as water-stressed and those with less than 1000 m^3 as water scarce, which already exists in some parts of the country" [3].

"In some arid and semi-arid regions, groundwater is the primary water source to meet various needs of communities for drinking and agriculture. Moreover, groundwater is essential and preferable due to its relatively good quality" [4,5]. "With the increasing use of groundwater for agricultural, municipal, and industrial needs, the annual extraction of groundwater is greater than the net average recharge from natural resources. There is a steady area increase in the area irrigated from groundwater since independence. This has gone up from 6.5 M-ha in 1951 to 35.38 M-ha in 1993 and is rising at the rate of 1.5 M-ha annually" [3].

"At the present rate, it is expected that by 2025 presently estimated water resources would be fully utilized" [6]. "Even at the present rate of population growth and urban development, the gap in the requirement and availability of water in mega-cities is going to be quite large. It is also expected that the generation of wastewater will also increase considerably" [6].

"Re-use of this wastewater for groundwater recharge will become essential in urban areas where surplus water is not available for recharge. This is also needed for environmental conservation. The overexploitation of groundwater resources beyond the annual replenishment leads to the continuous decline of water levels, reduction of good yield, drying up of shallow wells, deterioration of groundwater quality, seawater intrusion in coastal aquifers, etc. These indirectly make agriculture uneconomic mainly for small-scale farmers" [6].

"About 86.47 M-ha-m surplus monsoons runoff is available for recharge in 20 river basins of the country. However, on the basis of the availability of monsoon runoff and the storage potential of the vadose zone, the feasible groundwater storage has been estimated as 21.42 M-ha-m of which 16.05 M-ha-m will be utilizable" [7].

"Therefore, the exploitation, conservation, and judicious use of water form one of the important elements in a country's development and planning. After a few years, water will be a scarce resource and, therefore, needs to harness in the most scientific and efficient manner or by recharging the groundwater aquifer in which the application of GIS and RS will play an important role" [7].

"There is an urgent need for artificial recharge of groundwater by augmenting the natural infiltration of precipitation into subsurface formation by some suitable method of recharge. Over-exploitation of groundwater has occurred leading to continuous decline of water table in different parts of the country. If immediate steps are not taken to arrest the decline of water table, it will not be possible even to sustain the present level of production. One of the ways to arrest and sustain the decline of water table is undertaking various methods of artificial recharge of groundwater. A severe decline in groundwater levels is observed in many parts of country, where the green revolution has been most successful. This situation calls for a constant monitoring of groundwater behaviour, in all the areas that are getting fast depleted, and requires adoption of sensible ways to control withdrawals so as to keep them within the limits of recharge capacities" [8].

The selection of suitable sites has been suggested by Integrated Mission for Sustainable Development (IMSD) of National Remote Sensing Agency (NRSA), Indian National Committee on Hydrology (INCON), and National Institute of Hydrology (1995). The entire study area was reviewed for the construction of suitable water harvesting structures and on the basis of above mentioned recommendations the water harvesting structures such as Check Dams, Farm Ponds, Nala Bunds and Percolation Tanks were considered for their suitability. On the basis of the study of land and water resources of the area, suitable water harvesting and recharge structures have been suggested so that the declining water table can be arrested at the desired level.

Keeping this in view the study has been undertaken to identify the favorable areas for artificial recharge and suggest suitable recharge techniques to augment the aquifer system. The analysis was carried out for the entire study area using remote sensing data and GIS technique.

2. MATERIALS AND METHODS

The study area lies between the Baur and Behgul rivers of Jamrani Dam Command. The study area is located in Jamrani dam command covering part of Bareilly and Rampur districts of Uttar Pradesh, and part of U.S. Nagar district of Uttarakhand state. It is located between latitude of 28° 29' 56" and 29° 06' 56" N and longitude of 79° 06' 43" and 79° 36' 33" E. Total geographical area and perimeter under study is about 2,17,640 ha and 346 km, respectively, of which 73,084 ha falls in U.S Nagar district, 84,933 ha in Rampur district and rest (59623 ha) in Bareilly district. The eastern boundary of the area is marked by Baur river, western by Behgul river, northern by Nainital district of Uttarakhand and southern by Dojora river (Bareilly district).

This study deals with the details of the study area, and application of remote sensing and GIS for the investigation of land use, slope and temporal changes in the land uses / land covers. Besides this, artificial groundwater recharge techniques and land and water resources characteristics of the Jamrani Dam Command have been elaborated using GIS software Geomatica v10.0. Thereafter, detailed procedures adopted for the determination of various physical-chemical parameters of water sample of the study area, have also been discussed in this study.

The integrated approach of GIS and Remote Sensing is recognized as a highly effective technology in evaluation, management and monitoring of natural resources and environment. To study various phenomena, occurring on the earth surface, is not an easy task, as these phenomena are very complex and dynamic. But, with its high speed, accuracy, storage and versatility, GIS provides a promising solution [9]. *In this research both, satellite data as well as extensive field data, were used for preparation of various thematic maps. As far as satellite data are concerned IRS-1D LISS III, November 2005 data were procured for the entire river interbasin and used in the analysis.* GIS approach is playing a rapidly increasing role in the field of hydrology and water resource development. These models have proved to be helpful in solving various issues like (i). water utilization, (ii). surface and sub-surface water management, (iii). river basin development, and (iv). sustainable development of water resources [10].

The physical-chemical analysis was performed in water quality laboratory of department of Irrigation and Drainage Engineering and in the department of Soil Science in G. B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, Uttrakhand. The collected water samples were analyzed for their physico-chemical properties as per standard procedure [11]. The categorization of the available groundwater for their suitability for irrigation were studied with the help of criteria given by Richard [12], Wilcox's [13], Wescot and Ayers [14] and Belkhiri et al. [15].

The study area lied in the Jamrani dam command, covering Bareilly and Rampur districts of Uttar Pradesh, and Udham Singh Nagar district of Uttarakhand (Fig. 1). It was located between latitude of 28^0 29' 56" and 29^0 06' 56" N and longitude of 79^0 06' 43" and 79^0 36' 33" E. Total geographical area and perimeter under study were about 2,17,640 ha and 346 km, respectively, of which 73,084 ha fell in Udham Singh Nagar district, 84933 ha in Rampur district and rest (59,623 ha) in Bareilly district. The soils of the Jamrani Dam Command area fall under three major categories. They are *Bhabar*, *Tarai* and alluvial plain. The soil map (Fig. 2) of the Jamrani Dam Command consists of associations of various soil series identified.

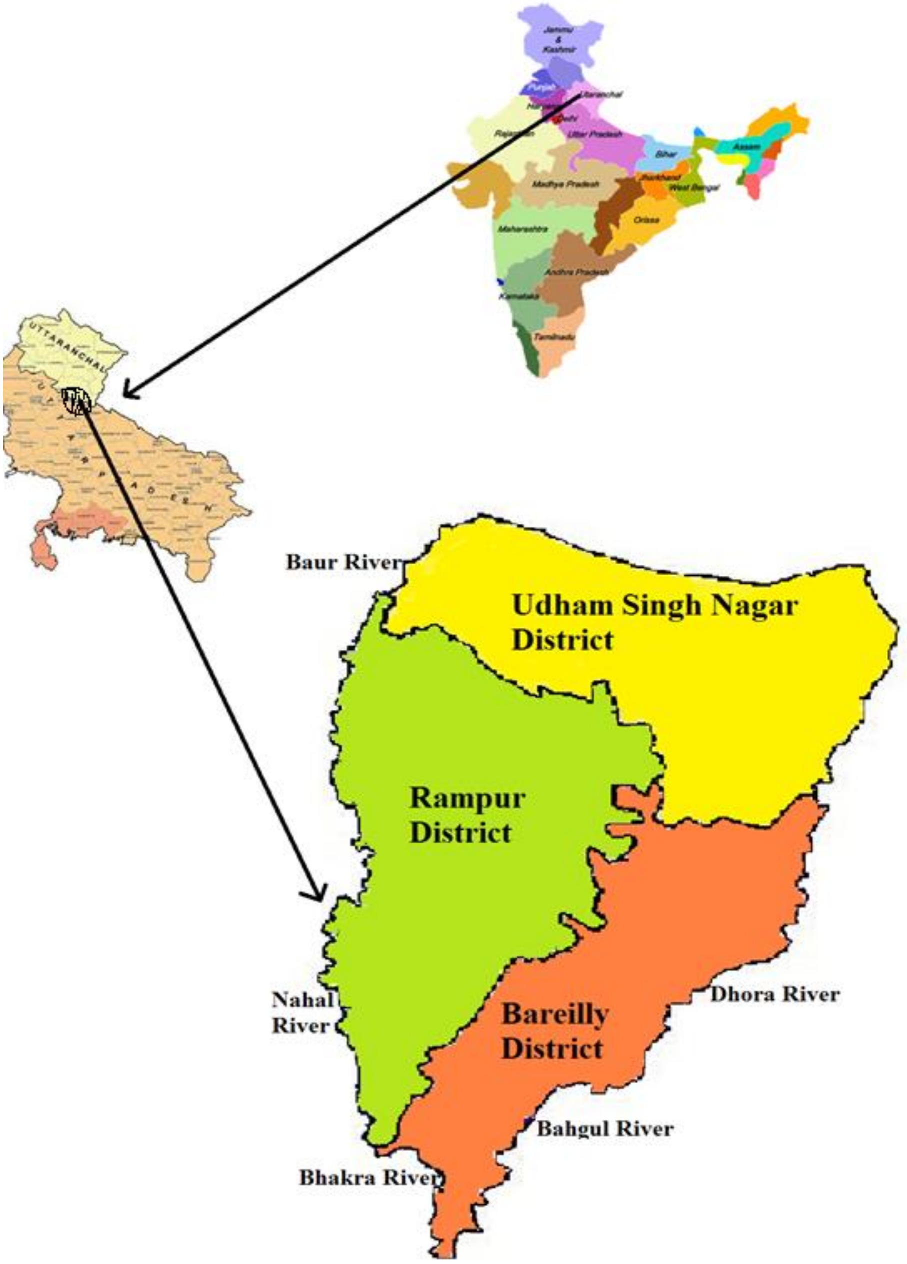

Fig. 1. Index map of Jamrani Dam Command

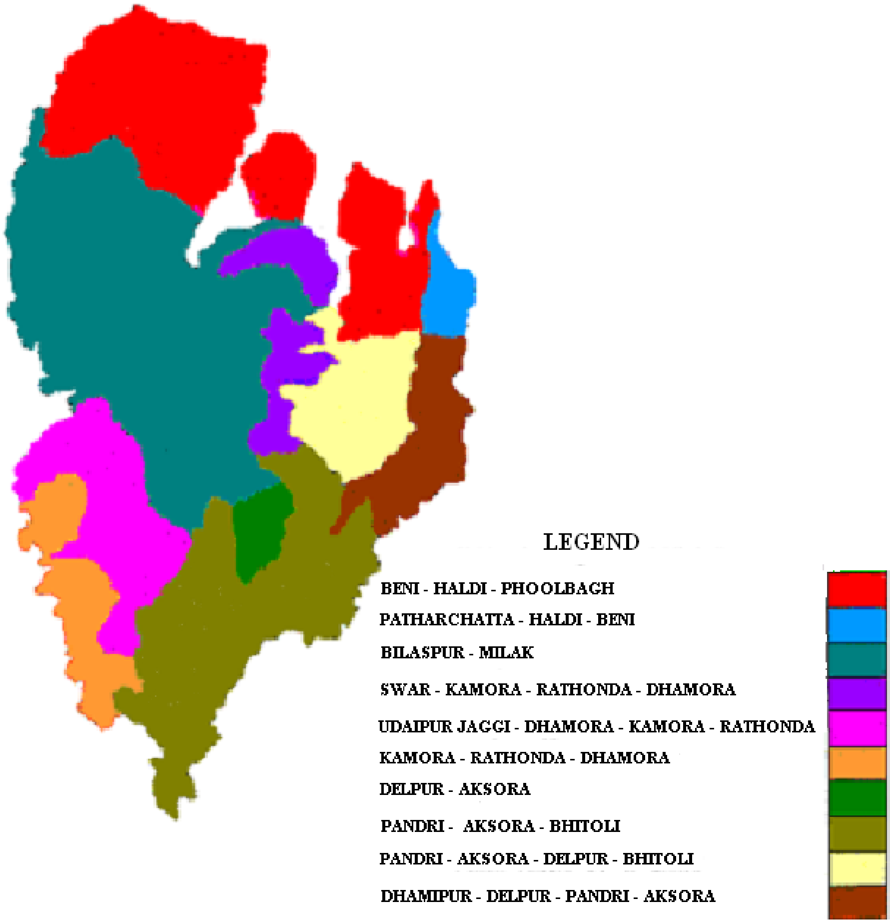

Fig. 2. Soil map of Jamrani Dam Command

The area under study is served by a close network of 29 canal system. About 13.5% of the total culturable command area (CCA) of the Jamrani Dam Command lies in *Tarai* belt, spread over the parts of Gadarpur and Rudrapur blocks in Udham Singh Nagar district, and about 78.16% of the total CCA lies in Gangetic alluvial zone spread over Baheri, Shergarh and Meerganj blocks of Bareilly disctrict; and Bilaspur, Milak and Swar blocks of Rampur district.

At present about 625M m^3 water is annually available through different existing canal systems under *Tarai* and Gangetic sub-regions of the Jamrani Dam Command. The monthly supply of the canal water, in the area under study, varies from about 34 M m^3 in the month of November to about 94 M m^3 in the month of August.

3. RESULTS AND DISCUSSION

The present study was conducted for the planning and management of land and water resources in Jamrani Dam Command area of Uttarakhand and Uttar Pradesh, using GIS and remote sensing.

In the study, different thematic maps viz. contour map, slope map, drainage map, soil map, map locating canals and river network, observation wells, water sampling sites etc. were prepared using GIS software Geomatica v 10.0 and satellite imagery (false colour composite), land use map etc. The deteriorating condition of groundwater calls for an urgent need for a detailed study of soil conditions, geo-hydrology and groundwater behavior to develop suitable strategies for the assessment of groundwater and planning for proper groundwater management so that the declining of water tables can be arrested at a desired level.

A DEM is a digital file of terrain elevations for ground positions representing the elevations of the ground and objects. Besides providing a source of elevation, the DEM may be used for topographic information, flow pattern, flood risk areas identification and to determine accessibility. With the help of contour layer, digital elevation model (DEM) was prepared using algorithm 'VDEMINT' (algorithm for DEM) available in Geomatica v 10.0. The DEM of Jamrani Dam Command is shown in Fig. 3. Land elevation varied from 175 to 300 m in the study area.

Slope of a region is the key parameter in deciding suitable land use, and identifying the areas for appropriate artificial groundwater recharge measures in the study area. The slope is also an important parameter for deciding land capability classification.

A slope map was prepared using 'SLP algorithm' of Geomatica v 10.0. Percent areal extent of different slope classes in the study area is shown in Fig. 4. It was observed from the slope map that most of the lands were having slope percent less than 1. It was also noticed that slope of major area of agricultural land varied from very gently sloping to moderately sloping whereas, forest areas were mainly located on higher slopes (moderately steep slope to steep slope).

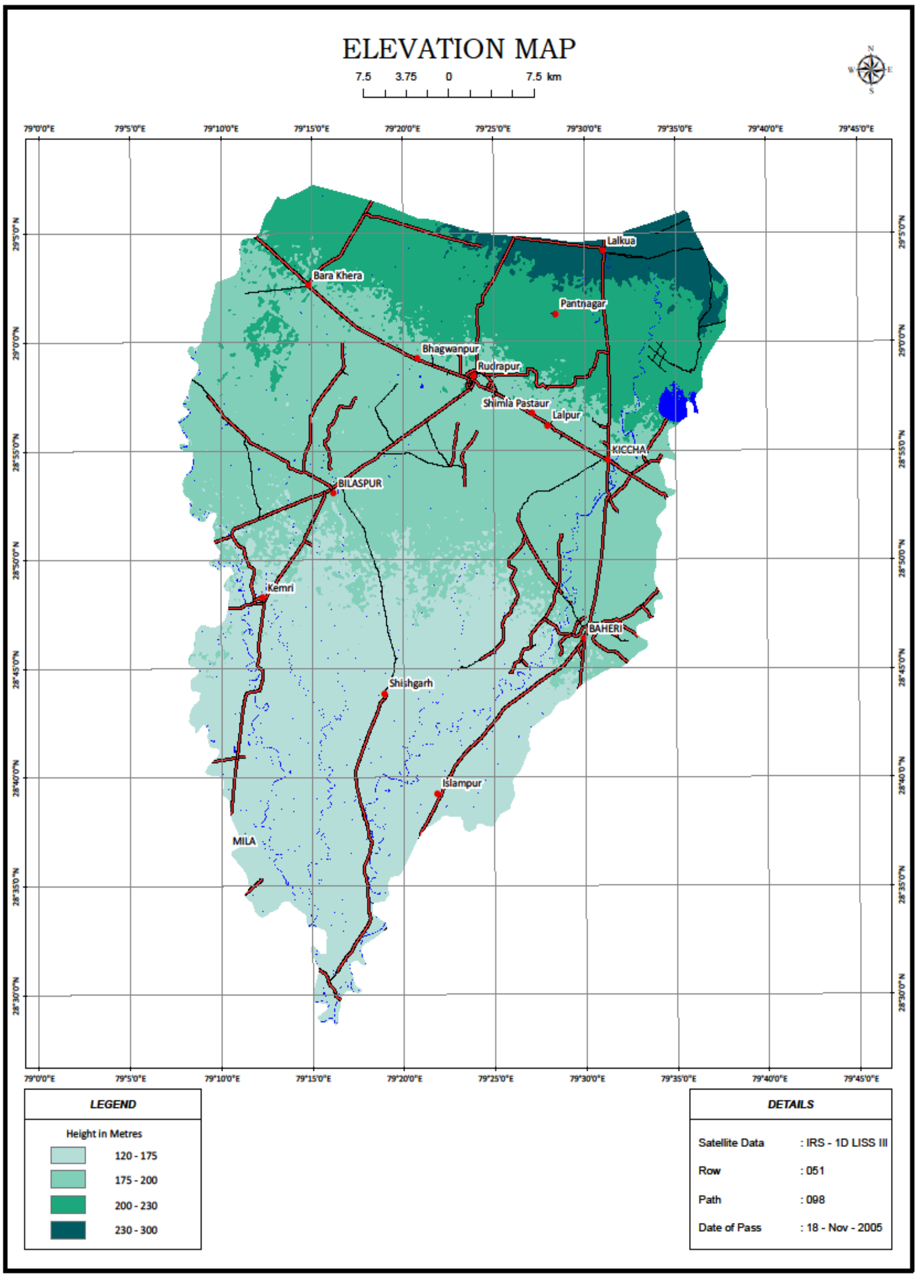

Fig. 3. Elevation Map

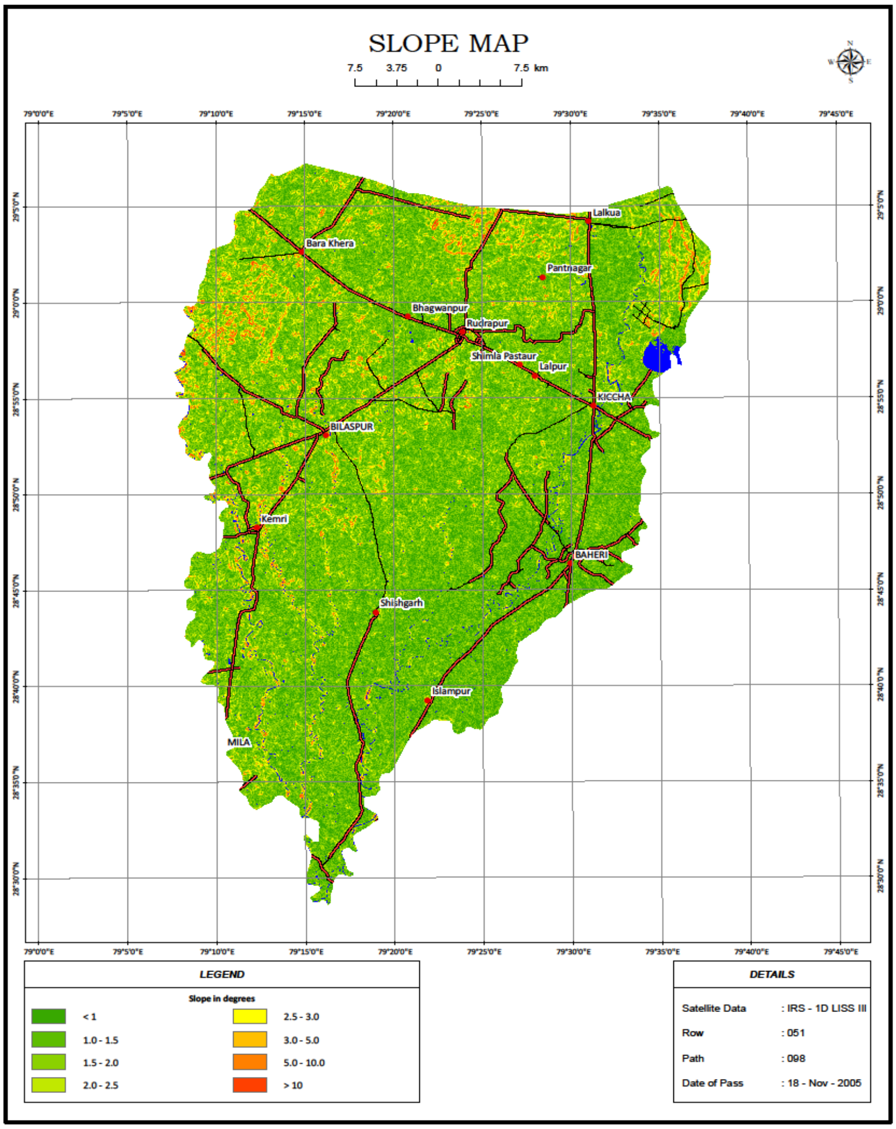

Fig. 4. Slope Map

Different land uses/land covers were digitized with GIS environment by visual interpretation using digital satellite data of IRS 1D, LISS III for November 18, 2005. The satellite imagery was masked with the area of interest (artificial groundwater recharge) using clipping /sub setting tools of the software .The satellite data of 2005 were classified into nine classes. During field visit, the image elements were correlated with the ground truthing and the interpretation key was developed. Satellite data were classified into forest, agricultural land, current fallow, forest plantation, forest blank, scrub land, built up, dry river channel and river. Forest was observed mainly in northern aspects (north, north-east, north-west) and at higher altitude whereas major agricultural activities were taken up mainly in southern aspects (south, south-east, south-west). It is evident from Table 1 that out of total area under study, almost 22.81 per cent was observed under agriculture followed by agri/current fallow (54.22 %), forest (6.12 %), forest plantation (4.93 %), scrub land (7.79%), built up (1.09%), dry river channel (0.61%) and rivers (1.42%).

The effective methods of the recharging underground reservoirs are construction of recharge structures, reducing pressure on groundwater draft and increasing surface water sources up to some extent. On the basis of the fore-going discussion and considering guide lines, the following measures may be adopted for recharging the groundwater aquifer for different soil associations of Jamrani Dam Command.

Table 1. Areal extent under different land uses on the basis of satellite imagery

Sl. No.	Land use/Land cover	Area (sq. km)	% of total area
1	Agriculture	496.48	22.81
2	Agri/current fallow	1179.95	54.22
3	Forest	133.17	6.12
4	Forest plantation	107.27	4.93
5	Forest blank	22.03	1.01
6	Scrub	169.53	7.79
7	Built up	23.85	1.09
8	Dry River Channel	13.18	0.61
9	River	30.95	1.42
	Total	2176.40	100

In this system the artificial recharge is made to restrict the surface runoff through streams and by making additional water available for percolation. The surface water impounded during monsoon behind the structure spreads over the entire stream bed thereby increasing the wetted area. The impounded water helps in replenishment of groundwater. Jamrani Dam Command consists of an extensive network of natural streams. These streams are Baur, Behgul, Dhakra, Bhakra, Gola, Nahal, Dhimri, Dhora etc., flowing from north to south. A detailed study of the area has shown that all of these streams in Tarai belt are of effluent type, which drains sub-soil water. The water level in these streams, in Tarai belt, remains below the ground water level during most of the year. Thus in the Tarai belt; these natural streams discharge the function of both surface and sub-surface natural drainage system. A series of check dams could be constructed on a stream to recharge the depleted groundwater aquifers [16,17].

Percolation tanks are generally constructed on the small streams or rivulets of the 2nd to 3rd order with adequate catchment for impounding surface runoff. These tanks are used entirely for recharging the aquifer through percolation. Construction of percolation tanks take into account the catchment area, likely runoff, designed storage as well as the area to be benefited due to the structure. The basic requirement for percolation tank site is a permeable strata to facilitate easy infiltration and percolation.

From the soil textures of different soil series in Jamrani Dam Command at different profiles (0-15 cm and 15-30 cm) Haldi, Patharchatta, Dhamora, Pandri, Aksora and Bhitauli soil series were sand dominated as they contain more than 50 percent sand content in its top layer and these soils were well drained to moderately well drained ones. So, for these soil associations in Jamrani Dam Command, percolation tanks may be the most suitable recharging technique by utilizing excess monsoon season water available in the form of runoff obtained from the land surface.

As the soils were almost sandy in the problematic areas, the presence of bunds near cropped area would not create the waterlogged conditions. The percolation ponds may serve as a safety measure for absorbing the flood and mitigating its havoc, and as a venue for fish culture. The land with the construction of a percolation tank gets its value enhanced 2 to 6 times as compared to its initial value. Construction of a large number of smaller percolation tanks at different places in the problematic area would be more useful and need satisfying than a single tank at a selective place. Since the percolation tank is useful for a large number of farmers living wide over, the construction of such tanks is socially tenable and grammatically beneficial besides their economic feasibility.

Bunds may also be constructed in farmers' fields. These serve dual purpose of rainfed farming and water harvesting during the scarcity period and recharging of the groundwater aquifer. The construction of trenches in the riverside area across the slope would enhance the recharge of the area.

So, for these soil associations in Jamrani Dam Command, where Bilaspur, Kamora, Delpur, Dhamipur, Swar and Beni soil series were prominent (silty clay loam to silty loam, soil with lower sand and high clay content), stagnated water applied for growing paddy (with raised bunds) can be hold by them efficiently to help in recharging the groundwater aquifers.

Dug well recharge method can be powerful tool for the above soil series where the silt and clay contents in the upper surface are high. Under subsurface practice, the exiting dug wells may be utilized as recharge structures when filter materials or pebbles would properly back fill these wells. Most of the water of monsoon seasonal runoff flow wasteful since there was no any recharge plan at either side of the channels. The recharge capability of the riparian area can be increased by modification of these channels like putting permanent low check dams or constructing ditches / furrows across the slope.

4. CONCLUSIONS

In the world scenario, the India, with 17% of world population, has only 2.4% of land and 4% of fresh water resources. Being developing country, there is increasing demand of the water for domestic and industrial uses. Since the surface water resources are limited, the major source of water supplies for agricultural and other purposes has been taken from groundwater systems. In order to meet the ever-increasing demand of water has resulted in over-exploitation of groundwater resource, causing continuous decline in water table in various parts of the country. As a result, the situation turned grim and it calls for a constant vigil in monitoring of aquifer behavior in all the sensitive areas and adoption of ways for controlling withdrawals to keep them within the limits of recharge capacities. Agricultural productivity depends on efficient use of these resources through their conservation and management. Due to lack of proper planning and skills, there are many areas which suffer for need of utilizable land and water resources. Artificial groundwater recharge plan is very important to maintain the groundwater at a safe and desired level in future in the Jamrani Dam Command for their proper management and planning using GIS and remote sensing.

On the basis of above study the following conclusions were drawn:

- A total of 20 distinct soil series were identified, in the Jamrani Dam Command area. Soils of Jamrani Dam Command varied from neutral to slightly acidic and is rich in organic matter. The texture varied from silty clay loam to sandy loam.
- Groundwater draft was estimated in the study area and it varied from 4281.93 - 14118.6 ha-m for the year 2010 and was of increasing order during 1988-2010. It was due to increase in number of tube wells and other groundwater pumping structures every year because of the rise in demand of water for increasing human and livestock populations, increase in growth of industries and their demand of water.
- Groundwater inventory for assessment of groundwater development potential in the year 2010 indicated that out of eight blocks, lying under the study area, 2 blocks were under over exploited category and 2 were under critical category. In Bilaspur, Baheri, Gadarpur and rudrapur blocks the trend of stage of groundwater development was increasing from 1988-2010 and further exploitation may be done with caution. Overall category for stage of groundwater development was critical during the year 2010. The water table was continuously going down which showed that over-exploitation of groundwater was taking place in major part of the Jamrani Dam Command, so there is need for artificial groundwater recharge. The study suggested that for critical and exploited category, provision of groundwater recharge and water harvesting structures should be beneficial to reduce the load on groundwater reservoir.
- Out of total area under study, almost 22.81 per cent was observed under agriculture followed by agriculture/current fallow (54.22 %), forest (6.12 %), forest plantation (4.93 %), scrub land (7.79%), built up(1.09%), dry river channel(0.61%) and rivers(1.42%) on the basis of satellite imagery for the year 2005 under different land uses.
- The existing cropping pattern in the command area showed that wheat, paddy and sugarcane were the major crops grown in the area which may be treated as high water-demanding crops. There is an urgent need to change the prevailing cropping pattern by occupying more area under low water demanding crops, reducing pressure on groundwater up to a certain extent. This may be achieved by introducing more area under pulses and oilseed crops such as *Arhar*, *mung*, *urd*, gram, pea, lentil, mustard etc. The farmers in the problematic areas should also be discouraged from growing, crops like Mentha and other vegetables, which are very high water-demanding crops.
- Localized rainwater harvesting systems in the form of check dams in Jamrani Dam

Command were an effective solution to the water crisis due to their ability to channelize rainfall runoff into the underground aquifer. This offers a decentralized system for decreasing the impact of drought and allows the people's involvement in critical water management tasks with simple, local skill-based, cost-effective, and environment-friendly technologies.

- The areas under Swar and Milak blocks of Rampur district and Shergarh and Meerganj blocks of Bareilly district of the study area were identified as the main problem areas where the condition of groundwater mining was prevailing and need immediate attention and suitable remedial measures to manage the problem well within time. The canal network may be extended to the problematic areas to supply water for irrigation and also to serve as a potential source for recharging underground aquifers.
- There is a good network of rivers in Jamrani Dam Command. Most of the water from monsoon runoff flows wastefully since there is no any recharge plan for either side of the channels. The recharge capability of the riparian area can be increased by modification of these channels like putting permanent low check dams or constructing ditches/ furrows across the slope.
- Apart from these, the farmers may be educated and made aware of the problem of depleting groundwater resources and the necessity of economic use of water resources and recharging the groundwater to maintain it at a desired and safe level.

CONFERENCE DISCLAIMER

Some part of this manuscript was previously presented in the conference: 3rd International Conference IAAHAS-2023 "Innovative Approaches in Agriculture, Horticulture & Allied Sciences" on March 29-31, 2023 in SGT University , Gurugram, India. Web Link of the proceeding: https://wikifarmer.com/event/iaahas-2023-innovative-approaches-in-agriculture-horticulture-allied-sciences/.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Katyal JC. Relevance of integrated concept. The Hindu survey of Indian Agriculture. 1998. 1997;25-31.
2. United Nations Organisations. Comprehensive assessment of the fresh water resources of the world. Report of the Secretary General, commission on Sustainable Development, fifth session, 7-25 April, 1997, New York; 1997.
3. Cosgrave JW. Challenge of managing world's water resources. Asian Transport and Infrastructure. 2000;7(3):1-24.
4. Malmir M, Javadi S, Moridi A, Randhir T, Saatsaz M. Integrated groundwater management using a comprehensive conceptual framework. Journal of Hydrology. 2022;605:127363.
5. Adimalla N, Wu J. Groundwater quality and associated health risks in a semi-arid region of south India: Implication to sustainable groundwater management. Human and Ecological Risk Assessment: An International Journal. 2019;25(1-2):191-216.
6. Pandey DS. Hydrology and ground water potential, Bhadohi district, Uttar Pradesh. Proceedings of the seminar on the "Challenges in Ground Water Development" held at Tirupati, Andhra Pradesh. 2000;1-11
7. Sharma AK, Kumar S, Singh HN. Soil survey, mapping and land evaluation for agricultural use and planning in the area under the responsibility of the University. Experiment Station, G.B. Pant University of Agri. & Tech., Pantnagar; 1995.
8. Stephenson GR, Zuzel JF. Ground water recharge characteristics in a semi arid environment of south west Idaho. Journal of Hydrology. 1981;53(2):213-217.
9. Seth SM. Physically based hydrological modelling. GIS@development; 1999.
10. Navalawala BN. Water resources development in India: Shift in policy paradigm. Water & Energy Intentional; 2002.
11. APHA. Standard methods for examination of water and wastewater. 15^{th} Ed. American Public Health Association, Washington, D.C; 1989.
12. Richards LA. Diagonices and improvement of saline and alkali soils. U. S. Dept. Agriculture, Handbook. 1954;60: 160.

13. Wilcox LV. Classification and use of irrigation waters. USDA Crc. 969, Washington, D.C. 1955;19.
14. Wescot DW, Ayers RC. Water quality in irrigation with reclame municipal waste water; A guidance manual edited by G. S. Pettygrobe and T. Asano, State Water Resources Control Board Sacramento, Calif; 1984
15. Belkhiri L, Boudoukha L, Mouni L. Groundwater quality and its suitabilityfor drinking and agricultural use in Ain Azel Plain, Algeria. Journal of Geography and Regional Planning. 2010;3(6):151-157.
16. Ciuff CB. Water harvesting in arid lands. Desalination. 1989;72(1-2):149-159.
17. Song J, Han M, Kim T, Song J. Rainwater harvesting as a sustainable water supply option in Banda Aceh. Desalination. 2009;248(1-3):233-240.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/100378