JRLA, 2(1), December 2025: 1273-1285 **Online ISSN: 3048-667X**

JOURNAL OF THE ROYAL LAUREATES ACADEMY

www.rlaindia.org

EVALUATING THE RESPONSIBLE FACTORS INFLUENCING GROUNDWATER VULNERABILITY IN HARYANA

Ms. Nisha

Research scholar, Department of Geography NIILM University, Kaithal

Dr. Sandeep Rana

Professor, Department of Geography NIILM University, Kaithal

ABSTRACT

Finding and evaluating the key contributors to groundwater vulnerability and studying their spatial variation across various locations of Haryana is the primary goal of the present study. Statistical analysis, GIS, and remote sensing methods were all part of the studies descriptive and analytical research strategy. Information on groundwater depth, drainage density, slope, land use/land cover, soil properties, geology, and rainfall was among the primary and secondary data used. To assess groundwater vulnerability, we used GIS for spatial analysis and descriptive statistics, correlation, weighted overlay, and Multi-Criteria Decision Analysis (MCDA). Intensive agricultural operations, rainfall variability, land use changes, fast urbanisation, and groundwater extraction are the factors that most affect groundwater vulnerability, according to the data. The Eastern part of Haryana had reduced groundwater recharge and excessive extraction for irrigation reasons, making it less vulnerable to groundwater shortages than the Southern and Western regions. Finding susceptible zones and providing support for sustainable groundwater management are both made easier using GIS-based spatial analysis, as this study shows. It suggests increasing groundwater monitoring systems, limiting groundwater abstraction, boosting crop diversification, managing artificial groundwater recharge, and micro-irrigation technologies to improve irrigation efficiency. Researchers, water resource managers, environmental planners, and legislators in Haryana can

use the results to inform their work in developing long-term plans for the protection and sustainable use of the state's groundwater supplies.

Keywords: Groundwater Vulnerability, Geographic Information System (GIS), Remote Sensing, Groundwater Management, Haryana

I. INTRODUCTION

Because it is used for agriculture, industrial supplies, and drinking water, groundwater is considered one of India's most precious natural resources. The heavy reliance of agriculture on tube wells and bore wells in Haryana makes groundwater an especially important factor in the state. Groundwater extraction has increased significantly in the state to sustain high-yielding crop types, as a result of the fast intensification of agriculture during the Green Revolution. Agricultural productivity and food security have been greatly improved by this development, but groundwater reserves have also been enormously stressed. Reduced groundwater levels and worsening groundwater quality have been seen in numerous areas of Haryana as a consequence of ongoing over-extraction, insufficient natural recharge, and shifting climate patterns. Therefore, in order to manage water resources sustainably, it is crucial to assess the causes of groundwater vulnerability.

The vulnerability of groundwater systems is the degree to which they can be impacted by both natural and human-caused processes that lead to contamination or depletion. A number of factors, including geological formations, hydrological features, climate, land use practices, and human activities, interact to affect the quality and availability of groundwater, which is the underlying idea. The vulnerability assessment enables policymakers and resource managers to prioritise conservation measures by identifying areas where groundwater is more likely to be affected by pollutants or excessive extraction. To ensure long-term water security and environmental sustainability in Haryana, vulnerability assessment is critical because groundwater supports nearly every sector of economic development.

Groundwater vulnerability varies greatly across Haryana due to the state's varied topography and hydrogeology. The physiographic features of Haryana, which is situated in the northwest Indo-Gangetic Plain, are varied, spanning from the arid and semi-arid plains in the southwest to the Shivalik foothills in the northeast. Varieties of recharge capacity, porosity, and permeability characterise the state's alluvial aquifers. Groundwater recharges more quickly in areas with coarse sand deposits, but pollutants may be able to infiltrate more easily in these same areas. On the other hand, areas where clay-rich sediments are abundant shield surfaces from contamination and limit recharge. Due to regional variations in geology, groundwater vulnerability can vary in different areas.

The climate also plays a significant role in determining how vulnerable Haryana's groundwater is. The state's climate ranges from semi-arid to sub-humid, with hot summers and cold winters and unpredictable monsoon rains. Precipitation is not uniformly distributed throughout the year; the southwest receives much less precipitation than the northeastern districts. Aquifer and groundwater recharge rates are both impacted by this inequitable distribution. Groundwater depletion has been accelerated in some districts due to prolonged dry periods, frequent droughts, and rising temperatures linked to climate change. The efficiency of natural recharge processes is further diminished by unpredictable rainfall patterns, leaving groundwater resources more susceptible to declines in quantity and quality.

Among the many human-caused variables impacting the susceptibility of Haryana's groundwater, agricultural practices rank high. Groundwater abstraction has become an issue, especially in the eastern and central districts, due to the extensive cultivation of water-intensive crops like wheat and paddy. The rapid depletion of aquifers has been hastened by the combination of subsidised electricity for groundwater pumping and intensive irrigation practices. Nitrate, phosphate, and pesticide contamination of groundwater is another concern due to the widespread use of chemical fertilisers, herbicides, and pesticides. Leaching of these agrochemicals via the soil profile negatively affects groundwater quality, posing considerable threats to human health and ecosystem integrity. Therefore, agricultural management methods are crucial to understanding groundwater risk in the region.

Urbanization and industrialization have also emerged as key drivers to groundwater vulnerability in Haryana. Rapid expansion of urban centers such as Gurugram, Faridabad, Panipat, and Sonipat has increased groundwater demand for domestic and commercial purposes while simultaneously generating large quantities of wastewater. Inadequate sewage treatment facilities, leakage from sewer networks, improper disposal of solid waste, and discharge of untreated industrial effluents have introduced a variety of contaminants into groundwater systems. Heavy metals, hydrocarbons, and other hazardous chemicals originating from industrial activities have been detected in several parts of the state, highlighting the need for comprehensive groundwater quality monitoring and pollution control measures.

II. REVIEW OF LITERATURE

Nagal, Balbir et al., (2024). This study aims to delineate groundwater potential (GWP) zones of the Haryana state, India, using geospatial techniques for the year 2023. In this, multiple thematic layers created and integrated through geographic information system (GIS) and the analytical hierarchy process (AHP). The data utilized in this research were collected from multiple sources, including the shuttle radar topography mission (SRTM), Sentinel-2 satellite imagery, the food and agriculture organisation (FAO), and the India meteorological department (IMD). Thematic layers including slope, land use/land cover (LULC), soil, geology, drainage density, and lineament density, were created and weighted through the AHP. The layers were subsequently integrated through the weighted overlay analysis (WOA) method to create a GWP map for the area. This GWP map of the year 2023 was compared utilizing groundwater level (GWL) data of the year 2018 from the Central Ground Water Board (CGWB), resulting in a similarity rate of 77.55%. The results indicate that the moderate GWP zone covers 3.71% of the study area, followed by the high GWP zone, which covers 33.24% of the study area. Very high GWP covers only 11.96% of the region. The low and very low GWP zones encompass 7.59% and 3.51%, respectively. The results show that most of the territory has moderate to high GWP, with minor areas having low or extremely low potential. This shows the efficacy of GIS-AHP methods in identifying GWP zones and serves as a crucial instrument for the management of water resources in arid regions such as Haryana.

Raheja, Hemant et al., (2022). Irrigation in the Indian state of Haryana relies heavily on groundwater. Human health and community development are greatly impacted by the quality of groundwater. The purpose of this study was to examine the irrigation water quality in a rural area of the Indian state of Haryana using 449 sets of groundwater samples. To further assess the viability of groundwater for irrigation purposes, the following parameters were chosen: electrical conductivity (EC), sodium adsorption ratio (SAR), percentage sodium (%Na), magnesium adsorption ratio (MAR), permeability index (PI), and residual sodium carbonate (RSC). From what we can tell, about 23.38% of the groundwater samples were over the allowed limit for EC, 51.46% for SAR, 51.91% for %Na, 52% for MAR, 44.32% for PI, and 44.32% for RSC. According to these metrics, the groundwater samples that were collected were of low quality. Additionally, the spatial distribution of irrigation parameters was drawn and groundwater sampling locations were mapped using the ArcGIS tool. The majority of the groundwater samples taken in the state's central region were found to be above the allowed irrigation limits, according to the results. The study concludes that the study site's groundwater should be properly managed before being used for irrigation.

Shyam, Radhe et al., (2022). Present study deals with water quality (WQ) assessment season-wise ionic concentration in the Mewat district of Haryana, India. A total of thirty-six groundwater samples were collected, twelve each for the pre-monsoon, monsoon and post- monsoon seasons of 2016, to know the status of WQ for drinking and irrigation purposes. Piper, Durov and Gibbs plots were used to find out the water type and the factors controlling the chemistry of groundwater, respectively. Piper diagram reveals that Ca-Cl and mixed Ca-Mg-C1 typed water during the pre-monsoon, monsoon and post monsoon season’s where- Na-Cl water type indicates salinity problem. Gibbs plot depicted that the weathering of rocks is the major reason behind the ionic chemistry of the groundwater. Water Quality Index (WQI) has been calculated to know the overall WQ based on physico-chemical parameters estimated for this study. It was found that Na+ concentration was dominant among cations and Cl- among anions. Moreover irrigation indices (KR, RSC, P.I, Cl-/HCO3-, SAR and Na%) represent that majority of the groundwater samples during pre-monsoon (PRM) season were suitable for agricultural purposes but in monsoon (MON) and post monsoon (POM) season majority of samples lie in unsuitable zone. The groundwater in the study region presents a high risk of salinization. Using the baseline data generated through this work, there is an immediate need for carrying out a detailed study to address the groundwater issues, understand salinity mechanisms, expansion of salinization in the fresh water aquifers and to suggest suitable management and remedial measures. Extension of this work is being carried out in the form of purpose driven study under National Hydrology Project aided by World Bank.

Ravish, Sandeep et al., (2018). The rating of the condition of subsurface water in urban and rural regions of Haryana (India) is reviewed in this paper. This is completed to contrary the backdrop of its present rating, propensity, and recognizance of tenors disposing of the rating of urban subsurface water and doable alterative measures in North-Eastern Haryana. Haryana is a state with a large requirement of water for agriculture, industry and domestic purposes. Geographically Haryana does not have the privilege of the river (except the Yamuna in the eastern part) running through it and thus has to rely heavily on groundwater. Analyzes have proved that North-Eastern Haryana subsurface water rating is disposed of by the geology and geochemistry of the atmosphere, the flow of urbanization, industrialization, landfill/dumpsite leachates, heavy metals, microbiological contamination, and impact of weathers. Alterative measures informed comprise conservation of aqua sprig, suitable treatment of wastes and building of sanitary landfills, monitoring of all ground use sullying activities, and remedy of aqua before is applied for regular use. Sustained analyzing of subsurface water rating is mandatory to preoccupy any abominable outcomes. The goal of this paper is to summarize the status of groundwater quantity and quality, challenges and research needs in North-Eastern Haryana, India based on available literature.

Datta, P.. (2018). The study area Faridabad District is situated in the south-eastern part of state Haryana in the National Capital Region Delhi, India. From past few decades, change in land use pattern has affected water resources in the area both in terms of quantity and quality. To avoid further degradation of groundwater, the present study aims to identify the sources and the processes contributing to groundwater salinity and pollution, based on hydrogeochemistry in integration with GIS. The groundwater vulnerability has been assessed by rock–water interaction, geochemical processes, river/canal seepage, pollution and inter- mixing, variation in land use activities. The study suggests that the region-specific factors such as unplanned land use pattern and waste disposal, drainage as well as intermixing of groundwater play significant role in groundwater pollution besides geochemical processes. Salinity in shallow aquifers is usually as a consequence of leaching of evaporates in waterlogged areas along canals during rain or irrigation; mineral weathering; evaporation induced concentration of dissolved salts; saline groundwater movement from deeper to shallower aquifers due to continued indiscriminate groundwater over-abstraction; and expanding lateral extent of pollution in the overexploited aquifers.

III. RESEARCH METHODOLOGY

This study examined the variables impacting Haryana's groundwater vulnerability using a mixed-methods approach, using both descriptive and analytical techniques. The primary goals of the research were to(1) determine the geographical distribution of groundwater vulnerability and(2) identify the natural and anthropogenic variables that contribute to this vulnerability.

Selected districts reflecting the main agro-climatic zones of Haryana were the sites of the study. Data was gathered from two sources: primary and secondary. We used secondary data from government agencies, published publications, and satellite-based datasets to learn about the following: rainfall, geology, soil type, land use/land cover, groundwater depth, drainage density, slope, and aquifer features. We relied on primary sources such as field observations and groundwater sampling where needed.

Thematic layers impacting groundwater risk were integrated using a GIS and Remote Sensing-based technique. Using geographic information system (GIS) software, thematic maps were generated from spatial datasets; land use patterns and environmental changes impacting groundwater supplies were examined with the use of remote sensing data.

The study took into account important aspects that can affect the susceptibility of groundwater, such as precipitation, soil type, slope, land use/cover, depth of groundwater, drainage density, and aquifer features. The impact of these parameters on groundwater vulnerability was determined through both individual and combined analyses.

For the purpose of creating groundwater vulnerability maps, the data was processed in a GIS context utilising descriptive statistics, weighted overlay analysis, and Multi-Criteria Decision Analysis (MCDA). To further investigate the connection between the chosen variables and groundwater susceptibility, a correlation analysis was also run. To make sure the results are reliable, they were double-checked with existing hydrogeological data and groundwater observations.

IV. RESULTS AND DISCUSSION

Table 1. Relative Importance of Factors Influencing Groundwater Vulnerability in Haryana (2024)

Factors	Mean Score	Standard Deviation	Rank
Groundwater Extraction	4.71	0.42	I
Agricultural Activities	4.55	0.51	II
Rainfall Variability	4.39	0.58	III
Land Use/Land Cover Change	4.22	0.61	IV
Urbanization	4.15	0.65	V

Geology and Soil Characteristics	4.01	0.69	VI
Drainage Density	3.84	0.72	VII
Slope	3.62	0.76	VIII

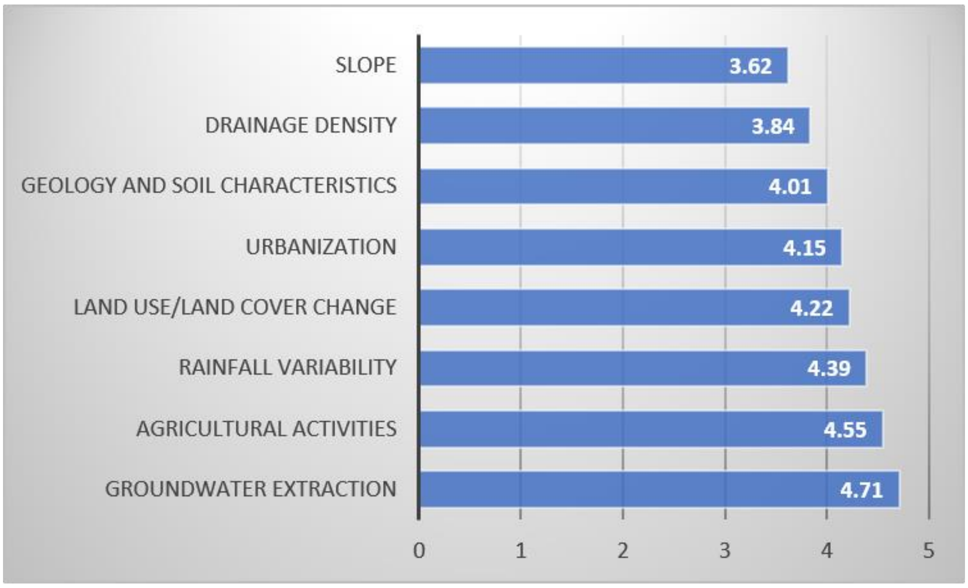

Figure 1. Relative Importance of Factors Influencing Groundwater Vulnerability in Haryana (2024)

According to the mean scores and standard deviations for the year 2024, Table 1 shows the relative relevance of factors impacting groundwater vulnerability in Haryana. There was a strong agreement among respondents that excessive withdrawal of groundwater is the main cause of declining groundwater conditions, as indicated by the highest mean score of 4.71 ± 0.42 and first rank, which indicates that groundwater extraction is the most significant factor contributing to groundwater vulnerability. The significant influence of intensive irrigation methods and the overuse of fertilisers and pesticides on groundwater depletion and contamination was reflected in agricultural operations, which ranked second with an average score of 4.55 ± 0.51. The third most important factor, rainfall variability (mean = 4.39 ± 0.58), emphasises the impact of unpredictable monsoon patterns and diminished groundwater recharging. The fourth and fifth places, respectively, were held by land use/land cover change (mean = 4.22 ± 0.61) and urbanisation (mean = 4.15 ± 0.65), indicating that groundwater resources are under more strain due to lower infiltration and changing land-use patterns caused by rapid infrastructure development. With an average score of 4.01 ± 0.69, geology and soil features were rated sixth, suggesting that they moderately impact the storage and circulation of groundwater. The lowest ranks were given to drainage density (mean = 3.84 ± 0.72) and slope (mean = 3.62 ± 0.76), suggesting that anthropogenic influences are seen as having a greater influence on groundwater recharge and runoff than these physical elements. Natural environmental factors in Haryana play a relatively secondary role, according to the results. Human-induced activities, such as intensive agriculture and excessive groundwater extraction, are the main causes of groundwater vulnerability.

Table 2. Groundwater Vulnerability Status Across Agro-Climatic Regions of Haryana (2024)

Region	Low (%)	Moderate (%)	High (%)	Very High (%)
Eastern Haryana	18.4	42.7	29.6	9.3
Western Haryana	8.5	24.8	46.9	19.8
Southern Haryana	5.7	19.3	49.4	25.6

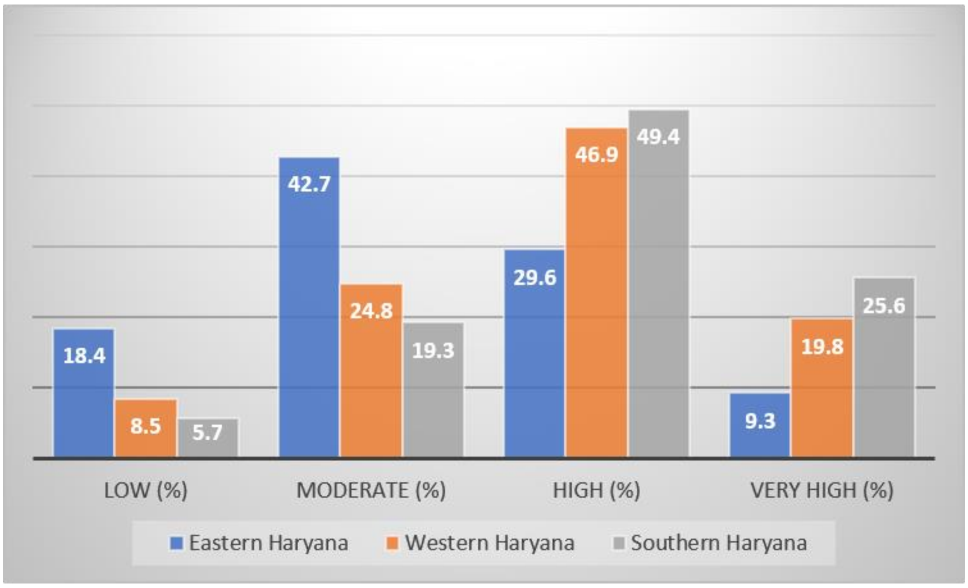

Figure 2. Groundwater Vulnerability Status Across Agro-Climatic Regions of Haryana (2024)

In 2024, Table 2 shows the groundwater vulnerability status in all of Haryana's main agro-climatic areas, classified as low, moderate, high, or extremely high. The results show that groundwater vulnerability varies significantly among regions. The groundwater situation is improved in Eastern Haryana; 42.7% of the land is moderately vulnerable, 18.4% is lowly vulnerable, 29.6% is very highly vulnerable, and 9.3% is extremely highly vulnerable. Contrarily, groundwater stress is far more severe in Western Haryana, with 46.9% of the region being highly vulnerable, 19.8% being very vulnerable, and only 8.5% being in the low vulnerability group. Southern Haryana is particularly at risk; around half of the region is highly vulnerable (49.4%), and another 25.6% is very vulnerable; in contrast, only 5.7% and 19.3% of the region have low and moderate vulnerability, respectively. From Eastern to Western and Southern Haryana, the results show that groundwater vulnerability increases with time. This means that areas with less rainfall, more groundwater extraction, and more water scarcity are more likely to have groundwater depletion and quality deterioration. These results highlight the critical importance of groundwater management plans tailored to individual regions, especially in the southern and western parts of Haryana, where sustainable water use, artificial recharge, and conservation should take precedence.

Table 3. Correlation between Responsible Factors and Groundwater Vulnerability

Variable	Correlation Coefficient (r)	Significance (p-value)
Groundwater Extraction	0.89	<0.001
Agricultural Activities	0.83	<0.001
Rainfall Variability	-0.76	<0.001
Urbanization	0.74	<0.001
Land Use Change	0.71	<0.001
Geology	0.65	<0.01

Table 3 shows the relationship between the main causes and the vulnerability of Haryana's groundwater. With their low p-values, the results show that all the variables we looked at had a significant link with groundwater vulnerability. Excessive withdrawal of groundwater is the most influential factor leading to increased susceptibility, as indicated by the highest positive association ($r = 0.89$, $p < 0.001$) with groundwater extraction. There is a highly significant positive association between agricultural activities and groundwater stress and pollution hazards ($r = 0.83$, $p < 0.001$), suggesting that intensive irrigation methods and the heavy use of fertilisers and pesticides greatly amplify these issues. The negative consequences of fast urbanisation and changes in land cover on groundwater recharge and quality are revealed by the substantial positive correlations between urbanisation ($r = 0.74$, $p < 0.001$) and land use change ($r = 0.71$, $p < 0.001$). Geology shows a moderate positive association ($r = 0.65$, $p < 0.01$), suggesting that soil and geological features impact the vulnerability of groundwater through changing aquifer parameters and the transport of contaminants. Contrarily, there is a strong negative correlation between rainfall variability and groundwater vulnerability, suggesting that higher and more consistent rainfall enhances natural recharge and reduces vulnerability to groundwater depletion, while reduced or erratic rainfall increases the opposite. The results show that natural and anthropogenic factors both affect Haryana's groundwater vulnerability, but groundwater extraction is the main driver. This highlights the need of sustainable groundwater management, efficient irrigation, and good land-use planning to prevent groundwater stress in the future.

Table 4. Multiple Regression Analysis of Factors Influencing Groundwater Vulnerability

Variable	Beta Coefficient	t-value	p-value
Groundwater Extraction	0.421	9.84	<0.001
Agricultural Activities	0.307	7.23	<0.001
Rainfall Variability	-0.268	-5.91	<0.001
Urbanization	0.196	4.37	0.002

Land Use Change	0.182	3.95	0.004

Model Summary

R	**R^2**	**Adjusted R^2**	**F-value**	**p-value**
0.918	0.842	0.837	187.36	<0.001

Table 4 displays the outcomes of the multiple regression analysis that was carried out to ascertain the impact of different factors on the vulnerability of Haryana's groundwater. The results show that the regression model accounts for a large amount of the variance in groundwater vulnerability and is statistically significant. A high coefficient of determination ($R^2 = 0.842$) and a strong correlation coefficient ($R = 0.918$) are shown in the model summary, suggesting that the chosen independent variables account for 84.2% of the variation in groundwater vulnerability. After accounting for the number of predictors, the model's robustness and reliability are further confirmed by the Adjusted R^2 value of 0.837. The combined influence of the explanatory factors is extremely important in predicting groundwater vulnerability, as shown by the statistically significant overall model with an F-value of 187.36 ($p < 0.001$). Groundwater extraction is the most significant factor affecting groundwater vulnerability, as it has the greatest standardised beta coefficient ($\beta = 0.421$, $t = 9.84$, $p < 0.001$) among the predictors. Intense farming methods and excessive irrigation heighten groundwater stress, which is further supported by the fact that agricultural activities have a notable positive impact ($\beta = 0.307$, $t = 7.23$, $p < 0.001$). Greater and more regular rainfall decreases groundwater vulnerability by improving aquifer recharge, as seen by the considerable negative effect of rainfall variability ($\beta = -0.268$, $t = -5.91$, $p < 0.001$). Moreover, expanding urban areas and changing land-use patterns lead to groundwater depletion and reduced recharge potential, as also shown by land use change ($\beta = 0.182$, $t = 3.95$, $p = 0.004$) and urbanisation ($\beta = 0.196$, $t = 4.37$, $p = 0.002$). When looking at the groundwater vulnerability in Haryana, the regression analysis shows that agricultural activities and excessive groundwater extraction are the main causes, with rainfall variability acting as a mitigating factor. To protect the state's groundwater supplies, these results highlight the importance of regulations that allow for the sustainable abstraction of groundwater, efficient irrigation methods, scientific land-use planning, and water management systems that are robust to climate change.

Table 5. Overall Groundwater Vulnerability Classification (2024)

Vulnerability Class	**Area (%)**
Very Low	8.2
Low	17.5
Moderate	28.4
High	31.7
Very High	14.2

All groundwater vulnerability classifications in Haryana for 2024 are shown in Table 5. According to the findings, the highest susceptibility class encompasses a significant percentage of the state's landmass, constituting 31.7% of the total. Almost a third of the state is in a moderately vulnerable category, which means it is at high danger of becoming extremely vulnerable in the absence of adequate management measures. This group encompasses 28.4 percent of the total area. In addition, 14.2% of the landmass is considered extremely vulnerable, meaning that areas are facing serious groundwater stress as a result of things like over-drilling, intensive farming, decreasing recharge, and fast urbanisation. In comparison, areas with relatively stable groundwater conditions and better recharging potential make up just 8.2% of the area, while only 17.5% of the territory falls into the low vulnerability category. In total, 45.9% of Haryana's landmass is vulnerable to groundwater levels of very high or very high severity, whereas just 25.7% of the state's landmass is relatively safe from such conditions. Groundwater resources are under increasing stress across the state, and this distribution shows how critical it is to implement sustainable groundwater management practices like controlled abstraction, artificial recharge, efficient irrigation, watershed development, and scientifically planned land-use policies to prevent further groundwater loss and guarantee water security in the future.

V. CONCLUSION

Excessive groundwater extraction, intensive agricultural practices, rainfall unpredictability, land use changes, urbanisation, hydrogeological conditions, and natural and human-induced variables all contribute to groundwater vulnerability in Haryana, according to the study. Groundwater depletion and increased susceptibility are caused by a number of factors, the most important of which is groundwater exploitation. Based on the results of the spatial analysis, the eastern region of Haryana is less vulnerable than the southern and western regions. This is because the eastern region has better recharge conditions, is semi-arid, and relies heavily on groundwater for agricultural activities.

Groundwater vulnerability zones and the relative influence of several governing elements were effectively identified by the integration of GIS, Remote Sensing, and statistical analysis. The study highlights the importance of groundwater regulation, effective irrigation technology, crop diversification, scientific planning, artificial recharge structures, and constant monitoring of groundwater supplies for sustainable groundwater management. In order to guarantee water security in Haryana for the long term, it is vital to strengthen policy interventions and encourage community involvement in groundwater conservation. Researchers, politicians, and planners in the state can use this study's findings as a scientific foundation to create groundwater management policies that are resilient to climate change, sustainable for the environment, and beneficial to agricultural output, social progress, and economic growth.

REFERENCES

1. Adimalla, N., & Qian, H. (2021). Geospatial distribution and potential noncarcinogenic health risk assessment of nitrate-contaminated groundwater in southern India: A case study. Archives of Environmental Contamination and Toxicology, 80(1), 107–119. https://doi.org/10.1007/s00244-020-00762-7
2. Adimalla, N., & Taloor, A. K. (2020). Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using geographic information system (GIS) and groundwater quality index (GWQI) techniques. Groundwater for Sustainable Development, 10, 100288. https://doi.org/10.1016/j.gsd.2019.100288
3. Biswas, S., Mukhopadhyay, B. P., & Bera, A. (2020). Delineating groundwater potential zones of agriculture-dominated landscapes using GIS-based AHP techniques: A case study from Uttar Dinajpur district, West Bengal. Environmental Earth Sciences, 79(12), 1–25. https://doi.org/10.1007/s12665-020-09053-9
4. Chaudhary, V., & Satheeshkumar, S. (2018). Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. Applied Water Science, 8(8), 1–17. https://doi.org/10.1007/s13201-018-0865-9
5. Datta, P. (2018). Anthropogenic perturbations induced groundwater vulnerability to pollution in the industrial Faridabad district, Haryana, India. Environmental Earth Sciences, 77. https://doi.org/10.1007/s12665-018-7947-4
6. Doneen, L. D. (1964). Notes on water quality in agriculture (Water Science and Engineering Paper No. 4001). Department of Water Science and Engineering, University of California, Davis.
7. El Bilali, A., Taleb, A., & Brouziyne, Y. (2021). Groundwater quality forecasting using machine learning algorithms for irrigation purposes. Agricultural Water Management, 245, 106625. https://doi.org/10.1016/j.agwat.2020.106625
8. Gharbi, A., Ali, Z. I., & Zairi, M. (2019). Groundwater suitability for drinking and agriculture purposes using irrigation water quality index and multivariate analysis: Case of Sidi Bouzid aquifer, central Tunisia. Environmental Earth Sciences, 78(24), 1–19. https://doi.org/10.1007/s12665-019-8733-y
9. Gugulothu, S., Subbarao, N., Das, R., & Dhakate, R. (2022). Geochemical evaluation of groundwater and suitability of groundwater quality for irrigation purpose in an agricultural region of South India. Applied Water Science, 12(6), 1–13. https://doi.org/10.1007/s13201-022-01583-w
10. Harichandan, A., Patra, H. S., Dash, A. K., Sethy, K. M., Sahu, S. K., & Ghosh, M. (2021). Suitability of groundwater quality for its drinking and agricultural use near Koira region of Odisha, India. Sustainable Water Resources Management, 7(4), 1–18. https://doi.org/10.1007/s40899-021-00505-z
11. Kamaraj, J., Sekar, S., Roy, P. D., Senapathi, V., Chung, S. Y., Perumal, M., & Nath, A. V. (2021). Groundwater pollution index (GPI) and GIS-based appraisal of groundwater quality for drinking

and irrigation in coastal aquifers of Tiruchendur, South India. Environmental Science and Pollution Research, 28(23), 29056–29074. https://doi.org/10.1007/s11356-021-12702-6

12. Karunanidhi, D., Aravinthasamy, P., Subramani, T., & Muthusankar, G. (2021). Revealing drinking water quality issues and possible health risks based on the water quality index (WQI) method in the Shanmuganadhi River basin of South India. Environmental Geochemistry and Health, 43(2), 931–948. https://doi.org/10.1007/s10653-020-00613-3
13. Nagal, B., Prabhakar, A., & Pal, M. (2024). Assessment of groundwater potential over the Haryana region: GIS-AHP versus field data. https://doi.org/10.21203/rs.3.rs-5603723/v1
14. Raheja, H., Goel, A., & Pal, M. (2022). Evaluation of groundwater quality and its suitability for irrigational use in Haryana State, India.
15. Ravish, S., Setia, B., & Deswal, S. (2018). Groundwater quality in urban and rural areas of north-eastern Haryana (India): A review. ISH Journal of Hydraulic Engineering, 27, 1–11. https://doi.org/10.1080/09715010.2018.1531070
16. Shyam, R., Krishan, G., Kheraj, & Kumar, K. (2022). Evaluation of groundwater quality for life-supporting activities: A case study of Haryana, India. International Journal of River Basin Management, 22. https://doi.org/10.1080/15715124.2022.2135518