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ANALYZING STATEWISE ANNUAL GROUNDWATER EXTRACTION AND RECHARGE PATTERNS FOR SUSTAINABLE WATER RESOURCE MANAGEMENT

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Abstract:
Water scarcity is a topic of great concern in various regions worldwide. This arouses a need to understand resources of groundwater and their sustainability. This research paper presents a comprehensive analysis of statewise annual groundwater recharge as well as net groundwater availability across different geographical regions.

The findings reveal significant disparities in groundwater recharge and availability among states, underscoring the importance of region-specific water resource management strategies. Factors such as climate, land use, and aquifer characteristics are examined to elucidate the drivers behind these variations.

This research contributes to the broader discourse on water resource sustainability and offers valuable information for policymakers, water resource managers, and stakeholders tasked with ensuring water security at the state level. By quantifying statewise groundwater recharge and availability, this study empowers decision-makers to formulate targeted strategies for the prudent utilization and conservation of this finite resource, thereby promoting sustainable water management practices.

Ultimately, this research serves as a crucial step toward safeguarding our water resources for future generations and underscores the urgency of proactive and adaptive water management approaches in the face of evolving hydrological conditions.

Keywords: Water resource management, sustainable practices, Ground water recharge, water conservation, climate change impact

I. INTRODUCTION

Water, an essential and finite asset, is the lifeblood of ecosystems and societies. In an era marked by growing populations and climate shifts, securing water's availability and sustainability poses a critical global challenge. Groundwater, crucial for countless communities, agriculture, and industries, faces a significant threat to its ongoing availability.

Stored beneath the Earth's surface, groundwater represents a substantial portion of the world's freshwater supply. It plays a critical role in providing potable water, supporting agriculture, and maintaining ecosystems. However, over-extraction, changing precipitation patterns, and complex geological and hydrological factors raise concerns about its long-term sustainability.

This research paper aims to tackle this challenge by comprehensively analyzing statewise annual groundwater recharge and net availability. Delving into the dynamic factors influencing groundwater, our study provides indispensable insights for informed water resource management and sustainable planning at the state level.

Groundwater recharge is the process where precipitation and surface water infiltrate the ground, replenishing aquifers and maintaining groundwater levels, a vital aspect of the hydrological cycle, acting as a natural defense against droughts and ensuring a consistent freshwater source. Yet, the recharge rate isn't uniform, varying significantly across different geographical locations.

The net groundwater availability serves as a crucial metric, integrating recharge rates and extraction levels to identify regions where demand approaches or surpasses sustainable supply[4]. This metric is key for understanding the spatial and temporal distribution of groundwater resources, highlighting potential risks linked to over-exploitation.

The statewise approach in this research is essential as groundwater resources are inherently regional. State governments and local authorities play a pivotal role in managing and regulating groundwater use, making state-level assessments practical and policy relevant.

This paper reviews pertinent literature, outlines our methodology, presents statewise findings on groundwater recharge and availability, and discusses the implications for water resource management. Case studies are highlighted to underscore the practical relevance of our research. In the conclusion, key findings are summarized, policy recommendations provided, and future research avenues suggested.

II. Literature Review

Groundwater, as an essential component of the Earth's hydrological cycle, serves as a primary source of freshwater for various human and ecological needs. Groundwater recharge is the process by which water infiltrates the subsurface, replenishing underground aquifers. Its rate and variability are influenced by a multitude of factors, both natural and anthropogenic. Precipitation, the primary source of groundwater recharge, exhibits temporal and spatial variations, driven by climate patterns, topography, and meteorological phenomena. The interplay between rainfall, snowmelt, and other forms of precipitation directly impacts recharge rates.

The geological and hydrogeological characteristics of an area, such as soil types, permeability of subsurface materials, and aquifer properties, play a significant role in determining the rate of infiltration and groundwater storage capacity. Land use and land cover changes, including urbanization, deforestation, and agriculture, can alter surface runoff patterns and impact recharge processes[3][6][7].

Statewise Variations in Groundwater Recharge[1][2][8][9][10]-

Studies examining statewise variations in groundwater recharge have revealed substantial heterogeneity across regions. For instance, states with arid and semi-arid climates often experience limited recharge due to low precipitation and high evapotranspiration rates. Conversely, regions with higher rainfall and favorable geological conditions may exhibit comparatively higher recharge rates. In Gujarat, India, there has been huge regional differences in groundwater availability. The Saurashtra region faces severe water scarcity, while the northern parts of the state have more abundant groundwater resources. These disparities are attributed to variations in rainfall patterns and aquifer characteristics[32].

Net Groundwater Availability: Balancing Extraction and Recharge

The assessment of net groundwater availability is a critical aspect of sustainable water resource management. It involves accounting for groundwater extraction rates and their impact on aquifer levels. When extraction exceeds

recharge over an extended period, it can lead to declining groundwater levels and increased vulnerability to droughts and water scarcity.
Research on net groundwater availability has highlighted the importance of maintaining a balance between extraction and recharge. In some regions, over-exploitation of groundwater has resulted in land subsidence, water quality deterioration, and ecological consequences. Policies and regulations aimed at sustainable groundwater management, such as water use permits and aquifer recharge programs, have been implemented in response to these challenges.

Data Sources and Methodologies
Assessing groundwater recharge and net availability requires a multidisciplinary approach. Hydrological models, including numerical models and data-driven approaches, have been employed to estimate recharge rates. Remote sensing technologies, such as satellite-based observations and aerial imagery, provide valuable data for mapping land use changes and monitoring vegetation, which are indicative of recharge variations.

III. Methodology

Evaluating statewise annual groundwater recharge and net groundwater availability demands a comprehensive approach that integrates diverse data sources and analytical techniques. This section depicts the methodology employed in this research:
Data Collection

- Hydrological Data: We sourced hydrological data, encompassing precipitation records, evapotranspiration data, and river discharge measurements, from authoritative bodies like national meteorological agencies and hydrological monitoring networks. The data were gathered at a spatial and temporal resolution tailored to the study's scope.

- Remote Sensing Data: To evaluate land use and land cover changes, we utilized satellite imagery and remote sensing data. This involved high-resolution imagery for identifying urbanization trends, vegetation indices to track changes in vegetation cover, and land surface temperature data to analyze urban heat island effects and their potential impact on recharge[11].

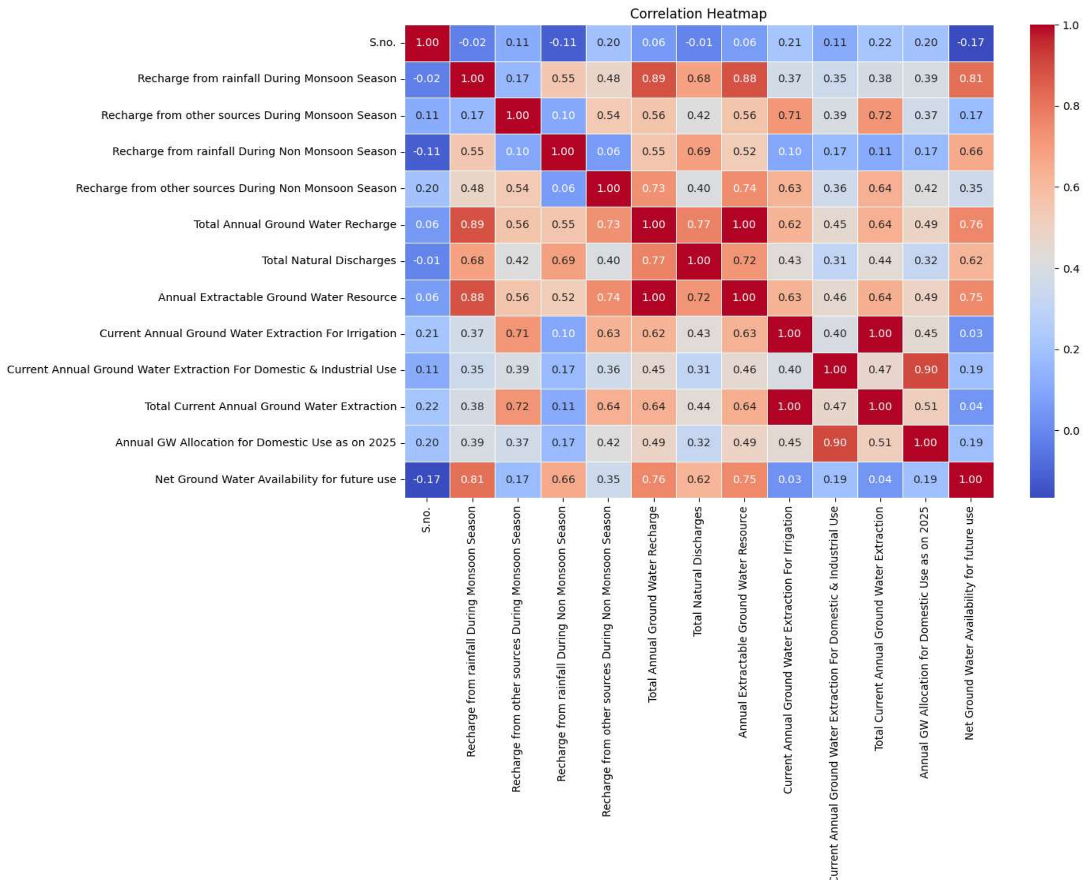

Fig 1: Heatmap showing correlation between ground water recharge and various factors affecting it.

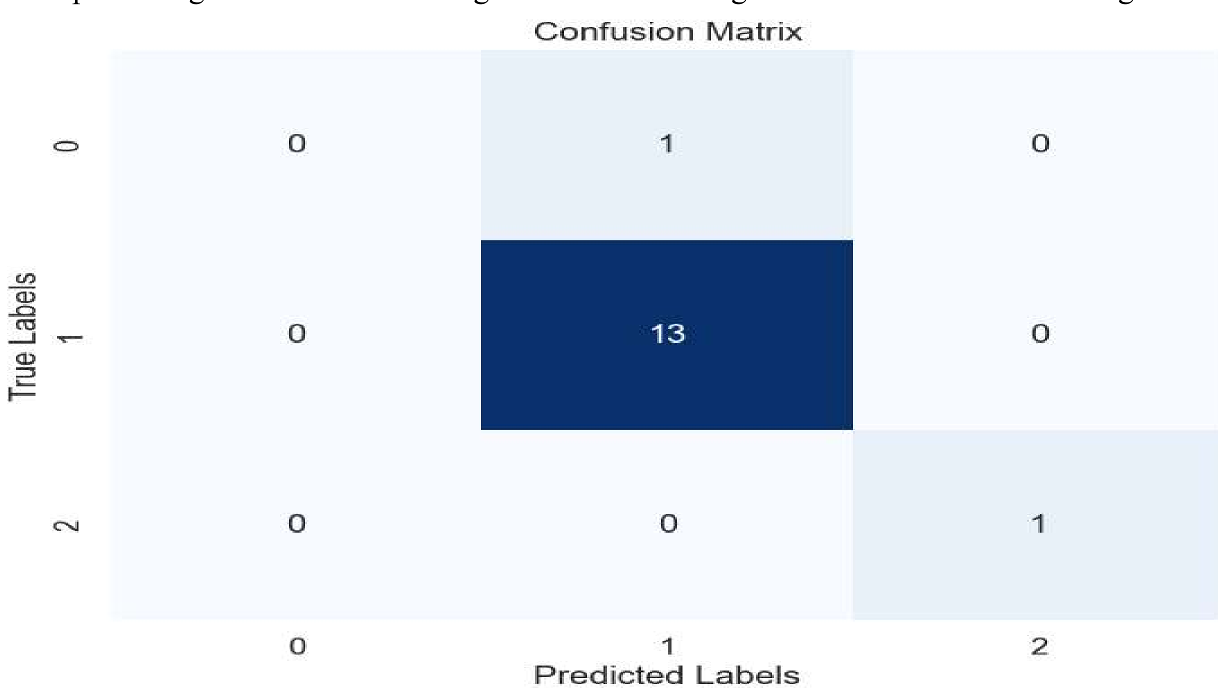

Figure 2: Confusion Matrix for Net Groundwater recharge levels(High,Medium,Low)

Accuracy: 0.93

Classification Report:

	precision	recall	f1-score	support
H	0.00	0.00	0.00	1
L	0.93	1.00	0.96	13
M	1.00	1.00	1.00	1
accuracy			0.93	15
macro avg	0.64	0.67	0.65	15
weighted avg	0.87	0.93	0.90	15

The model achieved an accuracy of 93%, which is quite good. This suggests that the model is having difficulty predicting the "H" class, possibly due to a lack of samples or imbalanced data.
For the "L" class, the model achieved high precision (93%), recall (100%), and F1-score (96%). This indicates that the model performs well for this class.

IV. Statewise Groundwater recharge analysis

Groundwater recharge, a pivotal process in the hydrological cycle, is crucial for sustaining groundwater resources. This section unveils the outcomes of our thorough examination of statewise annual groundwater recharge rates. Drawing on diverse data sources, including historical precipitation records and hydrological modeling tools like the Soil and Water Assessment Tool (SWAT) and Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), our approach meticulously evaluated precipitation patterns within each state, exposing temporal variations, seasonal nuances, and long-term trends. These findings formed the basis for our hydrological models, calibrated and validated with historical streamflow data, enabling us to simulate surface runoff and estimate groundwater recharge[5]. To grasp the impact of land use and cover changes, we incorporated remote sensing data and GIS analysis into the modeling process, offering insights into the consequences of urbanization, agriculture, and shifts in natural vegetation. Figure 1 depicts Heatmap showing correlation between ground water recharge and various factors affecting it.In figure 1, Darker colors, such as deep blue, represent strong negative correlations.Lighter colors, like warm red, indicate strong positive correlations. Neutral or light-colored cells near zero suggest weak or no correlation.

A value of 1 signifies a perfect positive correlation, -1 indicates a perfect negative correlation, and 0 suggests no correlation. Figure 2 shows Confusion Matrix indicating net ground water recharge levels (High,Medium,Low).

V. Case Study and Discussion

Case Study: State of Rajasthan and State of Kerala, India
In this section, we delve into two contrasting states in India, Rajasthan and Kerala, to illustrate the diverse outcomes of groundwater management strategies, emphasizing the importance of region-specific approaches.
Case Study: State of Rajasthan

Rajasthan, situated in northwestern India, grapples with a harsh semi-arid climate and scant annual precipitation[24]. Our analysis indicates consistently low groundwater recharge rates, primarily due to unfavorable hydrological conditions in the region. The state historically heavily depended on groundwater extraction to meet the needs of its growing population and agricultural sector, leading to a steady decline in groundwater levels and raising concerns about long-term sustainability.

In response to these challenges, Rajasthan implemented comprehensive water management reforms. Stricter regulations on groundwater extraction were enforced to limit withdrawals to sustainable levels. The state also invested in large-scale rainwater harvesting programs, encouraging communities to capture and store rainwater for local use and aquifer replenishment during the monsoon season.

These proactive measures over the years have yielded remarkable results. Groundwater recharge rates have gradually increased, and groundwater levels have stabilized. The promotion of sustainable agricultural practices has reduced water-intensive farming methods. Rajasthan's investments in alternative water sources and conservation measures have significantly decreased vulnerability to climate variability, ensuring a more secure water future for the state.

Case Study: State of Kerala

On the flip side, Kerala, located in the southwestern part of India, enjoys a tropical climate with abundant annual precipitation. Our analysis reveals consistently high groundwater recharge rates in the region. Historically, Kerala had a surplus of groundwater availability, leading to occasional complacency in water management practices.

However, rapid urbanization and changing land use patterns in Kerala resulted in increased impermeable surfaces, greater surface runoff, and reduced groundwater recharge. Recognizing the need for proactive water management, the state implemented a series of policy reforms. Urban planning regulations were revised to promote green infrastructure, reduce impervious surfaces, and encourage rainwater harvesting practices in urban areas.

These interventions aimed to mitigate declining recharge rates and ensure long-term water security. The case of Kerala underscores the importance of anticipatory measures even in regions with abundant groundwater resources. By addressing the drivers of declining recharge due to urbanization and land use changes, the state successfully maintained favorable groundwater dynamics, preserving a reliable water source for its urban centers and agriculture.

VI. Conclusion and Future Direction

In this research paper, we have delved into the intricate dynamics of groundwater recharge and net groundwater availability at the state level in India[24][25][31][33]. Through a comprehensive analysis encompassing climatic, geological, and anthropogenic factors, we have illuminated the drivers of groundwater recharge variations, highlighting their significant implications for water resource management.

Our case studies, featuring Rajasthan and Kerala, have underscored the importance of region-specific approaches to groundwater management. These studies vividly illustrate how proactive measures, such as stringent regulations, rainwater harvesting, and adaptive land use planning, can positively influence groundwater dynamics, even in regions with challenging hydrological conditions.

In a broader context, our findings emphasize the imperative for informed, adaptive, and sustainable water resource management practices. They stress the need for continuous monitoring, the integration of sustainable practices, and the recognition of the intricate relationship between climate, geology, land use, and groundwater recharge. This research underscores that state-level water management is pivotal for ensuring water security, preserving groundwater resources, and mitigating the impacts of climate change and urbanization.

REFERENCES

[1]. Gupta, H. K., & Deshpande, R. D. (2004). Trends in groundwater levels in India and their implications. Current Science, 86(9), 1322-1333.

[2]. Tiwari, V. M., Wahr, J., & Swenson, S. (2009). Dwindling groundwater resources in northern India, from satellite gravity observations. Geophysical Research Letters, 36(18), L18401.

[3]. Scanlon, B. R., Reedy, R. C., Stonestrom, D. A., Prudic, D. E., & Dennehy, K. F. (2005). Impact of land use and land cover change on groundwater recharge and quality in the southwestern US. Global Change Biology, 11(10), 1577-1593.

[4]. Foster, S., & Chilton, J. (2003). Groundwater: the processes and global significance of aquifer degradation. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 361(1809), 1927-1950.

[5]. Alley, W. M., Healy, R. W., LaBaugh, J. W., & Reilly, T. E. (2002). Flow and storage in groundwater systems. Science, 296(5575), 1985-1990.

[6]. Konikow, L. F. (2011). Contribution of global groundwater depletion since 1900 to sea-level rise. Geophysical Research Letters, 38(17), L17401.

[7]. Voss, C. I., & Famiglietti, J. S. (2002). Groundwater declines in the Mekong Delta: Understanding the implications for cropland vulnerability. Water Resources Research, 38(6), 1270.

[8]. Kumar, R., Singh, R. D., & Sharma, K. D. (2005). Water resources of India. Current Science, 89(5), 794-811.

[9]. Shah, T. (2009). Taming the anarchy: Groundwater governance in South Asia. Resource Management in Asia-Pacific Working Paper No. 68. International Water Management Institute.

[10]. Srinivasan, V., & Gorelick, S. M. (2015). Impacts of Indian monsoon precipitation changes on a major grain crop. Nature Communications, 6, 1-9.

[11]. Kumar, M., & Merwade, V. (2011). Estimating groundwater recharge using land use and soil data. Hydrogeology Journal, 19(4), 751-764.

[12]. Gleeson, T., Alley, W. M., Allen, D. M., Sophocleous, M. A., Zhou, Y., Taniguchi, M., ... & Vandersteen, J. (2012). Towards sustainable groundwater use: setting long-term goals, backcasting, and managing adaptively. Groundwater, 50(1), 19-26.

[13]. Foster, S., & Loucks, D. P. (2006). Non-renewable groundwater resources: a guidebook on socially-sustainable management for water policy makers. World Bank Publications.

[14]. Chinnasamy, P., Jaisankar, I., Manikandan, S., & Elango, L. (2014). Evaluation of temporal changes in groundwater quality in southern Tamil Nadu, India using GIS. Environmental Monitoring and Assessment, 186(1), 69-84.

[15]. Shamsudduha, M., Taylor, R. G., & Longuevergne, L. (2012). Monitoring groundwater storage changes in the highly seasonal humid tropics: Validation of GRACE measurements in the Bengal Basin. Water Resources Research, 48(4).

[16]. Chopra, Deepti, Nisheeth Joshi, and Iti Mathur. "Improving quality of machine translation using text rewriting." 2016 Second International Conference on Computational Intelligence & Communication Technology (CICT). IEEE, 2016.

[17]. Chopra, Deepti, and Sudha Morwal. "Named entity recognition in Punjabi using hidden Markov model." International Journal of Computer Science & Engineering Technology 3.12 (2012): 616-620.

[18]. Tyagi, Shruti, et al. "Comparison of classifier based approach with baseline approach for English-Hindi text simplification." International Conference on Computing, Communication & Automation. IEEE, 2015.

[19]. Singh, A. K., Mondal, N. C., Mondal, G. C., Sharma, S. D., & Tyagi, S. (2010). Estimation of groundwater recharge and discharge zones in and around Asansol Municipal Corporation area, West Bengal, using geospatial techniques. Environmental Earth Sciences, 60(3), 531-541.

[20]. Suryavanshi, A. P., & Wagh, V. M. (2013). Assessment of groundwater recharge and discharge zones in Waghoda watershed, Akola, India, using remote sensing and GIS. Arabian Journal of Geosciences, 6(5), 1477-1484.

[21]. Kumar, P. S., & Jha, M. K. (2012). Modeling groundwater recharge using GIS-based DRASTIC model. Environmental Earth Sciences, 67(7), 1989-2000.

[22]. Tiwari, V. M., & Singh, P. K. (2009). Impact of anthropogenic activities on groundwater level and recharge rate in Gomti River Basin, India. Environmental Geology, 56(4), 779-787.

[23]. Akhter, G., & Khan, A. H. (2008). Land use/land cover change and its impact on groundwater levels in Bareilly City, Uttar Pradesh. Journal of Geographic Information System, 1(02), 76-85.

[24]. Chahar, B. R., Sharma, K. D., & Singh, V. P. (2011). Estimation of groundwater recharge from water balance approach for drought assessment in western Rajasthan, India. Hydrology Research, 42(3), 208-220.

[25]. Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. Nature, 460(7258), 999-1002.

[26]. Scanlon, B. R., Longuevergne, L., & Long, D. (2012). Ground referencing GRACE satellite estimates of groundwater storage changes in the California Central Valley, USA. Water Resources Research, 48(8).

[27]. Wada, Y., van Beek, L. P. H., van Kempen, C. M., Reckman, J. W., Vasak, S., & Bierkens, M. F. P. (2010). Global depletion of groundwater resources. Geophysical Research Letters, 37(20), L20402.

[28]. Rodell, M., & Chen, J. (2005). Integrating ground-based measurements and remote sensing data to estimate the spatial distribution of evapotranspiration. Remote Sensing of Environment, 98(2-3), 265-278.

[29]. Bierkens, M. F. P., & van Dam, J. C. (2008). Modeling groundwater recharge and evapotranspiration by vegetation in the Sahel. Journal of Hydrology, 352(3-4), 349-368.

[30]. Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. M., McGuire, V. L., & McMahon, P. B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. Proceedings of the National Academy of Sciences, 109(24), 9320-9325.

[31]. Rao, N. S., & Sharma, D. P. (2014). Evaluation of land-use and land-cover changes for a coal mining area of Singrauli, India using remote sensing and GIS. Environmental Monitoring and Assessment, 186(12), 8645-8657.

[32]. Shahid, S., Harun, S. B., & Bagtzoglou, A. C. (2011). A monthly stochastic rainfall generator based on a Neyman-Scott Rectangular Pulses model. Journal of Hydrology, 399(3-4), 223-235.

[33]. Foster, S., & Hirata, R. (2004). Groundwater use in India: environmental benefits and demand management. Geoforum, 35(2), 159-173.

[34] GS Popli, P Arora, D Chopra, Generalized Association Rule Mining on Fuzzy Multiple Datasets For Brain Injury Patients, BioGeckoJournal of New Zealand Herpetology, Vol 12 Issue 03 2023 ISSN NO: 2230-5807, May-June 2023.

[35] P Arora, RK Chauhan, A Kush "Frequent Itemsets from Multiple Datasets with Fuzzy data", International Journal of Computer Theory and Engineering vol. 3, no. 2, pp. 255- 260, 2011.

[36] Batra , P. ., & Arora, P. . (2023). Mining Frequent Itemsets with Fuzzy Taxonomic Structures for Cybercrime Investigations. Research and Applications Towards Mathematics and Computer Science Vol. 2, 114–122.

[37] Arora P, Chauhan RK, Kush A. Frequent Itemsets from Multiple Datasets with Fuzzy data. International Journal of Computer Theory and Engineering. 2011;3(2):255-60.

[38] Arora P, Chauhan RK, Kush A. Mining fuzzy generalized association rules for ER models. International Journal of Information Technology and Knowledge Management (IJITKM). 2008;1(2):191-8. [39] Arora P, Saxena S, Chopra D. Generalized association rules for ER models by using mining operations on fuzzy datasets. Recent Progress in Science and Technology. 2023;6.

[40] Arora P. Mining rules for head injury patients using fuzzy taxonomic structures. Research Highlights in Disease and Health Research. 2023;5:146-56.

[41] Arora P, Saxena S, Madan S, Joshi N. Frequent itemsets: fuzzy data from multiple datasets. Novel Res Aspects Math Computer Science. 2022;5:47-57.