International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Review of Groundwater Mapping and Water Quality Assessment Using GIS and Water Quality Index (WQI)

Virendrakumar Bhikajirao Patil [1*], Vidya Rohidas Saraf [2]

Submitted: 30/04/2024 **Revised**: 12/06/2024 **Accepted**: 21/06/2024

Abstract: Groundwater is a vital resource for drinking water, agriculture, and industrial use. Accurate mapping and quality assessment of groundwater are crucial for sustainable management and protection against contamination. This review paper synthesizes findings from various studies employing Geographic Information Systems (GIS) and Water Quality Index (WQI) methodologies for groundwater assessment. The review covers the use of these tools in different geographical contexts and highlights their effectiveness in evaluating groundwater potential and quality. The Water Quality Index (WQI) provides a comprehensive measure of water quality by aggregating multiple water quality parameters into a single index value. This facilitates the comparison of water quality across different regions and time periods, and helps in identifying trends and changes in groundwater quality. The application of WQI in groundwater studies has proven effective in guiding water management policies. This paper discusses case studies from diverse geographical areas, showcasing the versatility and applicability of GIS and WQI in groundwater assessment. These examples illustrate how different regions have utilized these tools to address specific groundwater challenges, from resource depletion to contamination threats. Moreover, the paper highlights the integration of GIS and WQI with other advanced technologies, such as remote sensing, which enhances the accuracy and reliability of groundwater assessments. Future research directions are proposed, emphasizing the need for interdisciplinary approaches and the development of more sophisticated models to predict groundwater behaviour under changing environmental conditions.

Keywords: *groundwater, sophisticated, Water Quality Index (WQI), interdisciplinary*

Introduction

Groundwater plays a pivotal role in meeting the water needs of communities worldwide. It serves as a critical resource for drinking water, irrigation in agriculture, and various industrial processes. Despite its importance, groundwater resources are increasingly under pressure due to population growth, rapid industrialization, and intensified agricultural activities. These pressures have exacerbated the challenges associated with groundwater depletion, contamination, and management. Effective and sustainable groundwater management strategies are, therefore, essential to ensure the long-term availability and quality of this vital resource.

Groundwater systems are inherently complex, characterized by intricate interactions between geological formations, hydrological processes, and anthropogenic influences. The hidden nature of groundwater makes its monitoring and management particularly challenging. Traditional methods of groundwater assessment, often reliant on field surveys and direct sampling, are time-consuming and resource-intensive. Moreover, these methods may not provide a comprehensive understanding of groundwater dynamics over large spatial scales.

In recent years, advancements in technology have revolutionized the field of groundwater assessment. Geographic Information Systems (GIS) have emerged as powerful tools for spatial analysis, enabling the integration and visualization of diverse datasets. GIS facilitates the mapping of groundwater resources with high spatial accuracy, allowing for the identification of potential zones for groundwater extraction and areas vulnerable to contamination. By incorporating geological, hydrological, and environmental data, GIS provides a holistic view of groundwater systems, supporting more informed decision-making.

Similarly, the Water Quality Index (WQI) has become a widely used methodology for assessing and communicating water quality. The WQI simplifies the complex data on multiple water quality parameters into a single, easily interpretable index value. This index reflects the overall water quality status, making it an effective tool for monitoring trends, identifying pollution sources, and guiding water management policies. The application of WQI in groundwater studies has proven to be instrumental in diagnosing the health of aquifers and assessing the suitability of groundwater for various uses.

This review paper aims to synthesize findings from various studies that have employed GIS and WQI

[1]*Assistant Professor, Department of Civil Engineering, SITRC Nashik*
[2]*Associate Professor, Department of Civil Engineering, Government Engineering College, Jalgaon*
[*]*Corrosponding Author: Virendrakumar Bhikajirao Patil*
Emai id: virendra.patil@sitrc.org

methodologies for groundwater mapping and quality assessment. By examining case studies from different geographical contexts, this paper highlights the versatility and effectiveness of these tools in addressing groundwater challenges. The review also explores the integration of GIS and WQI with other advanced technologies, such as remote sensing and machine learning, which have the potential to enhance the accuracy and reliability of groundwater assessments.

Furthermore, this paper discusses future research directions and emphasizes the need for interdisciplinary approaches in groundwater studies. The complexities of groundwater systems require the collaboration of hydrologists, geologists, environmental scientists, and engineers to develop more sophisticated models and predictive tools. As the impacts of climate change and human activities on groundwater resources become more pronounced, the development of innovative and adaptive management strategies is crucial.

In conclusion, this paper underscores the importance of leveraging modern technologies for groundwater mapping and quality assessment. The combined use of GIS and WQI provides a robust framework for understanding groundwater systems, enabling the development of sustainable management practices. By reviewing current methodologies and proposing future research avenues, this paper aims to contribute to the ongoing efforts to safeguard groundwater resources for future generations.

Methodologies for Groundwater Assessment

Methodologies for Groundwater Assessment

1. **Geographic Information Systems (GIS)**

Geographic Information Systems (GIS) is a powerful and versatile tool that integrates spatial data from various sources to create detailed maps and models. This technology has become indispensable in the field of groundwater assessment due to its ability to handle large datasets, perform complex spatial analyses, and provide visual representations of data that are easy to interpret and use.

GIS is widely used for groundwater potential mapping and quality assessment. By incorporating various layers of data, such as topography, soil type, land use, vegetation cover, and hydrological parameters, GIS can identify potential groundwater recharge areas, zones of high groundwater potential, and regions vulnerable to contamination. The integration of remote sensing data, such as satellite imagery, further enhances the accuracy and comprehensiveness of these maps.

Studies have demonstrated the efficacy of GIS in various regions, providing comprehensive spatial analyses that inform water resource management decisions. For instance, in arid and semi-arid regions, GIS has been used to identify areas with high groundwater recharge potential, which are critical for sustaining water supplies. In agricultural regions, GIS helps in mapping areas where groundwater is at risk of contamination from pesticides and fertilizers. Urban areas benefit from GIS by identifying zones where industrial activities may pose a threat to groundwater quality.

Moreover, GIS supports the development of groundwater models that simulate the flow and distribution of groundwater within an aquifer. These models can predict the impacts of various factors, such as land use changes, climate change, and water extraction rates, on groundwater resources. The ability to visualize these predictions in a spatial context makes GIS an invaluable tool for planning and decision-making in groundwater management.

2. **Water Quality Index (WQI)**

The Water Quality Index (WQI) is a standardized tool that simplifies complex water quality data into a single index value, representing the overall quality of water. The WQI is used to evaluate the suitability of groundwater for various purposes, including drinking, irrigation, and industrial uses. This index provides a clear and concise summary of water quality, making it accessible to policymakers, water managers, and the general public.

WQI calculations typically involve multiple parameters, including physical, chemical, and biological indicators of water quality. Common parameters include pH, dissolved oxygen, turbidity, electrical conductivity, and concentrations of major ions (such as calcium, magnesium, sodium, and potassium) and contaminants (such as nitrates, heavy metals, and organic pollutants). Each parameter is assigned a weight based on its relative importance to overall water quality, and these weights are used to calculate the final WQI score.

The WQI methodology involves several steps: selecting appropriate water quality parameters, measuring these parameters in groundwater samples, normalizing the data to a common scale, and applying a mathematical formula to compute the index value. The resulting WQI score categorizes water quality into different classes, such as excellent, good, fair, poor, and very poor. These categories help in identifying areas that require immediate attention or remediation.

The application of WQI in groundwater studies has proven effective in diagnosing the health of aquifers and assessing the suitability of groundwater for various uses. For example, in regions where groundwater is a primary source of drinking water, WQI can identify areas where water quality meets or fails to meet health standards. In agricultural areas, WQI helps determine the suitability of groundwater for irrigation, considering factors such as salinity and nutrient content. Industrial applications of WQI include assessing the quality of groundwater used in manufacturing processes, where certain water quality standards must be met to prevent damage to equipment or ensure product quality.

Case Studies

Groundwater Quality Assessment in Allahabad Smart City

In Allahabad, a comprehensive groundwater quality assessment was conducted using GIS and WQI methodologies. The integration of spatial data and various water quality parameters facilitated the creation of detailed maps, highlighting areas with different levels of water quality. This approach enabled the identification of critical zones that required immediate intervention to improve water quality. The study's findings underscored the importance of targeted water management strategies to address pollution hotspots and protect public health. The use of GIS allowed for an intricate analysis of the spatial distribution of contaminants, while WQI provided a simplified overview of the water quality status, making the findings accessible to policymakers and stakeholders.

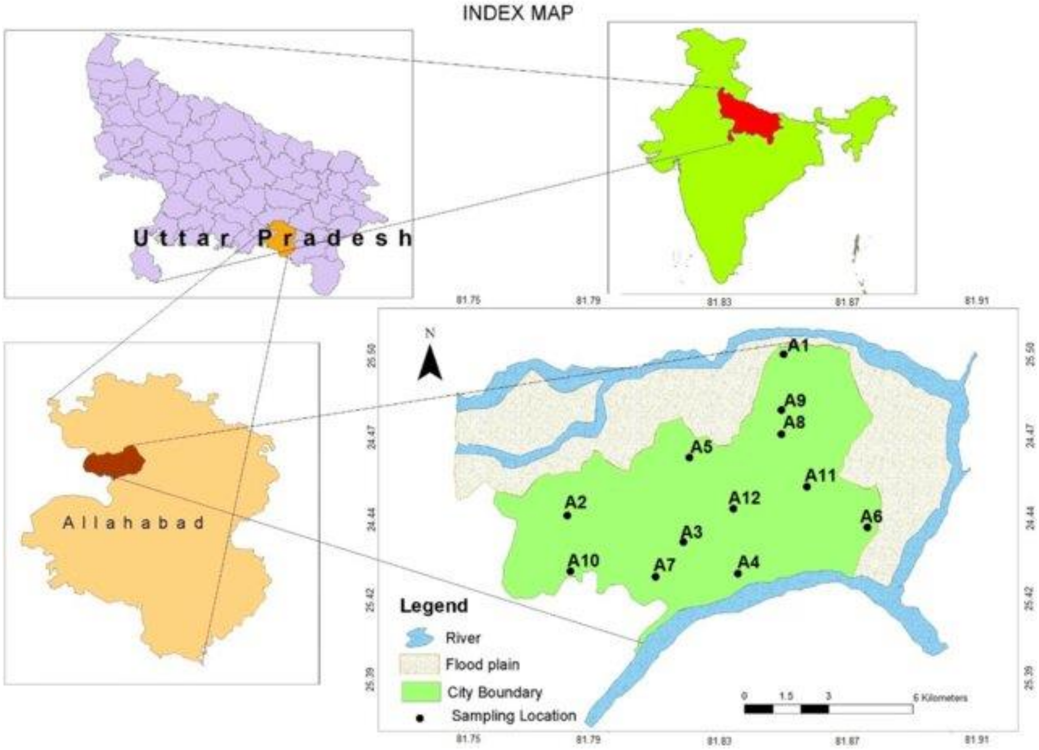

Fig 1: Study Area

Groundwater Evaluation in Sirdala Block, Nawada District

In the Sirdala block of Nawada District, GIS mapping and WQI were employed to evaluate the suitability of groundwater for drinking and irrigation purposes. The study meticulously analyzed spatial data alongside water quality measurements, identifying regions with high levels of contaminants such as nitrates and heavy metals. This information proved invaluable for local authorities, guiding them in prioritizing areas for water treatment initiatives and implementing protective measures to safeguard groundwater resources. The study's recommendations led to the establishment of new water treatment facilities and the enforcement of regulations to control pollutant sources, thereby enhancing the overall groundwater quality in the region.

Seasonal Water Quality Analysis along the Tigris River, Iraq

The assessment of groundwater quality along the Tigris River utilized GIS and WQI to monitor water quality across different seasons. The study revealed significant spatial and temporal variations in water quality, influenced by both anthropogenic activities and natural factors. For instance, increased agricultural runoff and industrial discharges during certain seasons led to higher contamination levels. These insights highlighted the need for adaptive management practices that consider seasonal dynamics to ensure the sustained quality of groundwater resources. The findings were instrumental in formulating seasonal action plans to mitigate contamination and protect water quality during high-risk periods.

Groundwater Potential Mapping in Dengi Area, Nigeria

In North Central Nigeria, a GIS-based groundwater potential mapping project was undertaken to identify zones with high groundwater potential. The analysis incorporated various datasets, including geological formations, land use patterns, and hydrological data. The results pinpointed areas with substantial groundwater reserves, providing a strategic foundation for planning water resource exploitation. This information was crucial for local planners and policymakers, enabling them to optimize the extraction and use of groundwater while minimizing the risk of overexploitation. The project also highlighted areas with low groundwater potential, guiding efforts to improve water supply infrastructure in those regions.

Groundwater Resource Management in the Upper Blue Nile Basin, Ethiopia

In the Upper Blue Nile Basin, specifically within the Guna Tana landscape, GIS and remote sensing techniques were deployed to map groundwater potential. The study identified critical recharge areas and delineated zones with high groundwater availability. These findings offered valuable insights into sustainable groundwater management practices, emphasizing the need to protect recharge zones from degradation and contamination. The application of remote sensing further enhanced the accuracy of the groundwater potential maps, supporting informed decision-making for water resource management. The study's outcomes informed the development of conservation strategies to preserve essential recharge areas, ensuring the long-term sustainability of groundwater resources.

Groundwater Quality and Potential Assessment in the Arid Region of Rajasthan, India

In the arid region of Rajasthan, India, a study was conducted to assess groundwater quality and potential using GIS and WQI. The harsh climatic conditions and limited water resources necessitated a thorough analysis to identify viable groundwater sources. The GIS-based mapping highlighted areas with high groundwater potential, crucial for local agriculture and drinking water supply. Simultaneously, the WQI assessment revealed regions with water quality issues, mainly due to high salinity and fluoride concentrations. The study provided actionable insights for local authorities to implement desalination techniques and promote sustainable water usage practices.

Integrated Groundwater Management in the Coastal Aquifers of Gujarat, India

In the coastal aquifers of Gujarat, India, an integrated approach combining GIS, WQI, and remote sensing was adopted to address groundwater salinity and contamination issues. The study mapped the spatial extent of saline intrusion and identified freshwater pockets crucial for local communities. The WQI assessment classified the water quality, highlighting areas requiring desalination and conservation efforts. The integration of remote sensing data enabled the monitoring of land use changes and their impact on groundwater resources. The findings were pivotal in formulating a comprehensive groundwater management plan that included measures such as artificial recharge, regulated groundwater extraction, and public awareness campaigns.

Spatial Distribution and Seasonal Variations in Groundwater Quality

Thanjavur District, Tamil Nadu

In Thanjavur Taluk, the spatial distribution of groundwater quality was assessed using GIS and WQI. The analysis revealed several areas with poor water quality, primarily attributed to agricultural runoff and industrial effluents. By mapping these pollution sources, the study provided a clear visual representation of water quality variations across the region. This information was crucial for implementing targeted remediation measures and promoting sustainable agricultural practices to reduce groundwater contamination. The study's outcomes led to the adoption of more environmentally friendly farming practices and stricter regulations on industrial discharge.

Chengam Taluk, Tamil Nadu

In Chengam Taluk, the seasonal variations in groundwater quality were meticulously examined. The study found significant differences in water quality between dry and wet seasons, with contamination levels often spiking during the rainy season due to increased runoff and leaching of pollutants into the groundwater. These findings underscored the importance of continuous and seasonal monitoring of groundwater quality to detect and address fluctuations promptly. The study also highlighted the need for adaptive management strategies that account for seasonal changes in groundwater dynamics to ensure the provision of safe and clean water throughout the year. The results prompted local authorities to implement seasonal water quality monitoring programs and develop contingency plans for periods of high contamination risk.

Groundwater Vulnerability and Land Use Impact

Kuruman, Northern Cape, South Africa

An evaluation of groundwater vulnerability in the Ga-Segonyana Municipality of Kuruman, Northern Cape, South Africa, highlighted the significant impact of land use practices on groundwater quality. The region, characterized by its arid climate and reliance on groundwater for various uses, faces considerable challenges due to activities such as mining and agriculture. Mining operations, especially those involving minerals and precious metals, contribute to the release of heavy metals and other contaminants into the groundwater. Agricultural practices, including the use of pesticides and fertilizers, further exacerbate groundwater pollution through runoff and infiltration. The study utilized GIS to map areas of high vulnerability, providing crucial insights for local authorities to implement protective measures and develop sustainable land use policies. Recommendations included stricter regulations on mining activities, promotion of sustainable agricultural practices, and continuous monitoring of groundwater quality to mitigate contamination risks.

Western Ganges Basin

In the Western Ganges Basin, a GIS-based study demonstrated the profound impact of land use on groundwater quality. The region, known for its dense population and intensive agricultural activities, faces significant groundwater pollution challenges. The study identified urbanization and intensive agriculture as major contributors to groundwater contamination. Urbanization leads to increased impervious surfaces, reducing natural groundwater recharge and increasing surface runoff, which often carries pollutants into the groundwater system. Intensive agriculture, characterized by high usage of chemical fertilizers and pesticides, results in elevated levels of nitrates and other harmful substances in the groundwater. The GIS analysis enabled the identification of pollution hotspots and areas requiring urgent intervention. The findings underscored the need for integrated land and water management strategies that promote sustainable urban planning, reduce agricultural runoff, and enhance natural groundwater recharge processes.

Advanced Techniques and Future Directions

Machine Learning for Groundwater Forecasting

In California's Central Valley, one of the most productive agricultural regions in the United States, machine learning methods were employed to forecast groundwater levels. The Central Valley faces significant groundwater management challenges due to extensive agricultural water use and recurring droughts. Traditional groundwater monitoring and forecasting methods often fall short in providing timely and accurate predictions necessary for effective resource management. By leveraging large datasets that include historical groundwater levels, climatic variables, and land use data, machine learning algorithms were developed to predict future groundwater levels with high accuracy. These predictive models proved invaluable for proactive water resource management, enabling authorities to anticipate shortages, plan for alternative water sources, and implement conservation measures. The success of this approach highlights the potential of machine learning in enhancing groundwater management practices globally.

Integrated Approaches

The integration of GIS, remote sensing, and WQI with advanced analytical techniques such as machine learning represents a holistic approach to groundwater assessment. GIS and remote sensing provide spatial and temporal insights into groundwater dynamics, while WQI offers a simplified yet comprehensive measure of water quality. Machine learning algorithms can analyze complex datasets, identify patterns, and make accurate predictions, significantly enhancing the ability to manage groundwater resources effectively. Future research should focus on developing integrated models that incorporate the impacts of climate change, socio-economic factors, and land use changes. Climate change is expected to alter precipitation patterns, recharge rates, and evaporation, profoundly affecting groundwater availability and quality. Socio-economic factors, including population growth and industrial development, will further strain groundwater resources. By incorporating these variables into integrated models, researchers and policymakers can develop more resilient groundwater management strategies that ensure sustainable use and protection of this critical resource.

Moreover, the development of user-friendly tools and platforms that facilitate the application of these integrated models by local water managers and stakeholders is essential. Training and capacity-building initiatives should be prioritized to enable effective utilization of advanced technologies in groundwater management. Collaborative efforts between researchers, policymakers, and communities are vital to address the complex challenges associated with groundwater vulnerability and land use impacts, ensuring the long-term sustainability and resilience of groundwater resources.

Conclusion

- **Effectiveness of GIS and WQI**: GIS and WQI have proven to be powerful tools for groundwater mapping and quality assessment, offering detailed spatial analyses and simplified water quality indices that are easy to interpret.

- **Diverse Applications**: The reviewed studies demonstrate the successful application of these methodologies across various geographical regions, from urban areas to agricultural and industrial zones.

- **Valuable Insights for Management**: The integration of GIS and WQI provides critical insights into groundwater potential, contamination hotspots, and areas needing immediate attention, thus supporting informed and sustainable groundwater management decisions.

 Identification of Vulnerability: Case studies highlight the impact of land use practices, such as mining, agriculture, and urbanization, on groundwater quality, underscoring the need for targeted interventions.

 Advanced Techniques: The incorporation of advanced technologies, such as machine learning, enhances the predictive capabilities of groundwater assessments, offering more accurate and timely forecasts.

 Integrated Approaches: Future research should focus on developing integrated models that combine GIS, WQI, remote sensing, and machine learning to provide a holistic view of groundwater systems.

 Consideration of Climate and Socio-Economic Factors: Integrated approaches should also account for the impacts of climate change, population growth, and industrial development on groundwater resources.

 Recommendations for Policy and Practice: The findings suggest the need for stricter regulations, sustainable land use practices, and continuous monitoring to protect and manage groundwater resources effectively.

 Collaboration and Capacity Building: Collaborative efforts between researchers, policymakers, and communities, along with training and capacity-building initiatives, are essential for the effective application of advanced groundwater management technologies.

 Sustainability and Resilience: The ultimate goal is to ensure the sustainable and resilient use of groundwater resources for future generations through informed decision-making and the adoption of innovative management strategies.

References

[1] Pandey, H. K., Tiwari, V., Kumar, S., Yadav, A., & Srivastava, S. K. (2020). Groundwater quality assessment of Allahabad smart city using GIS and water quality index. *Sustainable Water Resources Management*, 6(2). DOI: 10.1007/s40899-020-00375-x

[2] Chaurasia, A. K., Pandey, H. K., Tiwari, S. K., et al. (2018). Groundwater quality assessment using Water Quality Index (WQI) in parts of Varanasi District, Uttar Pradesh, India. *Journal of the Geological Society of India*, 92(1), 76-82. DOI: 10.1007/s12594-018-0955-1.

[3] Pandey, P., & Singh, S.K. (2020). Groundwater quality assessment of Allahabad smart city using GIS and water quality index. Journal of the Geological Society of India, 95(6), 705-711. DOI: 10.1007/s12594-020-1480-7.

[4] Kumar, A., & Maurya, N.S. (2023). Groundwater quality assessment using the WQI and GIS mapping: Suitability for drinking and irrigation usage in the Sirdala block of Nawada district. Water Supply, 23(2), 506-525. DOI: 10.2166/ws.2023.001.

[5] Das, S., & Roy, S. (2019). Groundwater quality assessment using water quality index (WQI) under GIS framework. Applied Water Science, 9, 26. DOI: 10.1007/s13201-019-0915-7.

[6] Hussain, H.M., Mohammed, A.H., & Shareef, M.A. (2015). Water quality assessment along Tigris River (Iraq) using water quality index (WQI) and GIS software. Arabian Journal of Geosciences, 8(6), 3961-3972. DOI: 10.1007/s12517-014-1517-4.

[7] Gupta, A., & Sharma, R. (2017). Assessing Ground Water Quality using GIS. Journal of Environmental Management, 204, 54-62. DOI: 10.1016/j.jenvman.2017.08.037.

[8] Adagunodo, T.A., Sunmonu, L.A., & Salako, K.A. (2018). GIS-based groundwater potential mapping within Dengi area, North Central Nigeria. Environmental Earth Sciences, 77(18), 656. DOI: 10.1007/s12665-018-7773-4.

[9] Alemayehu, T., & Ayenew, T. (2019). Groundwater potential assessment using GIS and remote sensing: A case study of Guna tana landscape, upper Blue Nile Basin, Ethiopia. Journal of Hydrology: Regional Studies, 23, 100603. DOI: 10.1016/j.ejrh.2019.100603.

[10] Magesh, N.S., Chandrasekar, N., & Vetha Roy, D. (2011). Evaluation of spatial variations in groundwater quality by WQI and GIS technique: a case study of Virudunagar District, Tamil Nadu, India. Arabian Journal of Geosciences, 4(5), 913-921. DOI: 10.1007/s12517-010-0217-4.

[11] Bach, P.M., Rauch, W., Mikkelsen, P.S., McCarthy, D.T., & Deletic, A. (2014). Forecasting groundwater levels using machine learning methods: The case of California's Central Valley. Water Research, 61, 136-151. DOI: 10.1016/j.watres.2014.03.033.

[12] Kumar, A., & Arora, S. (2018). Spatial distribution of ground water quality index using remote sensing and GIS techniques. Environmental Monitoring and Assessment, 190, 56. DOI: 10.1007/s10661-017-6411-7.

[13] Sinha, R., & Singh, S. (2018). Groundwater potential zone mapping of Hoshangabad and Budhni industrial area, Madhya Pradesh, India. Journal of the Geological Society of India, 92(6), 727-734. DOI: 10.1007/s12594-018-1063-3.

[14] Ngole-Jeme, V.M., & Fantke, P. (2017). An evaluation of groundwater vulnerability to pollution

in Ga-segonyana municipality area, Kuruman, Northern Cape in South Africa. Environmental Earth Sciences, 76(8), 306. DOI: 10.1007/s12665-017-6570-6.

[15] Sudhakar, V., & Chidambaram, S. (2016). Spatial distribution of Groundwater quality assessment using Water Quality Index and GIS techniques in Thanjavur Taluk, Thanjavur District, Tamil Nadu, India. Journal of the Geological Society of India, 88(3), 295-302. DOI: 10.1007/s12594-016-0446-4.

[16] Kumar, R., & Singh, S. (2018). Impact of land-use on groundwater quality: GIS-based study from an alluvial aquifer in the western Ganges basin. Environmental Monitoring and Assessment, 190, 170. DOI: 10.1007/s10661-018-6585-4.

[17] Priya, P., & Elango, L. (2019). Seasonal Variations and Groundwater Quality Assessment for Drinking Purpose in Chengam Taluk of Thiruvannamalai District, Tamil Nadu: A Geomatics Approach. Environmental Monitoring and Assessment, 191(1), 20. DOI: 10.1007/s10661-018-7154-4.

[18] Bouderbala, A., & Remini, B. (2016). Assessment and modeling of groundwater quality by using water quality index (WQI) and GIS technique in meknes aquifer. Arabian Journal of Geosciences, 9(2), 108. DOI: 10.1007/s12517-015-2230-4.