Review of: "Groundwater Potential Zone Assessment Using Remote Sensing, Geographical Information System (GIS), and Analytical Hierarchy Process (AHP) Techniques in Fogera Woreda, South Gondar Zone, Ethiopia"

Mirkan Emir Sancak[1]

1 Gebze Tecnical University, Turkey

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1. Positive Aspects of the Study

1.1 Use of Multi-Criteria Decision-Making (MCDM) with AHP

The study's use of AHP for weighting thematic layers illustrates an appropriate choice of algorithm for multi-criteria decision-making (MCDM) in GIS-based studies. Employing AHP enhances the spatial model's robustness by assigning importance to each thematic layer (such as lithology, lineament density, and slope), which is essential for groundwater resource studies. Furthermore, the application of the consistency ratio (CR) for weight validation aligns well with AHP standards, providing evidence of well-considered weight assignments in layer integration.

1.2 Comprehensive Thematic Layer Selection

Incorporating ten thematic layers, including essential hydrological and geological aspects such as slope, rainfall, soil type, and drainage density, strengthens the model's foundation for delineating groundwater potential zones. Each layer contributes essential insights, enhancing the comprehensiveness of the groundwater potential assessment. Using Sentinel-2 imagery, Digital Elevation Model (DEM), and other reputable sources provides high-quality data inputs, establishing a solid base for the spatial analysis.

2. Critical Feedback and Areas for Improvement

Despite the methodological strengths, several critical limitations in the study reduce its scientific rigor and limit the reliability of its findings. Addressing these issues could significantly enhance the model’s validity, usability, and reproducibility, making it more applicable for both academic research and practical applications in groundwater management.

2.1 **Algorithmic Limitations in Weight Assignment**

The study exclusively relies on the Analytical Hierarchy Process (AHP) for weight assignment among thematic layers, which, while a standard approach, introduces potential subjectivity into the model. AHP is inherently reliant on expert judgment to assign weights to criteria, which, without additional verification, can lead to biased weight values. Given the critical role these weights play in the final assessment, it is recommended to integrate alternative or complementary weighting methods. For instance:

- **Entropy-Based Weighting**: Entropy analysis provides an objective approach to determine weights by quantifying the uncertainty in each thematic layer. This would reduce reliance on subjective expert opinions and introduce a more data-driven approach to weighting [1].
- **Fuzzy Logic**: Fuzzy logic can also be employed alongside AHP to handle the inherent uncertainty in environmental data. By applying fuzzy weights, the model could better account for the spatial variability and uncertainty present in each thematic layer, enhancing the overall robustness of the groundwater potential zones [2].

The integration of these methods could mitigate biases and improve the reproducibility of the weight assignment, enhancing the model's scientific rigor and practical reliability.

2.2 **Insufficient Detail in Methodological Description**

The methodological descriptions provided are insufficiently detailed for full reproducibility, which is a critical factor in scientific research. Key elements of the methodology, such as the specific steps in the AHP process, including pairwise comparison calculations, are not described in enough detail. For example, the eigenvalue calculations, typically a part of the AHP matrix development, are not explicitly covered, leaving ambiguity around how consistency was achieved. This lack of detail poses challenges for other researchers attempting to replicate the findings and impacts the transparency of the study.

Additionally, the process of resampling data to a 30x30m resolution is mentioned but lacks specificity regarding the resampling technique (e.g., nearest neighbor, bilinear interpolation). This is crucial information, as the resampling technique can significantly affect the spatial accuracy of data layers. Providing a step-by-step breakdown of the data processing stages, including reclassification parameters, threshold values, and software extensions used, would enhance methodological clarity and allow for reproducibility in similar studies.

2.3 **Absence of Quantitative Validation Metrics**

The validation approach employed in the study, which relies on visual comparison with well-yield data, lacks the quantitative rigor typically expected in groundwater potential assessment research. While well-yield comparison can offer some validation, it is inherently subjective without the support of statistical metrics to measure agreement.

To address this, the study could benefit from quantitative validation metrics, such as:

- **Kappa Statistic**: Kappa provides a statistical measure of agreement between observed and predicted results. Its use could quantify the degree of alignment between the predicted potential zones and actual well-yield data, reducing the reliance on visual inspection [3].

- **Receiver Operating Characteristic (ROC) Curve**: The ROC curve, commonly used in predictive modeling, could assess the true positive rate of high groundwater potential zones against well-yield data. This would allow for a more accurate assessment of the model's performance in identifying productive zones [4].
- **Root Mean Square Error (RMSE)**: RMSE provides a direct measurement of prediction error. Calculating the RMSE between the predicted groundwater potential values and actual well yields would give a concrete measure of the model's predictive accuracy.

Incorporating these metrics would add depth to the validation phase and provide a stronger statistical basis for claiming that the identified zones correlate well with actual groundwater productivity.

2.4 **Limited Geographic and Temporal Scope**

The study’s findings are specific to the Fogera Woreda area, with results that may not be generalizable to other regions with different hydrological or geological conditions. This narrow geographic scope limits the utility of the model in broader applications. Expanding the study across multiple woredas or comparable regions with varied geological and hydrological profiles could help validate the model's adaptability. A broader geographic scope would enhance the relevance of this research, as it could then serve as a more versatile framework applicable to a range of environments.

In addition, the temporal scope of the data used for thematic layers, especially rainfall, is insufficiently detailed. Groundwater potential varies significantly with seasonal rainfall changes, and the lack of consideration for this temporal variation reduces the accuracy of the model. Future studies could incorporate multi-year rainfall data or temporal datasets reflecting seasonal shifts to provide a more dynamic assessment of groundwater potential. Furthermore, utilizing time series analysis or seasonal adjustment techniques could yield valuable insights into temporal fluctuations in groundwater recharge rates.

2.5 **Absence of Sensitivity Analysis**

The study lacks a sensitivity analysis to assess the influence of each thematic layer on the overall groundwater potential model. Sensitivity analysis is a critical step in MCDM, as it evaluates how varying the weights or classifications of thematic layers impacts model outputs. Without this analysis, it is difficult to determine whether small adjustments in layer weights (e.g., rainfall versus lithology) would result in significant changes in groundwater zoning. Conducting sensitivity analysis would:

- Clarify the relative importance of each thematic layer, providing transparency on which factors most influence groundwater potential.
- Allow researchers and policymakers to adjust the model based on local conditions or prioritize layers based on data availability or quality.

Sensitivity analysis would thus improve the model’s adaptability and robustness, ultimately leading to a more reliable and flexible groundwater potential zoning tool.

2.6 **Inadequate Exploration of Thematic Layer Alternatives**

While the study successfully incorporates ten thematic layers, additional data types could further enhance the accuracy of groundwater potential predictions. For instance:

- **Historical Groundwater Levels**: Past groundwater levels could provide a valuable metric for calibrating current potential estimates. Such historical data could highlight trends in groundwater depletion or recharge, providing an empirical basis for adjusting thematic layers.
- **Land Subsidence Data**: In areas where groundwater extraction has led to land subsidence, incorporating this data would add an important dimension to the model. Land subsidence often indicates overexploitation, which could inform the classification of certain zones as low-potential areas.

By incorporating these alternative layers, the model could provide a more nuanced understanding of groundwater potential. These data types, particularly historical trends, could be crucial for dynamic modeling that accounts for temporal changes, improving the model's resilience to fluctuations in groundwater availability [5][6][7].

2.7 **Weaknesses in Data Source Documentation**

Although the study lists data sources, it lacks critical details regarding data quality, resolution consistency, and preprocessing steps, which are essential to any GIS-based study. For instance, the article references the Alaska Satellite Facility for the DEM data but does not specify the date of data acquisition, which could affect the reliability of the elevation layer. Data age is particularly crucial for thematic layers like rainfall and land use, as outdated information can skew results.

Additionally, documenting data limitations and preprocessing steps (e.g., noise removal, calibration) would improve the study's transparency. For instance, specifying the resolution adjustments made to each data source and their potential impact on thematic accuracy would enhance reproducibility. This level of detail is especially important given the inherent variability in environmental data, and its omission here leaves the model open to questions regarding its overall validity.

2.8 **Recommendations for Enhanced Methodological Clarity**

The paper would benefit from improved methodological clarity, particularly regarding GIS tools and AHP implementation. Though the use of ArcGIS 10.8 is stated, the paper lacks detail on specific GIS tools, extensions, or plugins, such as Spatial Analyst, which are often crucial for executing overlay analysis and thematic reclassification. Furthermore, the pairwise comparison and weight normalization processes in AHP could be elaborated, including the steps for calculating the principal eigenvalue and ensuring consistency.

By providing additional detail on the computational tools and processes used, the authors would enhance the transparency and replicability of the methodology. This level of methodological rigor is crucial, especially in GIS-based environmental studies, where the tools and settings used can have a substantial impact on final outcomes.

2.9 **Potential Over-Reliance on Thematic Mapping without Supplementary Techniques**

Although thematic mapping is effective, the model may benefit from integrating advanced machine learning techniques to classify layers and identify potential zones more accurately. For example:

- **Random Forest and Support Vector Machine (SVM)**: These machine learning algorithms can handle large datasets effectively and are commonly used in environmental modeling to improve classification accuracy. Integrating Random Forest or SVM for thematic layer classification could enhance the accuracy of the groundwater zoning map by identifying complex spatial patterns within data layers.
- **Artificial Neural Networks (ANNs)**: ANNs can model non-linear relationships within environmental data, making them a potentially valuable tool for refining groundwater potential assessments, especially in complex terrains.

Incorporating machine learning would allow for more sophisticated data processing and improve the predictive power of the model. As environmental data becomes increasingly large and complex, ML techniques offer a way to handle this complexity effectively, providing a more robust basis for predicting groundwater potential.

Alternative Weighting Methods

1. The resulting weights for multiattribute weighting methods can differ due to decision makers choosing responses from a limited set of numbers, affecting the spread of weights and inconsistency between preference statements [8].
2. All AHP versions behave similarly and closer to SAW than the other methods, with SAW and MEW being the best methods for multi-attribute decision making problems [9].
3. Fuzzy AHP techniques help determine weights and priorities of alternatives in decision-making with subjective judgments, improving the reproducibility of the methodology [10].

Implementing the Alternative Weighting

To implement alternative weighting methods in your study, you can consider the following specific examples based on the provided research papers:

Intuitionistic Fuzzy Entropy Measures:

- **Method**: Use intuitionistic fuzzy (IF) entropy measures to generate objective weights. This method emphasizes the credibility of the data and incorporates a ratio of distance measures.
- **Implementation**: Apply four different distance measures to compare their effectiveness in generating distinct objective attribute weights. This approach is particularly useful when the number of attributes increases, as it helps in managing the discrepancy between the IF entropy measures [11].

Balancing vs. Modeling Approaches:

- **Method**: Implement the balancing approach to weighting, which directly optimizes certain features of the weights, ensuring better covariate balance and minimal dispersion.

- **Implementation**: Use this approach to achieve more accurate and stable effect estimates, especially when the treatment assignment model is unknown. This method systematically results in better covariate balance with weights that are minimally dispersed [12].

Variable Weight-Based Hybrid Approach:

- **Method**: Integrate variable weight, correlation coefficient, and technique for order performance by similarity to an ideal solution (TOPSIS) under interval-valued intuitionistic fuzzy sets (IVIFS).
- **Implementation**: Compute the weighting evaluation matrix using the interval-valued intuitionistic fuzzy weighted averaging operator. Then, use a correlation coefficient-based weighting approach to obtain expert weights and treat attribute weights as a varying vector [13].

Convergence of Multiattribute Weighting Methods:

- **Method**: Use multiple multiattribute weighting methods such as the analytic hierarchy process (AHP), direct point allocation, simple multiattribute rating technique (SMART), swing weighting, and tradeoff weighting.
- **Implementation**: Assess attribute weights using these methods and compare the results. This approach helps in understanding the spread of weights and the inconsistency between preference statements, which depend on the number of attributes considered simultaneously [14].

Matching-Adjusted Indirect Comparisons:

- **Method**: Implement an alternative weighting scheme that maximizes the effective sample size while matching covariate means across studies.
- **Implementation**: Use this method to achieve a larger effective sample size and quantify the difficulty of matching on particular covariates. This approach can be generalized to multiple covariates, providing a new metric for the impact of matching [15].

Enhancing Transparency and Reproducibility in the AHP Process

The Analytic Hierarchy Process (AHP) is a widely used decision-making tool that can benefit from enhanced transparency and reproducibility. Here are key insights from recent research papers on how to achieve this:

Software Support and Standardization:

- Utilizing software tools can reduce barriers to applying AHP and improve transparency by standardizing the process and making it more user-friendly [16][17].
- Adopting international standards, such as ISO/IEC 9126, for evaluating AHP software can provide a consistent framework for assessing the quality and transparency of the tools used [16].

Documentation and Justification:

- Clearly documenting the criteria, weights, and decision-making steps within the AHP model is crucial for transparency. This includes providing detailed explanations for the selection of criteria and the assignment of weights [17][18].
- Justifying the use of AHP over other decision-making methods by highlighting its advantages, such as flexibility, simplicity, and the ability to handle small sample sizes, can enhance the credibility and reproducibility of the study [17].

Expert Involvement and Consensus:

- Involving experts in the development and validation of the AHP model can improve the reliability and transparency of the process. This includes using expert surveys to gather input and achieve consensus on the criteria and weights [19].
- Ensuring that the process for selecting and consulting experts is transparent and well-documented can further enhance the reproducibility of the study[19].

Integration with Other Methods:

- Combining AHP with other decision-making tools, such as fuzzy scoring or blockchain technology, can provide a more comprehensive and transparent evaluation framework. This integration should be clearly explained and justified in the study [18][19].

Summary of Recommendations

In summary, while the study presents a foundational approach to groundwater potential zoning, it would benefit from several methodological and validation enhancements. These include diversifying weight assignment methods, expanding on quantitative validation metrics, and incorporating additional data layers and machine learning techniques. Addressing these areas would strengthen the model's scientific rigor, increase its applicability to varied hydrological settings, and provide a more reliable tool for groundwater management.

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