New approach to optimize groundwater usage using multi-criteria decision making techniques

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Abstract: Chronic pumping of water from aquifers leads to groundwater depletion, leading to an alarming scarcity of groundwater supply. Early detection of low aquifers levels can prevent the complete exhaustion of groundwater. We propose a Groundwater Optimization model using Multi-Criteria Decision Making (MCDM) techniques based on field values of bore wells like aquifer level, availability of nearby bore wells, and depletion to recharge ratio. In order to achieve higher accuracy than the existing models, we take both predefined values and on-site values of individual bore wells. The hardware components include a calibrated pressure transducer, water sensor, GSM module, Raspberry Pi, and IoT module. They are used in order to send the in-field data. When the aquifer level drops below the threshold level, an SMS alert is sent to the owner of the bore well. The threshold level is dynamically determined using the key steps of MCDM methods. The MCDM methods are implemented in Python code to determine and fix the threshold for the instance. The frequency of data logging is adjusted by studying the input patterns, which saves storage. When the water level drops below the threshold level an aquifer recharge technique is sent as a recommendation. The proposed optimization model has the potential to be applied to a larger geographical area in the future.

Keywords: Groundwater, Optimization, MCDM, Depletion, Recharge, Threshold, IoT.

1 Introduction

1.1. Need for Ground Water Optimization

Putting aside the non-availability of water resources to meet the exponentially rising water demands, there is a particular aspect in Water Management that is usually not addressed by the public and other related authorities, the optimal use of available resources. The water resource that is being focused in the project is the groundwater, as it is 98% of the available fresh water. It serves the water requirements for the majority of the people across the globe. According to the International Groundwater Assessment Centre, large-scale abstraction of groundwater also leads to salt water intrusion and sea level rise. The groundwater depletion does not cause long-term effects alone. In recent times, due to excessive aquifer depletion many water tables have become non-existent, as a result many bore wells in metropolitan and agricultural areas faced acute water drain.

Though there are many other plans to cope with the situation, like river interlinking and rain-water harvesting, that are being implemented throughout the globe, it is highly essential to cater to this overriding problem of groundwater depletion with an optimal solution.

A. Reason for excessive Groundwater depletion

The incessant extraction of groundwater is the most common cause for groundwater depletion. We frequently pump groundwater from bore wells and other implemented structures and we do not give enough time to the aquifers to replenish the depleted water. Agriculture is the major reason for large-scale groundwater abstraction.
B. Effects of Groundwater depletion

The over exploitation of groundwater will force us to pump water from a deeper surface. Sometimes, it might also raise a high demand for new equipment used for deepening the existing bore wells. Large water bodies which serve as other sources of freshwater will become shallow. As an extension of this, the groundwater can also be contaminated by salt water from sea due to extreme depletion. This makes the groundwater unfit for usage. As large aquifers are depleted it will hinder food production and supply, which will cause starvation.

C. Solutions of Groundwater depletion

One of the things we can do to prevent unnecessary water stress is to avoid using water for luxury purposes. The regulation of pumping of water might help on legal grounds. And, our solution to this problem is recharging the groundwater or giving the replenishment time for aquifers to avoid complete drying up.

1.2. Multi-Criteria Decision Making Methods

Multi-Criteria Decision Making (MCDM) methods are more efficient when analyzing quantitative and qualitative data. In our proposed model hesitant fuzzy (HF) namely, HF-CRITIC (Hesitant Fuzzy Criteria Importance Through Inter-Criteria Correlation) and HF-MAUT (Hesitant Fuzzy Multi Attribute Utility Theory) are used to get hesitant fuzzy information in order to select the threshold level for an individual borewell[1]. The key steps involved in MCDM include defining objectives, defining criteria, fixing weightage of criteria, listing the options and rating the options. Once the first four key steps are completed we use Weighted Product Method (WPM) to determine the rating of options. The weight of various criteria is mentioned in Table.1 Criteria and Weightage. The principle of MCDM is demonstrated using a flow diagram in Fig.1. The formula WPM is

\[ A_i^{\text{WPM-Score}} = \prod_{j=1}^{m} a_{ij}^{w_j}, \]

for \( i = 1,2,3,4,\ldots, m. \) \hfill (1)

The formula might give rise to a problem of INT overflow, as we are doing multiplication of powers of integers. The exception handling used here is adding logarithm of exponent to the original formula: The modified Weighted Sum Method (WSM) method.

\[ A_i^{\text{WPM-Score}} = \sum_{j=1}^{n} w_j \log(a_{ij}), \]

for \( i = 1,2,3,4,\ldots, n \) \hfill (2)

WPM yields the performance values of options and does the pointwise ranking

A. Defining objective

The main objective of the model is to determine the threshold in such a way the water level does not reach the null point. The option with highest performance value is fixed as threshold.

B. Defining Criteria

The criteria for MCDM of threshold are current water level, depletion to recharge ratio, radial distance between analyzing bore well and nearest bore well, rainfall rate, latitudinal difference of bore well location and nearby water body.
C. Fixing Weightage
The weightage of the criteria plays an important role in ranking of options. The weightage of the defined criteria are shown below:

| Sl. No | Criteria                                           | Weightage (no unit) |
|-------|----------------------------------------------------|---------------------|
| 1     | Current Water Level                                | 5                   |
| 2     | Depletion to Recharge Ratio                        | 4                   |
| 3     | Radial distance between analyzing bore well and nearest bore well | 3                   |
| 4     | Rainfall Rate                                      | 2                   |
| 5     | Latitudinal Difference of Bore well location and nearby water body | 1                   |

C. Listing options
The water levels of bore wells at a particular instance are listed as options. The formula for option listing is:

\[
\text{Option}_i = i\% \text{QBD} \quad (3)
\]

where \(0 \leq i \leq 100\)

QBD = Quarter Bore well Depth.

D. Ranking of option
The WPM formula is used to rank the options and the weightage is obtained by the weightage table. The ranking of all options are passed as an array. The array is sorted in ascending order and the first element of the array is passed as value to the variable threshold. The threshold is fixed for the instance until there is a change in WSM results. Whenever the water level drops below the threshold a notification is sent to the owner of the borewell with detailed statistics.
2. Experimental details
The hardware components used to get the field data are microcontroller, data logger, pressure transducer, GSM module and IoT module. The microcontroller used for data integration is Raspberry Pi4 Model B with 2GB RAM. The data logger is imported as a software module. 2SMPP-02 Pressure sensor [Calibrated-Underground, 25°C to 85°C, Voltage, 40KPa, Gauge, tube,100µA] is used as pressure transducer. SIM900A GSM GPRS Module with RS232 Interface and SMA Antenna. The IoT module is ESP8266 and is integrated with Ubidots Cloud Platform.

3. Results and Discussion

3.1. Implementation
The implementation involves lowering the circuit developed using pressure transducer tubes through the entire depth of the bore well. To demonstrate the working a calibrated groundwater model is built and the corresponding criteria are normalized. The water in the bore well is continuously monitored. The frequency of data logging is decided by the differential slope value of water levels. This evidently saves storage, and power. The transmitting range of Wi-Fi modules can be boosted using routers if necessary. The threshold is fixed based on the MCDM-HF CRITIC method. Whenever the water level in the bore well drops, an alert message is sent to the owner of the bore well.

Figure 2. Functional Block Diagram

Figure 3. Developed Prototype
The SMS contains the depletion to recharge ratio and time stamp of when the water level dropped. A unique URL is also sent to view detailed analysis and aquifer recharge technique recommendation.

**Figure 4. SMS Alert Screenshot**

**Figure 5. Recharge Technique Recommendation**

**Figure 6. Work Flow**
4. Conclusions
This project helps to use the groundwater optimally. It also helps to prevent the complete exhaustion of aquifers. The detection of threshold helps to understand the hydrological features of bore wells and the implementation of suggested aquifer recharge technique helps the owner of the bore well to have sustained access to groundwater. This paves way for sustainable groundwater optimization.

- Borewell's water level is monitored continuously, so complete exhaustion is prevented
- Depletion to recharge ratio is detected to predict the artificial recharge technique
- Threshold is fixed by MCDM techniques and an alert message is sent when the water level is low
- The data is stored in the cloud for further analytics

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