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RESEARCH ARTICLE

Plant health monitoring: Intelligent systems for environmental geoinformation

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Abstract

This study presents methods for gathering and preprocessing data from observation wells using automated measurement systems. It also incorporates fuzzy logic models for calculations, signal data processing and intelligent analysis of mapping materials. The study also involves the creation of groundwater level distribution maps based on the gathered data. Advanced measurement methods are being explored for experimental and computational applications, leading to the development of technical solutions based on mathematical models. These innovations are crucial for enhancing automated monitoring techniques in hydrogeological regions to predict groundwater levels and quality.

Keywords: automated measurement systems; electrical conductivity; groundwater; intelligent data analysis; observation wells; salinity; water levels; ultrasonic and radio wave sensors

Introduction

The global challenge of ensuring a sustainable supply of drinking water, efficiently utilizing groundwater resources and understanding the regional water exchange dynamics demands significant scientific and practical efforts. These goals can be better addressed through automated measurement technologies and advanced software systems in water monitoring programs. Special emphasis is placed on remotely monitoring groundwater conditions and parameters within observation wells and developing automated methods for this purpose.

In countries such as the USA, Canada, France, China, the Netherlands, Denmark, Japan and Russia, the development of algorithms and software to improve automated measurement systems for monitoring hydrogeological parameters has become a pressing issue (1). Globally, research is focused on creating automated methodologies, computational algorithms and software packages to evaluate drinking water resources, determine groundwater reserves and measure underground water parameters.

At present, several countries employ automated systems to measure groundwater parameters (2). These systems regularly monitor factors such as groundwater levels, temperature and mineralization at specific intervals. Observation wells are equipped with hydrogeological instruments like electronic level meters and automated data collection devices to measure water levels and gather relevant data (3). Automated groundwater monitoring focuses on systematically tracking changes in groundwater influenced by natural and anthropogenic factors, employing predictive models and automated methods to evaluate groundwater regimes and quality (4).

Groundwater characteristics can be classified into physical, chemical and biological indicators (5): Mineralization refers to the concentration of dissolved minerals in groundwater, expressed in mg/L or ppm.

- Hydroregime properties: water level, water slope, water volume, etc.

- Groundwater temperature regime: temperature variations, amplitude, heat flow, etc.

- Hydrochemical properties: salinity, salt concentration (specific ions), levels of organic, biogenic and contaminant substances.

The objective of this work is to enhance the monitoring of the underground hydrosphere through intelligent methods and to develop innovative hardware and software solutions that improve the efficiency of collecting, recording and transmitting aquifer data, utilizing renewable energy sources.

Materials and Methods

This research utilized methods of intelligent data analysis, digital signal processing theory and mathematical modeling to develop new hardware and software tools. These tools aim to increase the effectiveness of underground water data collection, transmission and processing. Techniques like digital filtering and spectral analysis were applied and cognitive assessments of solar radiation were used to evaluate system performance.

To improve the efficiency of hydrosphere monitoring, the labor-intensive manual measurement process must be replaced with automated sensor systems for data collection at hydrogeological stations. The automated measurement device developed by the authors at the State Institute "HYDROINGEO" features sensors for water level, air pressure, temperature and electrical conductivity measurements. The system calculates water thickness based on air and water pressure using an air-conducting cable, with specialized software determining groundwater level, temperature and mineralization (Fig. 1).

The accuracy and efficiency of groundwater level measurement can be further improved through the use of artificial intelligence techniques and telecommunication systems, including ultrasonic and radio wave sensors. A method using an ultrasonic ping sensor to detect water levels has been developed. The system consists of a transmitter and receiver module; the transmitter detects the water level and sends the data to the receiver, which displays the information (Fig. 2).

In this case, the main module of the automated measurement device at the wellhead comprises a low-power control microcontroller (STM8 F051), ultrasound and radio wave sensors, a GSM module, a power supply and a video camera. The microcontroller (STM8 F051) manages sensor input and data transmission, while ultrasonic and radio wave sensors provide precise level measurements. The GSM module ensures remote communication with control servers. The main module is responsible for processing, control, wave transmission and reception and remote data communication. The floating component, housed within the well, consists of ultrasound, radio wave, temperature and conductivity sensors, as well as a battery -powered energy source. This component is responsible for measuring seven different groundwater quality parameters (6, 7).

A central control system has been developed for receiving and sending data to workstations and central control servers. The device measures water levels with millimeter precision, while the integrated temperature sensor measures water temperature in °C. An electrical conductivity sensor determines the conductivity of groundwater (8-12).

Remote access to data from the automated measuring device is possible. Additionally, a system has been developed for downloading data from the device's memory to a computer using an RS-232 cable. By using the "Load" software package, users can navigate to the "Read Data" tab and press the "Search" button. The data will then be displayed in the program window and saved to the computer's memory in a text file format at the chosen location. Furthermore, the data can be viewed both in text and graphical formats (showing level, temperature and electrical conductivity) by selecting the corresponding file (Fig. 2).

During the study, data on the water level, temperature and electrical conductivity of groundwater were collected from observation wells using an automated measuring device at two-hour intervals (Fig. 2). The data obtained from the device includes the following elements:

- 64z: The identifier of the device installed in the well

- 08/12/2022 20:30: The date and time recorded by the sensor

- Level = 9.807 m: The water level in the observation well, relative to the ground

- Temp = 20.5 °C: The water temperature

- EC = 1236 µS/cm: The electrical conductivity of the water

- Uak = 3.7V: The power supply voltage of the device (9).

Monitoring the hydrogeological regime is crucial for understanding the elements and balance of groundwater systems, especially in addressing various national economic issues through modern information communication systems, which rely on the integrated device-software complex.

Stationary hydrogeological observations are essential for studying the elements and balance of groundwater regimes, providing both qualitative and quantitative insights into the processes that govern groundwater formation. These observations allow researchers to identify the spatial and temporal dynamics of groundwater quantity, quality and properties. This understanding is necessary to justify the most effective water management measures, design projects to mitigate harmful water effects and apply intelligent methods for monitoring groundwater regimes.

Studying groundwater regimes enables the determination of the following:

1. Relationships necessary for predicting natural or disturbed groundwater conditions and understanding how regime elements depend on natural and artificial factors (or their combination).
2. Individual elements of the water balance, which are used to support water management activities, hydrogeological assessments and water balance calculations.
3. The nature and extent of human engineering impacts on groundwater systems, including changes in their regime and the rationale for using the most effective methods for managing, economically utilizing and protecting groundwater resources (10, 13).

In general, for a flow element with area S, the groundwater balance over a time interval ΔT is expressed by the following equation.

where µ represents the capacity for water supply, water loss, or the unsaturation of rocks; Q_1 and Q_2 indicate the inflow and outflow of groundwater within the flow element, respectively; W denotes the rate of infiltration recharge to the layer from precipitation and irrigation; and W_chuq refers to the deep flow of water from the underlying pressure horizon to the aquifer.

$$\mu \Delta H = \frac{Q_1 - Q_2}{S} \quad \Delta T + W \Delta T + W_{chuq} \Delta T \qquad (1)$$

Results and Discussion

The core of this method lies in determining all elements of the water balance Q_1, Q_2 and ΔT included in equation (1) based on information regarding the water level status in the wells that separate the flow elements. The methodology for employing this expression (1) to identify individual components of the water

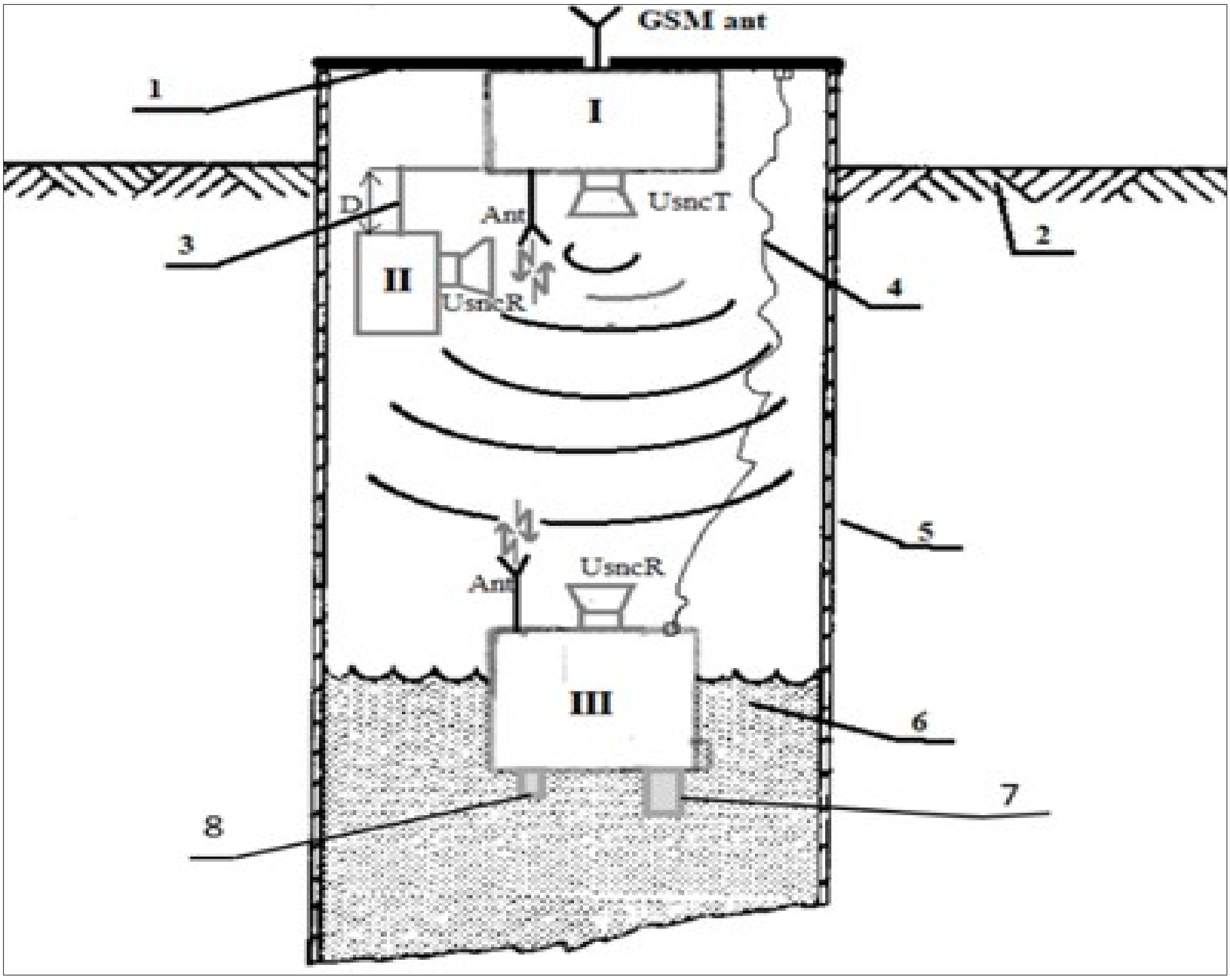

Fig. 1. Installation layout of the automated measurement system in the monitoring well.

The figure shows the following components: I - Transmitter module with ultrasonic sensor, radio wave receiver and GSM module, II - Receiver module with ultrasonic sensor, III - Receiver module with ultrasonic sensor and reflecting radio wave sensors ,1 - Well cover, 2 - Ground level 3,4 - Water-resistant ropes securing the sensor housing, 5 - Pipe structure, 6 - Groundwater, 7 - Electrical conductivity sensor, 8 - Indicator

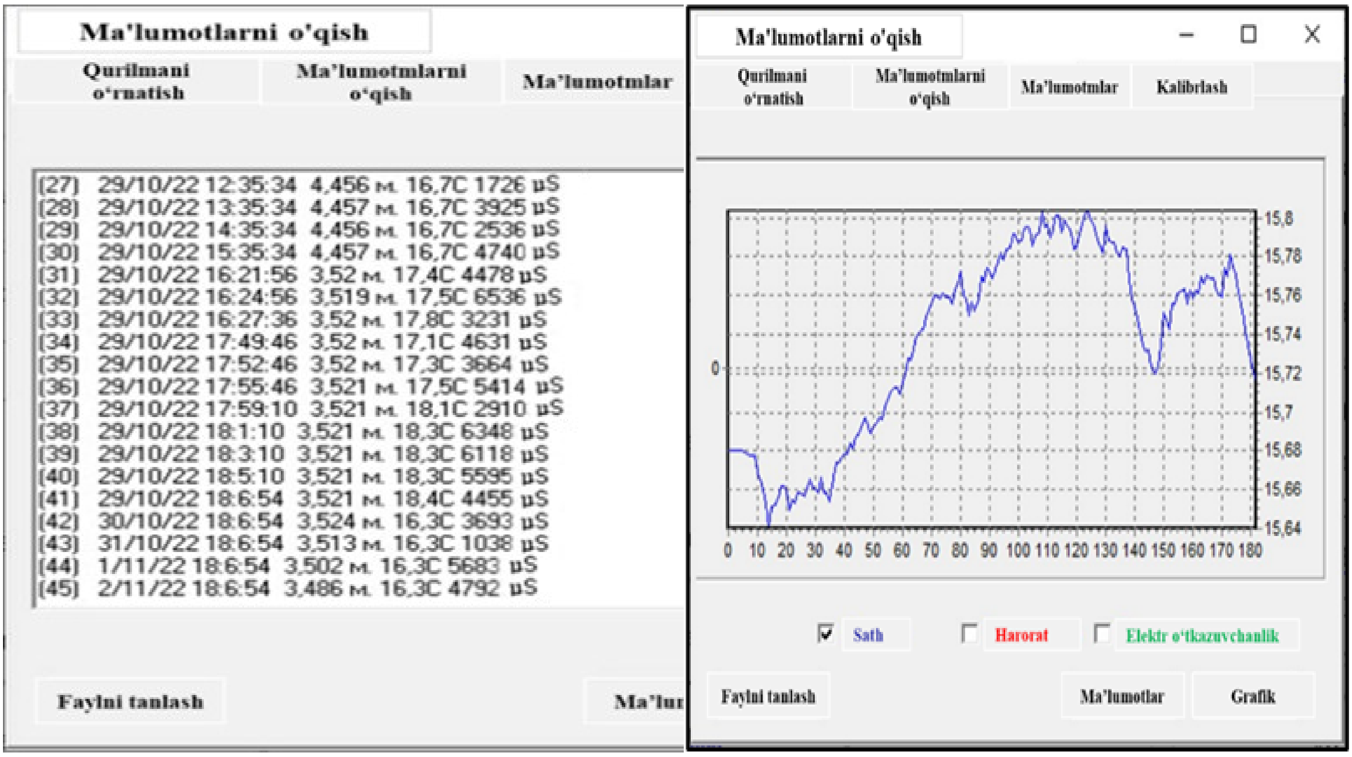

Fig. 2. Presentation of data obtained from an automated measuring device in graphic form.

balance and to analyze the balance on an annual basis is thoroughly detailed in the course "Groundwater Dynamics" and in specialized manuals (10, 14).

The combined installation of both types of lysimeters-those with constant and variable water levels-alongside a monitoring well allows for the measurement of changes in water level ΔH and the calculation of water loss and rock saturation using the formula m. This setup also enables the assessment of a crucial parameter related to deficiency (11, 15).

$$\mu = \frac{\Delta T}{\Delta H}\left(\frac{Q_1 - Q_2}{S} + W\right) \qquad (2)$$

The coefficients of relative positions, denoted as λ_h, characterize the extent of deviation of water levels from their long-term average values DL and are expressed as a percentage or fraction of the long-term amplitude A.

This mapping method for groundwater level regimes helps to address challenges related to the considerable variability in the filtration characteristics of the aeration zone and the lithological properties of the aquifer rocks, as well as the diversity in the area's geomorphology. The coefficient of the relative position of the water level is calculated using the following formula: λ_h.

$$\lambda_h = {(h_{max} - h_p)}/{(h_{max} - h_{min})} \qquad (3)$$

Accordingly, the calculated depth to the groundwater level is determined by the expression h_p(in meters from the surface of the earth)

In formulas (3) and (4), h_{max} and h_{min} refer to the maximum and minimum depths of the groundwater level throughout the entire observation period (in some cases, the 1 % and 99 % probability depths are used instead of h_{max} and h_{min}. This allows for the extension of forecast results obtained from a representative observation point over considerable distances

$$h_p = h_{max} - \lambda_h(h_{max} - h_{min}) = h_{max} - \lambda_h A \qquad (4)$$

during oscillation synchronization. Additional insights can be gathered from the accompanying map that shows the distribution of actual water levels from the previous year, represented in relative terms. The presence of both maps enables a more precise indication of the levels and the direction of predicted changes in water levels over the long term (10, 13).

The forecast level distribution map facilitates rapid decision-making regarding the planning and execution of various water management activities and can be utilized to address any hydrogeological issues. When determining hydrogeological parameters, information about fluctuations in water levels along coastal areas (during periods of rising or falling levels) is particularly relevant, as it describes how influencing factors affect their behavior.

In monitoring wells 1 and 2, located along the planned stream in the area, if changes in levels ΔH_1 and ΔH_2 are recorded at time t alongside the rate of change in the boundary piezometer, the relationship between these measurements can be expressed as follows:

$$\Delta H(x,t) = \Delta H_0(x,t) * R(\lambda)$$

describes the change of water level in rocks. Taking into account the level change in the piezometer at the border points, we get the ratio in the wells, which is equal to $\Delta H(x,t)/\Delta H_0(x,t) = R(\lambda)$ in the observation well piezometer. $R(\lambda)$ where - $\lambda^2 = x^2/4at$ is a spec-ial function determined from special tables with the value of the argument. a - conductivity coefficient can be calculated by the formula $a = x^2/4\lambda^2 t$ (piezo conductivity). According to the observation data of the stationary mode of groundwater (W=O) between the boundaries (rivers, canals, drains) of the resistance of the water bed in the studied area, when assessing the wells laid on the highway along the plane, normal to the edge of the water basin determination of the length ΔL is determined by the formula based on the condition of constant flow rate in the section of observation wells:

$$\Delta L = \frac{h_1 - h_0}{h_2 - h_1}(l_2 - l_1) \qquad (5)$$

The value of the infiltration source W or the parameter W/K can be determined from the information on the state of the level in three observation wells (for example, from the expression under the condition W = const)

$$\frac{W}{K} = \frac{h_2^2 - h_1^2}{l_3 - l_2} + \frac{h_1^2 - h_3^2}{(l_3 - l_2)l_2}$$

The unique aspects of hydrosphere monitoring in observation wells and the enhancement of information and technical support for automated measurement systems focus on tracking groundwater levels and overall mineralization. This approach facilitates continuous measurements, reduces the need for national hydroregime assessments, increases the reliability of information and enhances the efficiency and productivity of ongoing hydrogeological activities. It also enables the determination of total mineralization of groundwater through electrical conductivity measurements, leading to cost savings and real-time monitoring through a network of wireless sensors. This setup allows for continuous measurement of hydrometric properties over time.

Additionally, the device's intelligent algorithms include an online management system, which allows for data transmission at various time intervals. The automated measuring device for groundwater levels can be used to create a distribution map of aquifer levels, aiding in quick decision-making for water usage planning and implementation. This device also supports the calculation of key elements of water balance and monitors underground water regimes, as well as precipitation. It helps estimate infiltration, the amount of irrigation water reaching the groundwater level, total evaporation and underground flow, along with the necessary hydrogeological indicators (16).

Conclusion

To enhance the monitoring of underground waters in the hydrosphere, a scientific and methodological foundation for a geoinformation device designed to measure groundwater levels, temperature and electrical conductivity was established, along with data analysis and evaluation. This approach facilitates continuous measurements in observation wells, reduces the frequency of traditional measurements and improves the efficiency and productivity of ongoing hydrogeological activities. It also enables the determination of chemical indicators of groundwater, including general mineralization, salinity (PPT) and the concentration of dissolved solids (TDS, PPM) in total water. As a result, these advancements allow for the rapid adoption and implementation of measures to mitigate negative impacts on groundwater and support necessary organizational, technical and management decisions. The developed device and methodology can be directly applied in water management planning, enabling authorities to respond quickly to groundwater level changes and ensure sustainable resource use.

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Authors' contributions

JD conceptualized the study, conducted data analysis and drafted the manuscript. EA contributed to the study design, data collection and manuscript revision. AB assisted with data interpretation and statistical analysis. JA and IT provided critical feedback on the manuscript and contributed to the final revisions. All authors read and approved of the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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