IoT-based Multimodal Borewell Monitoring

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Abstract. Excessive groundwater extraction has led to a significant decline in water tables, highlighting the need for continuous monitoring. This study presents an Internet of Things (IoT)-based approach for real-time estimation of groundwater levels in borewells. In addition to water level measurements, parameters such as motor current and rainfall are tracked to evaluate their influence on groundwater dynamics. To assess practical feasibility, five monitoring nodes were deployed across a small educational campus in Hyderabad, India. Data collected over a two-month period indicate that the proposed low-cost system is both reliable and effective in real-world conditions, while also revealing interesting correlations between groundwater level variations and the monitored parameters.

1 Introduction

Groundwater constitutes a vital source of freshwater, particularly in regions where surface water availability is limited or unreliable. In countries like India, where significant spatial and temporal variability in rainfall exists, groundwater extracted through borewells serves as a critical lifeline for both domestic and agricultural needs [1, 2]. The widespread dependence on borewells has grown substantially over the past few decades, largely due to their ability to provide decentralised access to water in areas beyond the reach of piped or surface water infrastructure. Given this dependency, the systematic monitoring and management of borewell usage has become crucial. Continuous data collection regarding borewell performance, water table levels, and patterns of extraction is essential to safeguard these underground resources from depletion. Overexploitation without appropriate regulation has already led to falling groundwater tables in several regions, rendering numerous borewells dry and non-functional
[3].

Traditional field methods for measuring groundwater levels—such as graduated measuring tapes and manual well sounders—remain popular because they are inexpensive and straightforward; however, these approaches are inherently labour-intensive, vulnerable to operator error, and poorly suited to long-term deployments that demand high sampling frequency or large spatial coverage [4]. Recent studies emphasise that the prevailing spatiotemporal resolution of groundwater data in India is not enough for capturing rapid drawdown events and seasonal recharge pulses. Hourly to sub-hourly observations obtained

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from autonomous Internet-of-Things (IoT) nodes can fill this gap, yielding insights that periodic manual measurements can't provide [5]. Nevertheless, the global literature on low-cost, opensource IoT solutions for groundwater monitoring remains relatively thin, and most existing prototypes address only a subset of hydro-physical variables or are demonstrated at limited scales [6–10].

Espinoza et al. developed an economical real-time system that measures piezometric depth and temperature while simultaneously logging barometric pressure to enable accurate head correction [6]. Chan et al. proposed two Arduino-based designs that contrast a differential-pressure approach against a single absolute-pressure sensor, thereby illustrating cost–accuracy trade-offs for small community installations [7]. Calderwood et al. showed how multiple pressure-sensor nodes can be networked to form a distributed observatory capable of on-board data processing and local fault detection [8]. Complementing these efforts, Kombo et al. demonstrated that long-range, low-power wide-area networking (LoRaWAN) can reliably relay water-level data from remote boreholes to cloud servers, a feature crucial for regions lacking cellular connectivity [9]. Finally, Tanmay et al. introduced a novel string tension mechanism tailored for borewell shafts, enabling continuous depth tracking without submerging electronic components [10].

Most existing groundwater level monitoring solutions [6–9] rely on pressure sensors, which present several limitations [11]. These sensors operate within a fixed pressure range and must be calibrated according to expected water level variations. They are prone to issues such as drift, hysteresis, and temperature sensitivity, requiring regular calibration and correction. Prolonged exposure to water can also lead to material degradation or failure due to chemical reactions. Additionally, many of these systems do not incorporate complementary parameters like motor usage or rainfall, which are essential for a more holistic understanding of borewell dynamics.

This paper extends the work in [10] by using the data collected using these devices in borewells in the IIIT Hyderabad campus. The major contributions of this paper are • The IoT-enabled borewell water level monitoring system presented in [10] was specifically redesigned for extraction borewells. Five such devices were deployed across the IIIT Hyderabad campus, India, and operated over a two-month period.

- Complementary IoT-based current sensing modules were installed on the motors responsible for groundwater extraction. These enabled the monitoring of motor activity, providing insights into water pumping patterns and usage behaviour.
- To assess natural recharge, an IoT-based rain gauge was also developed and installed on campus to record local precipitation levels.
- The collected data was analysed in conjunction with the site's topographical contours, allowing inferences to be drawn regarding the spatial and temporal variations observed in water levels and motor activity.
- The relationship between variables like water depth, precipitation, terrain and motor current was explored to determine correlated variables.

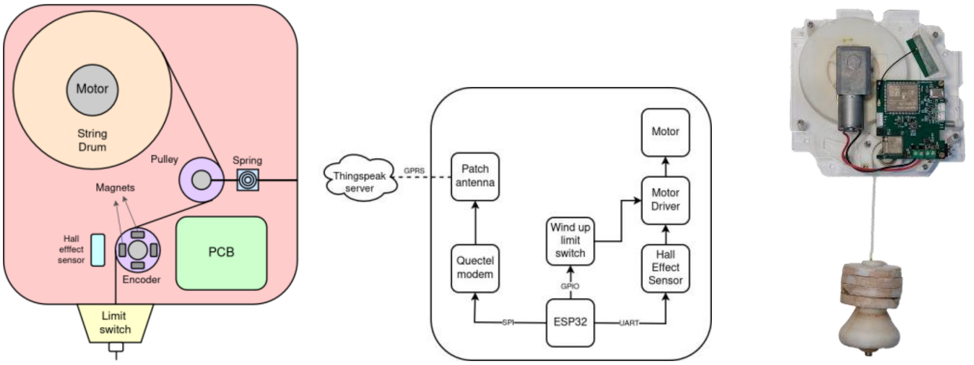
The proposed IoT-based approach streamlines the process of trend analysis of water consumption by eliminating the need for specialised equipment, manual labour, and significant time investments traditionally required to monitor these vital parameters.

The structure of the paper is as follows: Section II contains the hardware overview of the device. It is followed by an explanation of the data collection and processing in Section III. The results are discussed in Section IV. Section V concludes the paper and delves into the future directions of this work.

2 Hardware Overview

2.1 Water Level Device

The device uses a floating bob suspended in the borewell pipe by virtue of a nylon thread. The bob is lowered using a JGY-370 12V geared DC motor. Fig. 1b shows the high-level block diagram of a node. The custom PCB consists of an ESP32 WROOM microcontroller, a DRV8231ADSGR H-bridge motor driver for controlling the DC motor, a DRV5033AJQLPGM Hall effect sensor for counting magnetic pulses and a Quectel UC200 RF transceiver module, which establishes GPRS connectivity via a 2G/3G cellular network to push data to a cloud-based server on *ThingSpeak*[12]. In addition to these major components, the PCB consists of additional circuitry such as resistors, capacitors, and voltage regulators to ensure the proper functioning of these parts. The device is powered using a 12V, 3A power supply. The specifications of the device components are listed in Table 1.



(a) Schematic diagram (b) Block diagram (c) Assembled node

Fig1. Schematic diagram, block diagram, and assembled borewell node.

Fig. 1a shows the schematic diagram of the device. The string drum is attached to the motor, and it turns based on whether the bob needs to be lowered down or pulled up. The string then passes through a pulley connected to a spring, which keeps the string in tension. Ultimately, the string passes through a rotary encoder, which has 4 tiny magnets embedded on the circumference. When this encoder makes 1 complete revolution, the hall effect sensor picks up 4 individual pulses due to the change in magnetic flux. These pulses are used to measure the length of the string, which is being lowered or pulled, thus giving us the distance as

$$distance = \frac{\pi N_{pulses} D_{pulley}}{4}, \qquad (1)$$

where N_{pulses} are the total number of pulses recorded in a reading and D_{pulley} is the diameter of the pulley, which is 29 mm in this case. Fig. 1c shows an actual assembled node.

2.2 Secondary Devices

A DFRobot ‘Gravity: tipping bucket rainfall sensor’ rain gauge was installed [13]. It is a tipping bucket style rain gauge of size 118 mm ×59 mm ×80 mm, which gives a reading of

Table 1: Component specifications

JGY-370 DC Motor	
Rated voltage	12 V
Load speed	128 rpm
Load current	180 mA
Load torque	0.55 kg.cm
Stall torque	2.22 kg.cm
Stall current	1 A
Ratio	37.3

DRV8231ADSGR Motor driver	
Supply voltage	4.5-33 V
Output voltage	0.7-35.7 V
Operating current	3 mA
Output current	3.7 A

DRV5033AJQLPGM Hall effect sensor	
Supply voltage	2.5-38 V
Output voltage	0-38 V
Output current	0-30 mA

resolution 0.28 mm. The operating range of the sensor is 3.3-5 V. It is connected to an ESP32 microcontroller, which polls the rain gauge every 2 minutes and sends the rainfall data in mm via a SIM800L GSM module.

A YHDC SCT-013-000 CT current sensor [14] monitors the motors that pump water from the stepwells. The sensor is interfaced with an ESP32 microcontroller, which sends the motor on/off status with the help of the SIM800L GSM module every 10 minutes. The active duration of motor pumping is tracked using these current sensors. The sensor is rated for 100 A RMS, 120 A peak-to-peak input and converts it to a 50 mA output, with a turn ratio of 1:2000.

3 Data Collection and Processing

Five nodes were deployed in the IIIT Hyderabad campus at locations shown in Fig. 2. Three of these nodes, *A, B and C*, are in extraction borewells where there are motors present for pumping the water. The remaining two, *D and E*, are in injection borewells without motors to study the interaction of these with surrounding extraction borewells. The nodes take readings every 15 minutes. The devices send raw data to the ThingSpeak server, which needs to be processed before inferences are obtained.

3.1 De-trending the data

When a node is deployed in an extraction borewell, the bob cannot be pulled up to the reset position each time since it can get tangled with the pipe which is being used for pumping water. So, in order to get readings, the bob is allowed to reach the water level, the distance is recorded, and then the bob is pulled up by a fixed distance of 2 meters. This ensures that while the device is sleeping for the 15-minute interval, the bob remains suspended and the string remains in tension. This fixed distance was decided based on the collected data, where the water level does not rise as drastically as 2 meters in 15 minutes. Doing this means that in each reading, this fixed amount of 2 meters gets added as an overhead, which causes an increasing trend to develop in the data being sent to ThingSpeak. This trend is removed by subtracting 2 meters cumulatively from the data to get the original water level readings.

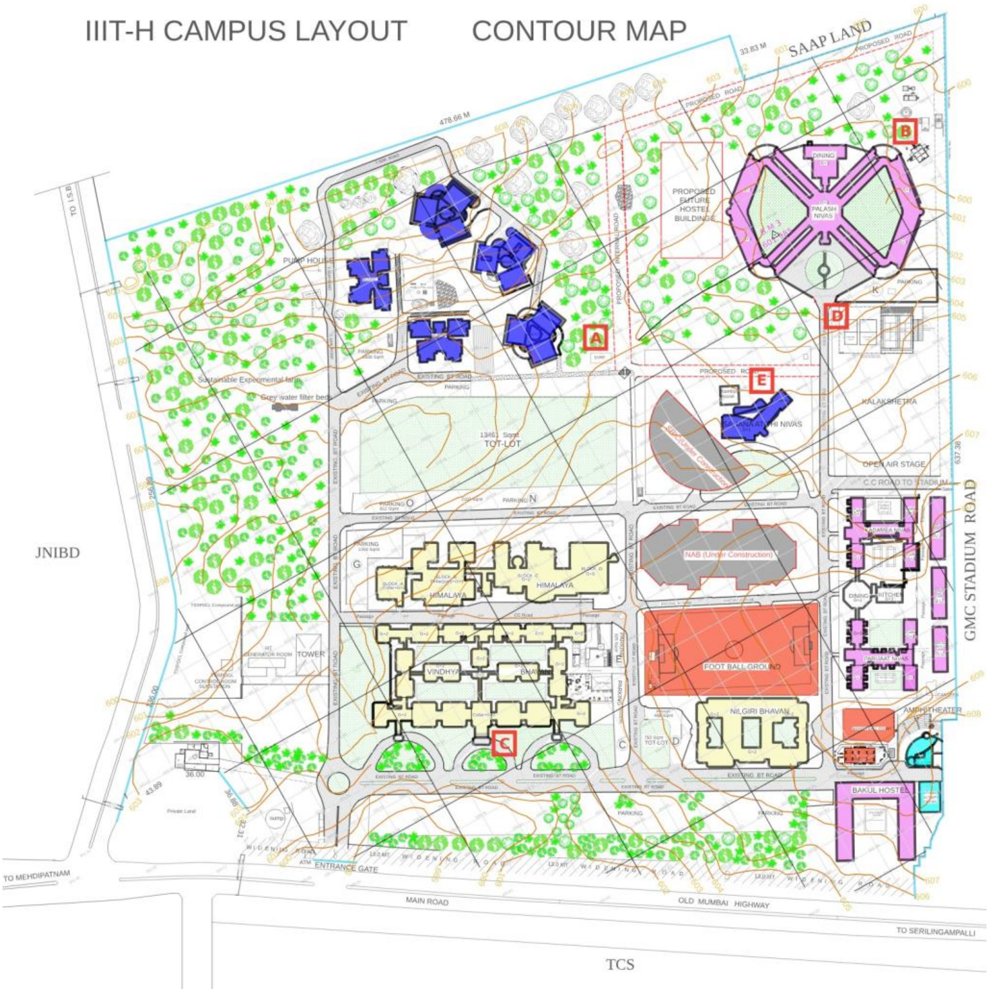
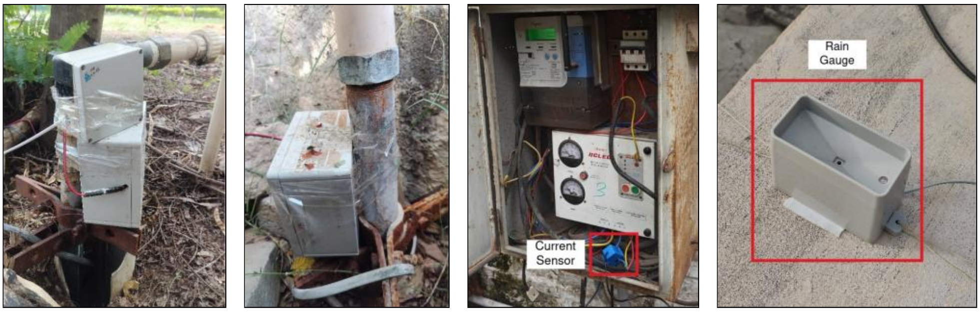


Fig. 2. Deployment map with campus contours



(a) Borewell A (b) Borewell B (c) Current sensor (d) Rain gauge

Fig. 3. Device deployment

3.2 Data smoothening

The raw data from ThingSpeak is processed to smooth it and remove outliers, which might be generated due to device malfunctions. Since we are working with hydrological time series data, a windowed median approach is taken to remove outliers and smooth the data[15]. The window size for borewells A and B is 5, 7 for borewells C and D and 3 for borewell E. The window sizes were determined based on the nature of the data via the trial-and-error method.

3.3 Rain data resampling and thresholding

The rain data, which is being collected every 2 minutes, was resampled to an hourly frequency by cumulatively adding the readings collected over one hour. This was done to get a realistic sense of rainfall. Moreover, these hourly readings were thresholded with the threshold being 2 mm of rain. Only readings greater than this would be considered as a legitimate precipitation event. This ensures that false positives which may have been registered are removed.

3.4 Calculating water table

The readings returned by the devices are with respect to the ground level at that point. This may not provide the complete picture to perform a comparative study; hence, the altitudes of the geographical locations of these borewells are also taken into account. Fig. 3 shows the contours and the elevation of the deployment locations with respect to the mean sea level. *A* is at 603.71 m, *B* is 599 m, *C* is 601.35 m, *D* is 601.55 m and *E* is at 603.74 m.

4 Results

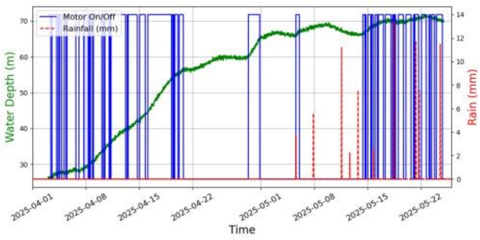
4.1 Water level vs topology

4.1.1 Extraction borewells

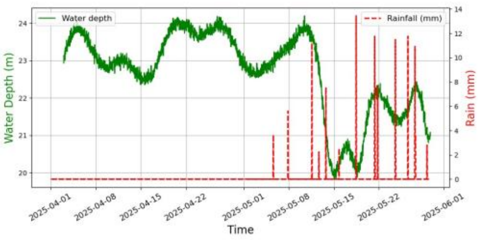
The extraction borewells on campus, namely borewells A, B and C, act as the primary sources of groundwater. The plots in Fig. 4a-4c shows the water depth trends in these borewells. It can be observed that the duration for which the motor is on shows a rise in the water depth, meaning a decrease in the water level. When the motor is turned off, the level recuperates back, which is characterised by a fall in the depth. The red dashed line depicts the rainfall in mm.

Seeing the trend in borewell A from Fig. 4a, it shows an increase in the water depth in the month of April, due to the absence of rainfall and excessive pumping owing to the water shortage in the municipal water throughout the city of Hyderabad. The noteworthy observation comes in the month of May when there were rains due to pre-monsoon setting in but the borewell still shows an increasing trend in water depth, which suggests that the aquifer which is connected to this particular borewell is likely to be a deep, isolated one which is not being recharged by the shallow aquifer which gets recharged by surface runoff and rains. This can be attributed to the borewell lying on a ridge point, according to Fig. 2, meaning the water naturally tends to flow away from this point. Moreover, it is likely that a rocky layer separates this deep aquifer from the shallow aquifer.

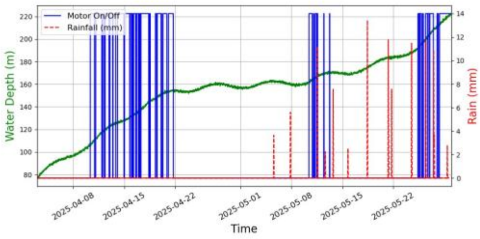
The trend in borewell B also follows a similar increasing trend in Fig. 4b, as was seen with borewell A in the month of April. This borewell has a lower depth compared to borewell A, which can be attributed to its lower geographical altitude, as can be observed from the contours in Fig. 2. This can imply the possibility that the water from the surrounding high lying areas flows towards this natural low point, which in turn recharges the aquifer connected to this borewell, thus resulting in a lower depth at which water is found. Upon the setting in of pre-monsoon in May, we observe a plateauing of the depth even though the pumping continues at the same rate, which hints towards a substantial recharge of the underground aquifer from the shallow aquifer. The contour lines also suggest that the surface runoff from the surrounding areas is likely to collect near this borewell, which further leads to better incorporation into the shallow aquifer at this location and, in turn, the deeper aquifer.



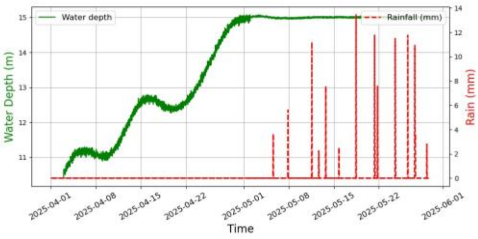
(a) Borewell A data



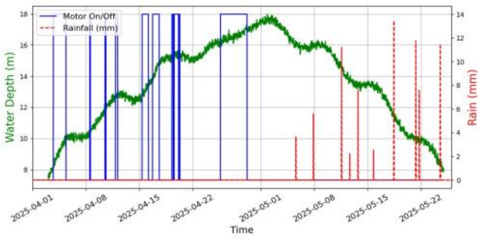
(d) Borewell D data



(b) Borewell B data



(e) Borewell E data



(c) Borewell C data

Fig. 4. Data from extraction and injection borewells: (1) Extraction borewells – Borewells A, B, and C (2) Injection borewells – Borewells D and E.

The trend in borewell C in Fig. 4c, again, shows an increasing trend during the month of April. A noteworthy observation here is the considerably low depth at which water is found in this borewell, as compared to the other two extraction borewells. This is due to the fact that there are multiple injection borewells and rainwater recharge pits in the vicinity of this borewell, which have led to a very healthy aquifer having a higher water level throughout the year. This borewell also recharges rapidly upon the onset of pre-monsoon and quickly reaches the pre-summer depth, once again possibly owing to very efficient recharge due to the rainwater harvesting efforts done in the vicinity.

4.1.2 Injection borewells

The injection borewells on campus, namely borewells in D and E, have the primary purpose of recharging the underground aquifers. These were also monitored during this study to see the behaviour of the water level without the effect of pumping. The results are shown in Fig. 4d and 4e

From the trend in borewell D as seen in Fig. 4d, the water level fluctuates slightly but isn't affected significantly during the summer months. With the onset of pre-monsoon, a clear decline is seen in the water depth, indicating that the surface runoff is likely to collect near this point and feed into the injection borewell. This observation is again consistent with the borewell lying in a relatively lower region in comparison to the surroundings, as can be verified from the contours in Fig. 2. The underground shallow aquifer is likely to follow these natural contours, hence resulting in prominently visible fluctuations in water depth due to rainfall at this location.

Borewell E in Fig. 4e shows an increasing trend in water depth, as was observed in the case of extraction borewells in an earlier section, even though this borewell is not being pumped. Moreover, this borewell dried up at around 15 m of depth and wasn't revived even after the onset of pre-monsoon. This observation could likely be explained by the presence of 3 new extraction borewells in the vicinity to facilitate water supply for construction activities demarcated by shaded grey regions in Fig. 2. It is possible that these new borewells and this injection borewell are connected to the same underground aquifer, and the excessive pumping, coupled with the inadequate recharge, has led to an increase in water depth and the subsequent drying up of this borewell.[1]

4.2 Water level vs precipitation

In order to quantify the relationship between rain and changes in the water depth, Pearson correlation was calculated between these two time series with varying delays in order to model the time it takes for the water to percolate and recharge the underground aquifer. The plots are shown in Fig. 5. The correlation was calculated after taking a 12-hour rolling mean of both the data frames in order to remove instantaneous fluctuations while preserving the underlying trend. It is observed from the plots of Borewells A and B that deep borewells do not show a significant positive correlation. This is attributed to the depth of the borewells increasing monotonically even after rainfall, whereas ideally, if the borewells were recharging, the correlation coefficient should have been negative. This could mean that deep borewells like borewells A and B, which do not have any rainwater channels feeding into them, are not strongly affected by rain.

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[1] Hydrological tests conducted over multiple seasonal cycles and long-term data are required to make conclusive statements about borewell quality. The geology estimation aims to illustrate how the water level device can aid the process.

From the plots of Borewells C and D, a strong negative correlation is observed. This means that both of these borewells recharge with rain. Borewell C, which is an extraction borewell, has multiple rainwater harvesting efforts implemented around it, which are likely playing a role in the borewell showing a negative correlation. Moreover, the correlation is most negative with a delay of four days, implying that it takes about four days for the surface water to percolate and reflect as a change in the water depth in the borewell. Borewell D, which is an injection borewell, is more likely to be connected to a shallow aquifer and reflects the changes in this aquifer. This can also be the reason why the most negative correlation in this case is seen at a delay of one day, as the shallow aquifer quickly recharges with surface rainfall.

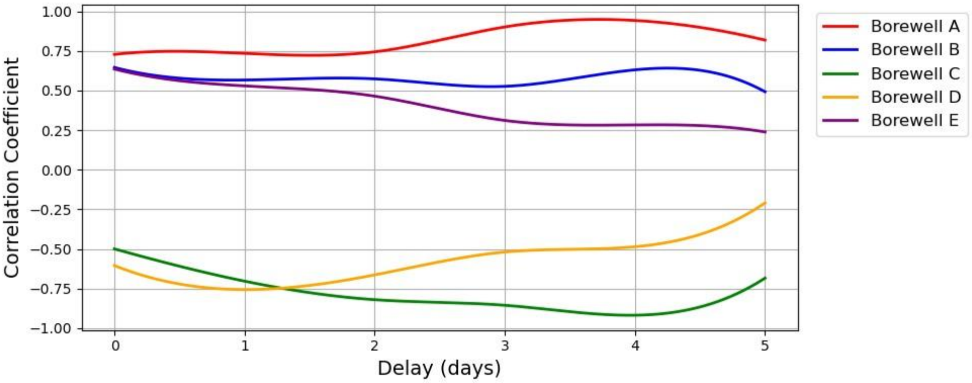

Fig.5. Correlation of water level with rain data

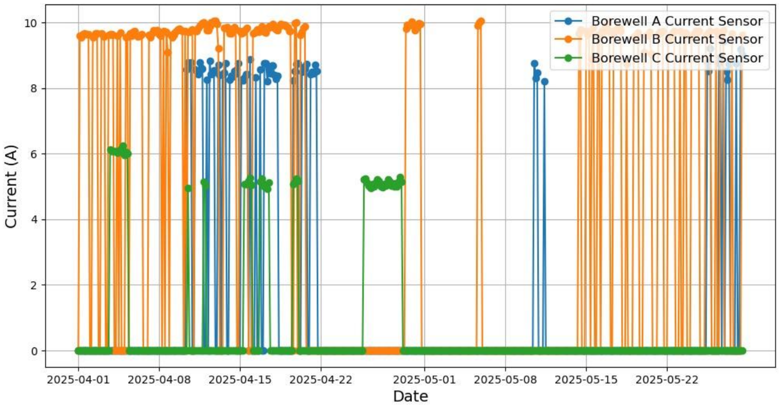

Fig.6. Motor current data

The purple plot in Fig. 5 shows the correlation of injection borewell E. This borewell had become dry around the onset of pre-monsoon, and hence it should not show any correlation with rainfall, which is what we are observing here with the trend approaching 0 from the positive end. The initial positive correlation might have been caused due to the increasing depth during the summer months.

4.3 Water level vs motor current

The motor current for the extraction borewells A, B and C was also tracked. The results are plotted in Fig. 6. It is observed that the motor current is not significantly affected by the water depth. Instead, the current consumed is dependent on the rating of the motor itself, which is 6 HP, 7.5 HP and 5 HP for borewells A, B and C, respectively. Some fluctuations are observed in the current consumption but these are within the operating parameters of the motors.

5 Conclusion

This work demonstrates the potential application of IoT technologies to monitor and evaluate natural resources. Several IoT devices were deployed across five borewells to monitor the water level, motor pump usage, and rainfall. The data shows tangible observations which are in line with the geographical characteristics of the environment. Such devices can help provide insights and early warnings about changes in underground geology, as was seen in the case of borewells A and E, so that appropriate measures can be taken to safeguard these crucial resources before long-term damage. In addition to this, long-term data acquisition could potentially help clearly demarcate aquifer connectivity, which is very crucial information for planned water usage.

Another important caveat is the difference that rainwater harvesting interventions make in the overall health and recharge capacity of borewells. Such data can bring about awareness and encourage people to engage in such simple but effective techniques, which return water to the ground and aim for a net-zero where the amount of water being pumped is equal to the amount of water being returned to the underground aquifers. Future work could explore longterm trends in groundwater systems over multiple seasons. The IoT-enabled monitoring system demonstrated in this paper represents a critical step towards more informed, data-driven approaches to water resource management, environmental conservation and sustainability.

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