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Abstract: Majority of farmers in India are irrigating their crops without using any irrigation scheduling criteria. Consequently, the application of excess irrigation water causes water logging, wastage of precious water resources, plant diseases, soil salinity as well as the lack of water results into crop water stress. In the present research work an automated Wireless Gypsum Block Sensor Network System (WSN) was developed to automate irrigation scheduling. The developed gypsum blocks sensors were interlinked with Global System for Mobile (GSM) Module with a microcontroller unit. The sensor performed well in the range of 10–19% volumetric moisture content. These sensors were reliable in the range of 30–90 kPa. The sensors highly correlated with coefficient of determination $R^2 = 0.93$ with slope 0.13 and small relative root mean square error (RRMSE) for given soil moisture potential at depth of 30–45 cm. The microcontroller starts the pump when soil moisture content reaches below the field capacity (FC) and stops when field reaches at FC of a given threshold rage 15–18. The field information is received by the user through mobile via transmitters and receiver using text messages. The system saves the water an average up to 7%.

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PUBLIC INTEREST STATEMENT

Water plays an important role in agriculture production system. Excess water for plant causes diseases as well as water logging and water scarcity causes stress to plant resulting in reduction yield. The irrigation scheduling is an old practice to save water however, using sensor to automate irrigation scheduling will not only enhance water use efficiency and power saving but also provide enough time for farmers to do another activity. The gypsum block wireless sensor network (WSN) also called as wireless sensor and automated network (WSAN) are spatially distributed with application of software and hardware technologies. These sensors monitors’ physical or environmental conditions such as rainfall, temperature, pressure, moisture content and vibrations etc. and passes the data to user with network. The developed system is cheaper, highly efficient in, water saving and low power consuming. The present research work opens up new vistas and revolution in on-farming and off-farming agriculture water management technologies on Indian farms.
1. Introduction
Good agricultural practices must include both the knowledge of water used by crop and techniques that permit an efficient irrigation management (Khan, Ali, Suryani, Ahmad, & Zakarya, 2013). The judicious application of irrigation water is one way to reduce water consumption and improve water use efficiency. The Wireless Sensor Network System (WSN) serves as backbone in modern precision agriculture and it is used for real-time automatic irrigation in fields for delivering precise and accurate amount of water for crop at each stage of its growing period (Romero, Muriel, García, & Muñoz de la Peña, 2012; Sakthipriya, 2014; Willig & Karl, 2005). It may also be used for sensing different parameters such as temperature, air relative humidity, leaf wetness, wind directions, water logging condition and real-time information about field and environmental conditions (Jimenez, Jimenez, Lozada, & Jiménez, 2012). With these information the users can adjust their strategies at any time so as to achieve the desired objective for efficient management of all agricultural inputs like water and fertilizers etc. (Abbasi, Islam, & Shaikh, 2014).

At present, several types of sensors are used for continuous monitoring of real-time soil moisture content (SMC) data for irrigation and for the prediction of hypothetical conditions about environment (Baggio, 2005). Wireless sensor techniques can be classified into the following categories based on their functional requirements such as tensiometer, resistance blocks, frequency domain reflectrometers (FDR), time domain reflectrometers (TDR), neutron moisture probe technology and remote sensing etc. (Kim, Evans, & Iversen, 2008; Pastuszka, Krzyszczak, Sławiński, & Lamorski, 2014). Some of these techniques are not much environmental friendly and affordable for the user for enhancing crop yields (Dursun & Ozden, 2011). The available techniques such as the tensiometer, resistance block and FDR sensor are most commonly used for automation of irrigation system and precise utilization of water (Dobriyol, Oureshi, Badola, & Hussain, 2012; Dukes, Zotarelli, & Morgan, 2010; Leib, Hattendorf, Elliott, & Matthews, 2002; Leib, Jabro, & Matthews, 2003; McCann & Starr, 2007; McCready, Dukes, & Miller, 2009). Resistance block sensors can either be used for spot measurements of moisture content automatically using a hand-held reader or data logger. These two techniques are widely available due to their low cost, ease of installation and durability (i.e., they can be used for many decades subjected to many calibration efforts and field studies) (Cardenas-Laihacar & Dukes, 2010; Chow et al., 2009; Fisher, 2007; McCann & Starr, 2007; Shock, Barnum, & Sedigh, 1998; Thompson, Gallardo, Agüera, Valdez, & Fernández, 2006). These sensors require a user to read the measured value in the field, labor, and daily monitoring of the field condition. To overcome these problems digital data logger are used by the researchers through wireless sensor network similar in configuration to Sakthipriya (2014).

However, very few researchers have made concerted and sincere efforts to develop a low cost automatic wireless sensor system in the areas of root zone soil moisture content. There are only few irrigation automation sensors available but they are expensive and limitations too; like difficult installation and operation etc. (Nolz, Kammerer, & Cepuder, 2013). Calibration and validation of indirect measurement with gravitational method pose another serious problem and is the main bottleneck in widespread use of these devices as the soil moisture characteristics vary from soil to soil due to their aggregates. Some statistical parameters were used by a few workers to compare the calibrated sensors and gravimetric method (GM) using mean difference (MD) (Addiscott & Whitmore, 1987) and the relative root mean square error (RRMSE) (Loague & Green, 1991) in the past. The results from the statistical analysis were used to evaluate the degree of coincidence of the readings given by developed sensors with that obtained by gravimetric method. An MD value equal to zero
denotes no difference between such measurements. A smaller RRMSE indicates better performance. Paired t-test was performed to check the statistical significance between developed gypsum block sensor and tensiometers (Jabro, Leib, & Jabro, 2005; Leib et al., 2003).

The present study was carried out to overcome the problems in available irrigation automation systems, mainly with two objectives: (1) To select the gypsum block sensors as soil moisture indicator for irrigation automation and; (2) To develop a real time soil moisture monitoring for irrigation scheduling for selected crops and data transmission using Global System for Mobile (GSM) module.

2. Materials and methods
The present study was conducted at ICAR-Indian Agricultural Research Institute, New Delhi. The field experiments were conducted at the experimental farm of the Water Technology Centre (WTC), IARI, New Delhi (latitude 28°64' N and longitude 77°16' E). The laboratory analysis of soil and plant samples was undertaken at the Irrigation Engineering Laboratory, WTC, New Delhi, India. The soil being sandy loam of alluvial origin and the developed system was tested for bare soil as well as cropped conditions for brinjal, onion and tomato.

2.1. Fabrication and specification of gypsum block soil moisture sensors
For fabrication of gypsum block sensors a mould containing 15 cubicles of size (5 × 4 × 2.5) cm in a wooden boxes type frame was fabricated using ply board of 10 mm thickness. The two numbers of 22-mesh stainless steel screen electrodes of (10 × 5 × 2) cm size were connected to 0.1 cm diameter thick single core with PVC coated wire. The electrodes were taken out with help of single ply aluminum wires. The electrodes were spaced 1 cm apart and embedded in the block. The 10 parts of plaster of paris and 8 parts of distilled water was mixed to prepare the slurry for fabricating the gypsum block sensor.

2.2. Calibration of gypsum blocks
The measurement of soil moisture was based on the electrical resistivity of the block which decreases as the water content increases and vice versa. The amount of electricity that was passing through the porous block depended partly on the material and partly on the water content as described by Evett, Tolk, and Howell (2005) and Nagy et al. (2013). The measurements of soil moisture by gypsum block sensor involve conversion of resistivity to soil matric potential and its conversion to volumetric soil moisture content (Ganjegunte, Sheng, & Clark, 2012; Nagy et al., 2013; Shock et al., 1998). These sensors can measure the soil moisture tension varying from 10 to 200 kPa, which corresponds to the entire range required in irrigation scheduling. It is suitable for all types of soils. The developed sensor was calibrated in pressure plate apparatus under different suctions (0.1, 0.3, 0.5, 1, 2, 3, 5, 7, 10, 12, 15 bars) and a relationship between the electrical resistance (Ω) and soil moisture tension was developed. For developed sensor the calibration Equations (1)–(3) were used based on the resistance.

For $R < 1$ kΩ:

$$P = -20 \left( R + 0.018 \left( T - 240 \right) - 0.55 \right) \quad (1)$$

For $R$ between 1 and 8 kΩ:

$$P = \frac{-\left(3.213R + 4.093\right)}{1 - 0.009733R - 0.01205T} \quad (2)$$

For $R > 8$ kΩ

$$P = -2.246 - 5.239R \left( 1 + 0.018 \left( T - 24 \right) \right) - 0.0675R^2 \left( 1 + 0.018 \left( T - 24 \right) \right)^2 \quad (3)$$

where $P =$ pressure in kPa, $T =$ temperature in °C.
The developed gypsum block sensors were also calibrated for both soil moisture content and temperature. Similar procedure as suggested by (Bertolino et al., 2002; Dela, 2001; Eldredge, Shock, & Stieber, 1993) was followed in this work. The sensors were embedded into soil samples in plastic container and allowed it to equilibrate with media for 24 h, then container were placed in controlled atmospheric condition in Water Technology Center (WTC). The temperature was changed every 8 h from 4 to 8°C with increase of 4°C in 24 h (Keyhani, 2010; Wittrock, Begrand, & Wheaton, 1991).

2.3. Soil analysis and data collection

Soil samples were taken from different locations in the field from depth 0 to 60 cm using tube auger to determine the physical and chemical properties shown in Table 1. Soil moisture characteristic curve of the experimental soil was determined by using the Richard’s Pressure Plate Apparatus (Gruber, Dorigo, Zwieback, Xaver, & Wagner, 2013; Provenzano, Rallo, & Ghazouani, 2015; RoTimi Ojo, Bullock, & Fitzmaurice, 2015). A total of 24 samples were taken to develop the soil moisture characteristics curve at different tensions between 0 and 15 kPa for each sample.

2.4. GSM module and sensors integrated with microcontroller unit

The different sensors namely, rainfall, water logging, LM35 temperature sensor (© Texas Instruments), humidity and motion and soil pH sensors were also integrated into the circuit Figure 1 to monitor the environmental and soil condition. After completing the lab testing the sensors was installed in the field Figure 2. For this, all the integrated circuits were assembled on the interface board according to the circuit layout. For operating the drip irrigation system automatically, the GSM module and all other components including sensor network were connected in a well-planned and systematic manner (Gutierrez, Villa-Medina, Nieto-Garibay, & Porta-Gandara, 2015).

All connections were made as per the design by using soldering rod and thus the desired circuit was developed. The Motor of 2 hp capacity was selected for irrigating the field which was connected to the developed circuit. A 12 V direct current (DC) relay unit was used to trip the water pump which was powered by 230 V alternating current (AC) mains as shown in Figures 2 and 3. The MP LAB software (© EULA) tool was used to write program in the assembly language for the conditions to be fed in the microcontroller unit PIC 16F87XA. The written program was then compiled to the machine readable hexadecimal format which the microcontroller can read. The written program converted to the hexadecimal format was then programmed in microcontroller unit using a universal programmer. The output voltage of the LM 35 temperature sensor is linearly proportional to the temperature. Temperature measuring range is −55 to +150°C. It is cheaper and small in size (Chavan & Karande, 2014). The relative humidity sensor was used to predict the environmental condition. The motion sensor can sense the motion, vibrations and disturbance at pump system, to avoid animals and theft. This information reaches to the user via GSM and SMS technology in form of text message.

2.5. Statistical analysis

In this work, four statistical parameters were adopted to assess the performance of each sensor against the moisture measurement by GM. The MD describes the average difference between sensor values and the corresponding GM measurements are expressed as Equation (4).

| Soil layer depth (cm) | Particle size distribution (%) | Soil texture class | Bulk density (BD) (g/cc) | Field capacity (FC) (%) | Permanent wilting point (PWP) (%) |
|----------------------|-------------------------------|-------------------|--------------------------|------------------------|-------------------------------|
|                      | Sand  | Silt  | Clay |                      |                      |                               |
| 0–15                 | 67.5  | 12.5  | 20   | Sandy loam            | 1.32           | 30.5                           | 9.8                          |
| 15–30                | 66.1  | 13.1  | 20.8 | Sandy loam            | 1.38           | 30.1                           | 9.3                          |
| 30–45                | 65.9  | 12.8  | 21.3 | Sandy loam            | 1.47           | 29.8                           | 12.8                         |
| 45–60                | 64.9  | 13.3  | 21.8 | Sandy loam            | 1.48           | 30.1                           | 16.8                         |
Figure 1. Flow chart of plan of developed WSN sensor system.
Figure 2. Circuit diagram of the developed gypsum block WSN sensor installed in field for automated irrigation.

Figure 3. Developed gypsum block WSN sensor installed in field for automated irrigation for management of water resources and irrigation scheduling.
where $M_{si}$ is the $i$th measurement obtained by a sensor, $M_{gi}$ is the $i$th measurement obtained using gravimetric method and $n$ is the number of samples.

The relative root mean square error (RRMSE) was calculated as the total difference between the sensor value and the gravimetric measurements of soil moisture content as a percentage of the mean gravimetric measurement value as per Equation (5).

$$\text{MD} = \frac{\sum_{i=1}^{n}(M_{si} - M_{gi})}{n}$$

$$\text{RRMSE} = \sqrt{\frac{\sum_{i=1}^{n}(M_{si} - M_{gi})^2}{n}} \times \frac{100}{M_{gi}}$$

where $M_{gi}$ is the gravimetric measurement and which was calculated by Equation (6).

$$M_{gi} = \frac{1}{n} \sum_{i=1}^{n} M_{si}$$

The coefficient of determination $R^2$ was used for calculating the degree of similarity between sensors and gravimetric measurements. The values of MD and RRMSE being close to zero indicate a better performance of sensors. Paired t-test was used to determine the mean of difference between calibrated sensors.

3. Results and discussion

3.1. Soil moisture status

The soil texture of four layers (0–60 cm) analysis shows that the soil was sandy loam. Soil water potentials measured by tensiometers and gypsum block sensor during entire growing period of crops. The soil moisture characteristic curves were very similar for two plots at different depths for both tensiometer and gypsum block sensor as shown in Figure 4. The performance of sensors were directly depends on accuracy of soil moisture characteristic curve. These curve varied with soil depth because different soil moisture tension was observed at different depths and changes in bulk densities and disturbance of soil structure due to tillage and organic matters.

Figure 5 present the relationship between days after planting and soil moisture potential. The soil moisture potential measurements by tensiometers ranged from 8 to 60, 12 to 60, 10 to 70 and 10 to 72 for four layers 0 to 15, 15 to 30, 30 to 45 and 45 to 60 cm; respectively. The value of soil moisture tension of developed gypsum block sensor ranged from 30 to 35 kPa during early growing period of 35 days in both plots. Generally, observed sensor tension readings ranged between 10 and 90 kPa.

Figure 4. Soil moisture characteristic curve of filed.
during the entire growing period. Similar trend were also found for tension measured using tensiometers that ranged from 30 to 35 kPa during early 30 days from growing. Tensiometer tension readings were observed in the range of 10–70 kPa only. These were slightly lower than gypsum block sensor in both plots as shown in Figure 6(a) and (b). The soil moisture potential curve from gypsum block sensors showed that the maximum water productivity maintained by providing soil moisture
up to field capacity level and applicable for high tension range. Therefore, the gypsum block sensors can be operated in a drier range domain than tensiometer. These results obtained same with (Intrigliolo & Castel, 2004; Irmak & Haman, 2001). As a result it was concluded that the gypsum block sensor work best in sandy loam and best tool for automate irrigation scheduling.

The Figure 7(a) and (b) gives relation between volumetric moisture content (VMC) measured by gypsum block sensor and tensiometer with gravimetric method. The developed gypsum block sensor performed well in the range 10–19% of VMC as shown in Figure 7(a). The maximum measurement was 90 kPa at 10% VMC. These sensors were reliable in the range of 30–90 kPa. The tensiometer worked better in the range of 6–18% of VMC. The tensiometer did not measure lower than 10 kPa and which was approximately equal to 18% of VMC and maximum measurement was 70 kPa which was corresponding to 85 VWC. In the experiment it was observed that tensiometer readings were reaming at 30–40 kPa then corresponding VMC was 16–12% and tensiometer was found to be a reasonable only in the 30–55 kPa range.

Statistical summary of the sensor’s performance at different soil depths in both fields were analyzed as shown in Table 2. Paired t-test was performed to check statistical significance between gypsum block sensors which were installed in fields as shown in Table 3. The different sensors performed differently for various soil and crop combinations. While the positive t-test values indicated the selected sensors were appropriate for use with the soil and crop combination whereas the * marked sensor was not significantly appropriate to be used with the indicated crop and soil combinations. The developed gypsum block sensors performed better and highly correlated with tensiometer with coefficient of determination, slope and RRMSE were listed in Table 2 at 30–45 cm depth for both gypsum block sensor and tensiometer. But the tensiometer data were scattered above the 1:1 line which suggested an underestimation of moisture (paired t-test) as in Figures 6(a) and (b) and 7(a) and (b). Therefore this work concluded that
most of the developed gypsum block sensor performed good between depths 15–45 cm. The major root distribution patterns were concentrated in this root zone depth for all crops and the same was eventually used for designing the irrigation systems and planning the irrigation scheduling.

### Table 2. Statistical summary of the sensor’s performance at different soil depths

| Sensor                                           | Depth (cm) | No. of observations | RRMSE | Intercept | Slope | Relative basis (%) | $R^2$ |
|--------------------------------------------------|------------|---------------------|-------|-----------|-------|--------------------|-------|
| Soil moisture potential measured by gypsum block sensor | 30–45      | 8                   | 10.76 | 21.9      | −0.13 | −8.99              | 0.93  |
| Volumetric moisture content measured by gypsum block sensor | 30–45      | 8                   | 5.58  | 0.93      | 0.97  | −10.59             | 0.93  |
| Soil moisture potential measured by tensiometer    | 30–45      | 8                   | 21.0  | −0.17     | 21.02 | −8.59              | 0.90  |
| Volumetric moisture content measured by tensiometer | 30–45      | 8                   | 3.6   | 0.79      | 3.67  | −6.78              | 0.93  |

### Table 3. Paired t-test data of different sensors in two fields

| t-test       | Tomato | Brinjal | Onion       |
|--------------|--------|---------|-------------|
| Sensor 1 and 2 | 0.15   | 0.04    | 0.01*       |
| Sensor 1 and 3 | 0.65   | 0.0014* | 0.98        |
| Sensor 1 and 4 | 0.03   | 0.58    | 1.72        |
| Sensor 1 and 5 | 0.10   | 0.99    | 0.25        |
| Sensor 2 and 3 | 0.06   | 0.48    | 0.33        |
| Sensor 2 and 4 | 0.0014 | 0.0018  | 0.0012*     |
| Sensor 2 and 5 | 0.95   | 1.98    | 0.21        |
| Sensor 3 and 4 | 0.10   | 0.16    | 0.55        |
| Sensor 3 and 5 | 0.05   | 0.88    | 0.32        |
| Sensor 4 and 5 | 0.10   | 0.35    | 1.15        |

*The asterisk marked sensor is not significant for use with the crop.

### 3.2. Testing and evaluation of developed gypsum block sensor

#### 3.2.1. Low moisture sensing by the sensor

The system switches “ON Motor” when threshold values (SMC < 15%) reaches below field capacity if sensed by at least four sensors out of five sensors. After collecting all information from sensors the microcontroller unit gets activated and sends a message to user mobile in the form of “Motor ON” through transmitter and receiver via use of GSM and text message technology. The three rainfall sensors were installed in field at different places and have been programmed in microcontroller unit. The rainfall sensors get activated and “Motor OFF” when rainfall occur more than 3 min with rainfall intensity greater than 2.5 mm/h. As results
water saving, power saving and operation of pump can be stopped in rain period. The rainfall and relative humidity measured by sensors were shown in Figure 8. With help of relative humidity sensor user can get idea about environment as results user plan the irrigation scheduling to crop. The humidity data measured by sensor was shown in Figure 9. LM 35 temperature sensor measures field temperature on daily basis. The maximum and minimum temperature during the growing period was shown in Figure 9.

3.2.2. High moisture sensing by the sensor

Once the threshold values (SMC > 18%) reaches to its field capacity the microcontroller gets activated which then sends a signal to motor to shut off as a result the motor and solenoid valve shut down. Through the receiver and transmitter a message is send to the user in the form of “Motor OFF”. The response time of developed gypsum block sensor was observed 2 h from low moisture condition to high moisture condition as a result the pump was operated daily for 30 min in morning after taking the readings and 30 min in the evening in regular interval to maintain field capacity.

The water logged sensor has programmed like excess water in the field due to rainfall or due to irrigation, it gives the information to user, drains the water and keep the root zone of crop free from water logging condition. From these results user can identify water stress and water logged area with help of soil moisture and water logged sensors (Mazahrih, Katbeh-Bader, Evett, Ayars, & Trout, 2008). The field can be irrigated at particular places only where water is required needed with help of installed drip irrigation system and chances of occurrence of rainfall or not.

In other hand, the two “Rapidest Digital soil pH Fertility Meters” were used to analyze the acid level and fertilizer status of field. The fertilizer solution of N, P, and K was prepared in three different 10 liter tanks and which were directly connected with water distribution of drip system. The fertigation (application of liquid fertilizers through drip irrigation) was done through drip system which was operated automatic by user mobile through sensing particular text message to microcontroller unit (Hussain, Sahgal, & Riyaj, 2013). The fertigation applied where it is needed in field based on the readings obtained by meter. As results cost and over fertigation to crop is minimized.
3.3. Performance evaluation of developed gypsum block wireless sensor network system

It was observed that the system performance increased by use of microcontroller, circuit design and cost has reduced (El Marazky, Mohammad, & Al-Ghobari, 2011). The performance evaluation of soil moisture sensor was carried out under two different field conditions during growing season in three different crops namely tomato, brijal and onion (Chow et al., 2009). The accuracy, precision and quickness of the response sensors were calibrated with tensiometer and FDR sensors. The response time of gypsum block sensor was found 1 h (Dobriyal et al., 2012; Hedley & Yule, 2009).

Based on laboratory and field experiments, it was found that the developed system was able to irrigate the field based on programmed conditions in microcontroller unit. Figure 10 shows the soil moisture status under automated drip irrigation and conventional irrigation method based on crop water requirement and measured by developed gypsum block sensors. The daily soil moisture content variation from 24 to 26% for 10 days period. The system was able to irrigate crop as per water requirement. The water requirement measured in plot I was slightly higher than plot II. There was water saving of 8 and 6% in two plots respectively as shown in Figure 11. This difference was primarily due to estimation of water requirement because there were differences in soil condition i.e. physical and dynamic characteristic of soil which resulted into differences in soil moisture in the profile. The developed system was highly successful in maintaining the soil moisture content in the crop root zone at field capacity throughout the growing season (Figure 12).
4. Conclusion

The gypsum block wireless sensor network system was developed and tested for irrigation scheduling under drip irrigation condition. The developed gypsum block sensor performed well in the range of 10–19% volumetric moisture content. These sensors were reliable in the range of 30–90 kPa. The developed gypsum block sensors highly correlated with coefficient of determination $R^2 = 0.93$ with slope 0.13 and small relative root mean square error (RRMSE). The 8 and 6% of water saving were found in two plots respectively. It can be concluded that the present design of automated WSN system is resource efficient and consumes low power. The developed system was highly successful in maintaining the moisture in the crop root zone at field capacity throughout the growing season. The present research work opens up new vistas and revolution in on-farming and off-farming agriculture water management technologies on Indian farms.

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