Use of sensor based automated irrigation for the mitigation of groundwater depletion and pollution issues in Kalpitiya, Sri Lanka

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***Abstract**: Kalpitiya, is an important agroecological region in Sri Lanka, which has greatly strengthened the country's economy and food security. However, intensive farming practices in Kalpitiya have triggered its ground water depletion and pollution isuses. The objective of this study was to check the feasibility of a new sensor-based irrigation system against the prevailing groundwater depletion and pollution issues in Kalpitiya. The new system was used to automate a sprinkler kit by monitoring underground moisture contents via its high-frequency soil water content sensors placed at 15, 45 and 90 cm depths. During the study, irrigation uniformity and adequacy of the automated sprinkler kit (T1) were compared over those of the sprinklers operated with common farmers'experience based (T2) and timer controlled (T3) irrigations. T2 and T3 were also provided with the soil moisture detection facility as same as in T1. According to the results, the irrigation uniformities of T1, T2 and T3 were within an acceptable range (83-88%), but only T1 had 60% irrigation adequacy within 30cm depth. Further, soil water telemetric graphs and the adequacy values also proved that deep percolation was considerably higher in T2 and T3 over T1. The study confirmed that new sensor-based irrigation control was capable in saving irrigaton water and minimizing groundwater leaching through its real time soil moisture sensing mechanism. Thus, the new technique had the potential to used against the ground water depletion and pollution issues in Kalpitiya.*

Keywords: *Groundwater*, Internet of things, Kalpitiya, Sprinkler irrigation and Soil water content

1. Introduction

Kalipitya is a low-lying, sandy peninsula in the Puttalam District, Northwestern Province of Sri Lanka. It is located between 79° 40' - 79° 50' Eastern longitude and 8° 20' - 8° 90' Northern latitude. The total land area of the peninsula is about 160 km^2 with a population of 86,019. The whole peninsula is an economically hyperactive zone which hasgrately strengthened the country's agriculture and food security (Gunawardena and Pabasara, 2016).

The area is assessed as being a component of the Dry Lowland (DL3) agro-ecological zone, which receives a median annual rainfall of about 800-900 mm (Jayasingha *et al*., 2011). A thinner layer of freshwater occurs as floating over the brackish water at 1 - 3 m depth. The sandy aquifer is recharged by both direct infiltrations from rainfall during the northeast monsoon and return irrigation flows because the soil is extremely permeable. However, there are no any problems in Kalpitiya with either drainage or water logging.

Due to low water holding capacity, farmers tend to irrigate more water or apply it at a very high frequency. However, the water application practice has caused a notable pollution in the aquifer with agricultural chemicals like nitrate fertilizers and pesticide residues which are carried there through the excess irrigation flows. Jayasingha *et al*. (2011) also reported that the groundwater contamination with excess nitrates was much higher under intensively cultivated areas in Kalpitiya.

The main objective of this study was to check the feasibility of a noval sensor-based irrigation system as a soil moisture monitoring and controlling mechanism aginst the prevailing groundwater depletion and pollution issues in Kalpitiya. Further, the new irrigation control system is enabled by the Internet of Things (IoT) technology, and the soil moisture monitoring mechanism is consisted with Time Domain Reflectometry (TDR) type moisture sensors (TEROS 10) which can detect soil water contents under different soil depths at a very high frequency. It also has been found that the manufacturing cost of the sensor devices of the new irrigation control system was significantly far below than the commercially available data loggers, and the operators do not have to pay additional communication subscriptions since LoRa was used as the IoT connecting technology of the system (Chamara, 2021).

Moreover, similar sort of study has never been done before in Kalpitya, thus, this would be an initiative to IoT based precise irrigation control practice in Kalpitiya. Finally, the findings of this study would be greatly useful for making decisions and recommendations in future precise irrigation practices in Kalpitiya as well.

2. Materials and Methods

A. Experimental Duration and Location

The research was conducted in the experimental fields of Kandakuliya research station, Kalpitiya for the period of six months starting from October, 2021 to April, 2022.

B. Main Treatments

A soil moisture sensor unit was used to automate a sprinkler irrigation kit (T1). The sprinkler kit consisted with four sprinkler heads, and spacing between the sprinklers was 4 × 4 m. The soil moisture sensor unit had a moisture sensor network buried at 15, 45 and 70 cm depths to detect underground soil water contents.There were similar sprinkler kits as in T1 to practice farmers' experience based (T2) and timer controlled (T3) irrigations. T2 and T3 were also provided with the same soil moisture sensor units with the sensor network as described in T1, but the two sensor units weren't enabled with the irrigation control function. According to the main treatments, the sprinkler kits were operated seperately using a same water pump (2 hp) and the operational pressure in evey sprinkler kit was maintained as 0.75 bars.

C. Soil Moisture Sensor Unit

The soil moisture sensor unit was built on a ARDUINO MKR1310 development board and powered using a 1500 mA rechargeable solar battery as specified in Chamara (2021). Each sensor unit had three TDR type moisture sensors which were capable in detecting soil water contents every two and half minutes at the depths of 15, 45 and 75 cm. Then soil water content data were first transmitted into the LoRa gateway and then farwarded into the ThingSpeak IoT platform where the received data were stored, analyzed, and visualized. The platform was also used to generate on and off signals only to the sensor unit which was used to automate the sprinklers (T1), and the signal generation was done based on predetermined parameters relevant to soil moisture status of the experimental site as described by Chamara (2021).

D. Irrigation Specifications for different Treatments

T1 was always operated based on available water content of the soil. The difference between field capacity (θ_{fc}) and wilting point (θ_{wp}) was taken as the available water content, and during the study θ_{fc} and θ_{wp} were taken relavant to a sandy soil where θ_{fc} and θ_{wp} were 0.17 and 0.09 m/m respectively (Baker et al., 2017). T2 irrigation was done based on the farmers'experience on irrigation where the routine practice was to irrigate during morning (6 – 8 a.m.), mid day (12 – 2 p.m.) and evening (5 – 6 p.m.) for a period of 15 to 20 minutes, but only on very hot days, an additional irrigation which was not longer than 15 minutes was done in between morning and mid day (10 – 11 a.m.) times. In T3 the timer was used to schedule irrigation as three times per day each having a duration of 10 minutes.

E. Metrological Observations

During the period of study (on the month of March, 2022) humidity, max. temperature, wind speed, and evaporation around the experimental plots were recorded twice per day, in morning and evening.

F. Sprinkler Distribution Uniformity and Christiansen Uniformity Coefficient

Catch can tests were performed to measure the uniformity of each treatment. The catch cans were placed in a grid having 0.5m distance between the grid pairs. Sprinkler kits of different treatments were operated for 5 minutes at 0.75 bar pressure and the water was allowed to fall on the cans. Then the water height of every can was measured. For each sprinkler kit the test was repeated three times. Based on the can water heights, distribution uniformity (DU) and Christiansen uniformity coefficient (CU) were calculated for each treatment using the equations 1 and 2 respectively as given by Baker *et al*. (2017).

$$DU = \frac{d_{LQ}}{d_z} \quad \text{-------- } \textit{Equation 1}$$

$$CU = 100 \times \left(\sum_{i=1}^{n} \frac{|d_i - d_z|}{n d_z}\right) \quad \text{-------- } \textit{Equation 2}$$

Where;

d_{LQ} = Ave. low quarter depth of infiltrated water

d_z = Mean infiltrated depth for all observations

d_i = Depth of the observation *i*

n = Number of observations

G. Irrigation Distribution

The water heights of different cans obtained from the catch can test were plotted on a scaled grid to draw water distribution maps for each treatment.

H. Ground Water Distribution

During the study period, in each treatment the underground soil water contents were monitored every two and half minutes by the soil moisture sensors placed at 15, 45 and 75 cm depths and stoted in the ThingSpeak web platform. The soil water contents were dowloded and plotted aginst time (days) using MS Excel to develop telemetry graphs.

I. dequacy of Irrigation

The adequacy of irrigation was determined for each treatmet using graphs which were drawn using infiltration depths and fraction of field area. The infiltration depths were calculated from the data obtained from the catch can tests.

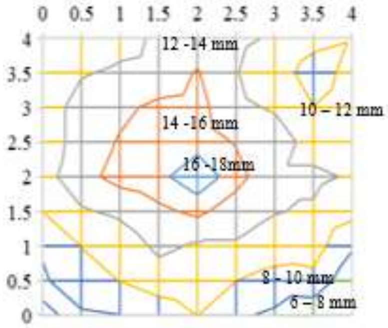
3. Results and Discussion

A. Weather Conditions

During the study, humidity, maximum temperature, and evaporation ranges were 79 - 72%, 32 – 34 °C and 5 – 5.6 mm/day respectively (Table 1). Wind speed notably fluctuated between 4.9 and 8.8 km/h.

Table 1. Metrological Data

Parameter	Dates on March, 2022					
	18	**19**	**20**	**21**	**22**	**23**
Humidity (%)	79	78	72	72	72	72
Temperature [Max.] (°C)	34	34	34	34	32	33
Evaporation (mm/day)	5.2	5.6	5.4	5.0	5.2	5.4
Wind speed (km/h)	4.9	7.5	8.8	7.2	8.7	7.4



A. Application Uniformity

The sprinkler uniformity (DU and CU) data are given in Table 2. It was found that DU ranged from 0.72 to 0.79 while CU ranged between 83 to 88%. The data revealed that all three sprinkler kits had an almost equal uniformity. However, there were mere uniformity differences among the treatments mainly because of the effect of wind speed.

Table 2. Sprinkler application uniformities of different treatments

Treatment	**DU**	**CU (%)**
T1	0.72	83.84
T2	0.79	87.38
T3	0.73	83.84

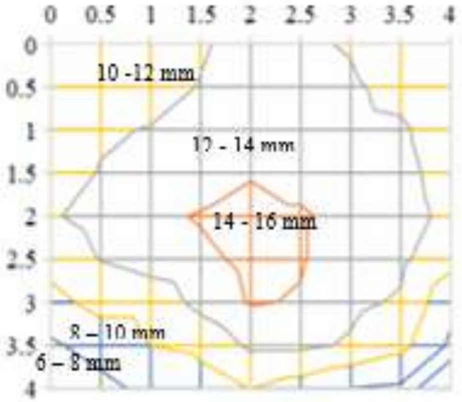


Figure 2. Irrigation Distribution Map of T2

Irrigation distribution maps of T1, T2, and T3 were given in figure 1, 2 and 3 respectively. The maps were plotted based on the results of the catch can tests. Those tests were done when the wind was unnocitable but it was hard to neglect that the overall effect of wind on the tests as zero. The maps followed the normal sprinkler distribution patterns where the highest irrigation depths were found at the center while the lowest depths occurred near the corners In Kalpitiya, the top soil roughly deepens into a depth of 30 cm and it mainly has sandy soil. If θ_{fc}, θ_{wp} and the maximum allowable fractional depletion (f_{dc}) of the top soil are 0.17 m/m, 0.09 m/m and 0.5 respectively, the depth of irrigation is 12 mm [((0.17 – 0.09) × 0.5) × 30 cm]. Further, this means that when soil water content drops into a value of 0.13 m/m, irrigation depth of 12 mm is required to bring it back to the field capacity. This estimated irrigation depth in the experimental plots highlited that water was deep percolated at the center of each plot as the maps of all three treatments clearly showed higher irrigatin depths over 12 mm closer to the center. Further, the irrigation distribution maps clearly explain that in order to avoid capturing of either a too low or too high reading it was possible to burry the soil moisture sensors at one forth length of the diagonal away from either corner of the plot.

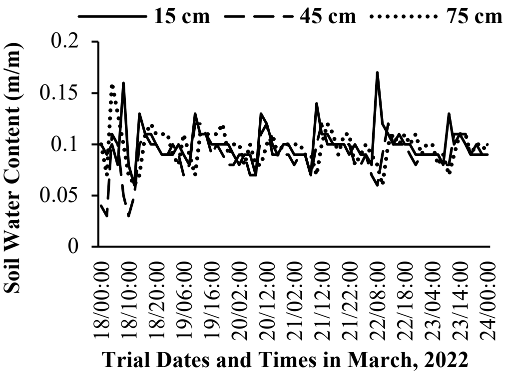


Figure 4. SWC telemetry data of T1

B. Ground Water Distribution

The soil water content (SWC) telemetric data given in figure 4, 5 and 6 showed the ground water distribution at 15, 45 and 75cm depths in each treatment over the period of 5 days starting from 18th to 23rd March, 2022.

The peaks indicated the beginning of irrigations in different treatments. A single peak was recorded daily in T1 while three peaks were noticed daily in T2. In Kalpitiya, sandy loam soil is dominant in between 30 and 90 cm depths, and θ_{fc} and θ_{wp} of sandy loam soil are 0.14 and 0.05 m/m respectively (Baker *et al*., 2017). However, T3 did not record noticeable peaks, but the data confirmed that the underground soil water contents in T3 at all three depths were within a range between field capacity and wilting point. In T2 and T3, always 15 cm depth first reached to a peak in soil water contents and then 45 and 75 cm depths orderly reached into the peaks. In all three treatments, at the depths of 15 cm, soil water contents rapidly passed the field capacity (0.17 m/m) as expected because the sensors were installed at the center of each plot where the deep percolation was possible at a greater extent as given in the irrigation distribution maps. However, only in T1, both 45 and 75 cm depths did not always reach to the field capacity (0.14 m/m) as the over irrigation was greatly limited by the automated irrigation control.

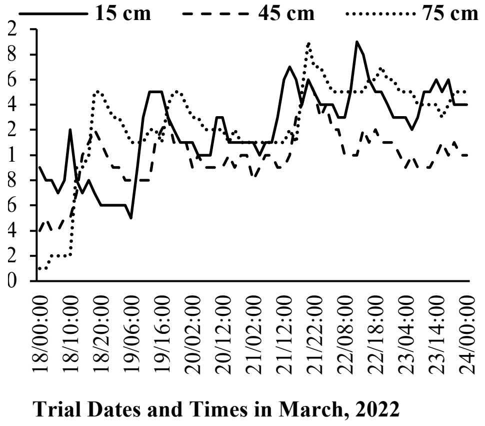


Figure 5. SWC telemetry data of T2

D. Adequacy of Irrigation

Adequacy of irrigation (AI) explains whether an irrigated field receives desired amount of water or more. In order to determine AI for all three treatments, the average catch can test values were plotted aginst fraction of land area as given in Figure 7. The required depth of 12 mm in Figure 7 was calculated for the 30 cm sand top soil when the maximum allowable fractional depletion (fdc) was 0.5. According to the graph, both T2 and T3 irrigation practices caused deep percolation beyond the depth of 30 cm, while T1 maintained around 60% adequacy of irrigation. Further, the graph also revealed that water use was limited to a greater extent in T1 than T2 and T3. This also in line with the findings of Eisenhauer *et al*. (2021) which stated that automated sprinkler control had greater water use efficiency over the manual control

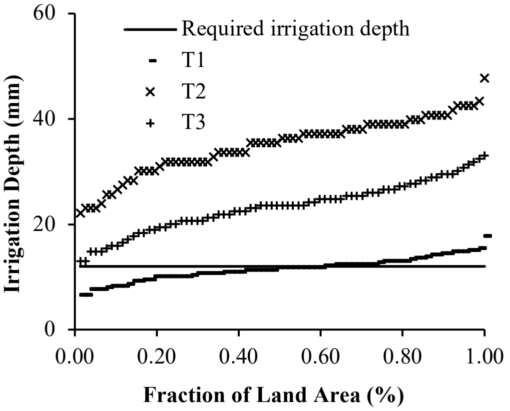


Figure 7. Irrigation adequacies for different treatments

4. Discussion

The study confirmed that new sensor based irrigation control unit was capable in saving irrigaton water and minimizing groundwater leaching through its real time soil moisture sensing mechanism. Thus, the new technique has the potential to be used against the ground water depletion and pollution issues in Kalpitiya.

However, the final result of the study would have been somewhat different if the irrigation automation had been done on a cropping field with a great care to some groundwater parameters. Thus, before making final recommendations, the study has to be repeated on a cropping field by paying more attention to crop growth and groundwater characters.

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IJ Amadoru works a senior lecturer attached to the Department of Plantation Management of Wayamba University of Sri Lanka. He holds a M.Sc in Agricultural Bio-systems Engineering and recently has completed his M.Phil in Agriculture, and his research interest is mainly on irrigation and farm machinery. He is also currently working as the section B secretary of Sri Lanka Association for the Advance of Science (SLAAS).