Temperature Model for Estimating Reference Evapotranspiration by Measuring Data Based on Arduino and Weather Station

P-ISSN: 1680-9300
E-ISSN: 2790-2129
Vol. (26), No. (2)
pp. 136-142

[1]Ahmed A. Thanoon, [2] Firas S. Ahmed, [3] Anfal A.Fadhil

[1] Department of Environmental and Water Resources Technologies Engineering, Mosul Polytechnic College, Northern Technical University, Mosul, 41002, Iraq

[2] Department of Prosthetics and Orthotics Techniques, Mosul Polytechnic College, Northern Technical University, Mosul, 41002, Iraq

[3] Department of Software, Collage of Computer Science and Mathematics, University of Mosul

Abstract:

Surface The Evapotranspiration plays an important role in the design of the water balance in agricultural areas, and affects the irrigation scheme and management of water resources. The study focuses on estimating the reference of evapotranspiration (ETo) using data collected from both an Arduino-based system and a traditional weather station. The Arduino (UNO) system was tested in seven days using the DHT11 sensor to measure temperature and humidity, which shows real-time temperature data on the LCD screen. In comparison, temperature data (maximum and minimum values) from the Mosul weather station were used to calculate ETo, which is a temperature model using the Hargreaves method operated with minimal input data. The results showed that the ETo values increased with rising temperatures. The curve ETo tendency starts at a low point at the beginning of the year due to cold, rainy conditions, then increases gradually to the maximum value in July due to the hot season and then gradually decreases to a lower less at the end year. This research indicates that in areas where wide weather data is not available, an Arduino-based layout can effectively act as a compact weather station and provide sufficient data for reliable ETo estimates.

Keywords: Reference Evapotranspiration (ETo), Sensor DHT11, Temperature Model, Arduino UNO.

1. Introduction

The use of Arduino systems to measure and display climate data has gained popularity due to their low cost and ease of use. Mainly, temperature data collected by Arduino devices (Kumar et al., 2017; Singh et al., 2020), reference evapotranspiration, as a basic input to estimate the main parameter in agricultural water management.

Reference evapotranspiration means that a water loss from a reference plant growing on a well-farm soil, which can be estimated through several methods based on the climate variable, it is called reference crop evapotranspiration (ETo) and is represented in the literature (Allen et al., 1998). Many ways have been developed to assess ETo under different climatic conditions, and the accuracy of these methods depends largely on data availability and local climatic characteristics (Droogers and Allen, 2002). A comparative study involving

Journal of Prospective Researches
Vol. (26), No. (2)
The paper was received on July 22, 2025; accepted on June 13, 2026; and published on June 16, 2026.
Corresponding author's e-mail: firas_saad@ntu.edu.iq

10.61704/pr.508

four methods for calculating the grass reference plants, including Blaney-Cridle, radiation, Penman and Pan evaporation methods (Doorenbos and Pruitt, 1977), and evaluated these mothods each to different climates in literaure (Jensen et al., 1990).

the Hargreaves method provides a simplified temperature-based approach to estimate ETo, using maximum and minimum temperature data, often obtained from Lysimeter's experiments on species such as Alta fescue grass (Hargreaves and Samani, 1985) .This temperature model (Hargreaves method) has been compared to other equations such as Jensen-Haise , Penman, Blaney-Cridle and Pan evaporation models, and performs with appropriate accuracy and satisfactory results in dry regions such as Arizona, especially for crops such as Alfalfa (Samani and Pessarakli ,1986).

Arduino Uno Microcontroller has 14 digital entrance output sticks, 6 analog inputs, 16 MHz ceramic resonators, and can be operated via USB or battery, making it multi -faceted for field purposes (Gupta and Kaur, 2018). Several studies have shown the development of Arduino-based systems to measure environmental parameters such as moisture and temperature in specific areas such as Iraq (Al-Shaibani et al., 2020; Al-Mahmood and Hassan, 2021).

In addition to stable monitoring, Arduino-based mobile weather stations are designed to monitor climate change in the local area, various matrix such as indoor/outdoor temperature, humidity, atmospheric pressure, height, dew point and heat index (Ujoodha et al., 2020). These mobile systems increase data resolution and spatial coverage by improving local climate assessment (Kumar et al., 2019).

Other tasks have integrated wireless sensor networks to help irrigation control provide exact real-time water scheduling estimates (Atta et al., 2011), and assist irrigation control to provide continuous environmental monitoring. Such systems support decisions for the use of effective water in agriculture, especially in dry and semi-dry areas.

The accuracy of the Arduino-based temperature and humidity sensor is valid against standard meteorological agents, which shows a good deal. This development has accelerated the adoption of low-cost agricultural applications worldwide. In addition, the classic weather station enhances strengthening the ETo estimation model by combining the data with Arduino collected data with data sets, so that the use of temperature models that are warranted where data deficiencies exist. This hybrid approach has proven effective in improving irrigation planning accuracy.

Temperature model are important for ETo assessment if complete climate data is not available, which is often the case of distance or resource-limited agricultural sectors (Allen et al., 1998; Yoder et al., 2005). In such cases, Arduino-based microcontroller systems can serve as mini-prototype weather stations, and fill the holes in climate monitoring by providing necessary temperature and humidity data (Mishra et al., 2021; Patel and Dave, 2019).

in conclusion, the purpose of this research is to estimate reference evapotranspiration using climate data collected from Arduino-based mini-weather stations and traditional weather stations, which provide a cost-effective and reliable solution for water resource management in agriculture.

Furthermore, before Tmax and Tmin are calculated daily or over any period, a point can only be a Tmax or a Tmin if the value is held constant at that value for at least 5 minutes (to eliminate transient high/low values) . This filter ensures that extremes that are recorded actually were extremes in the environment at the time, not artifacts of the equipment or electrical noise.

2. The hardware of Arduino system

The hardware components in system of Arduino included an Arduino Uno board, sensor temperature DHT11, LCD screen, bread board, connecting wires, and USB cable. This system was powered by a USB power bank and any source such as laptop computer. The hardware of Arduino system is shown in figure (1).

The software used for data processing is designed to sample the input signal several times, and then compute a moving average. This practice is intended to increase fidelity, as opposed to recording a single moment in time, and reduces the

10.61704/pr.508

noise level and other random fluctuations. Because of this, the reading is a more accurate reflection of the environment.

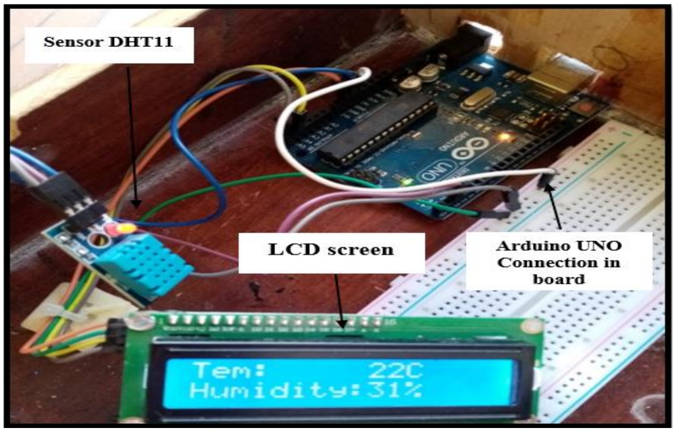

Figure 1. The Hardware of Arduino System

2.1 Arduino Un

Arduino Uno is a microcontroller board. Arduino has many inputs pins which are basically fed a variety of switches or sensors and controls a wide range of outputs such as lights, recorders, motors (Das et al., 2017; Abdul Wahhab et al., 2019; Sharma et al., 2019).

2.2 Sensor DHT11

The sensor measures both air temperature and moisture (humidity), the temperature expressed as centigrade and relative humidity express a percent ratio (Hasan, 2016). The sensor measures two key environmental parameters: air temperature and humidity. Temperature readings are provided in degrees Celsius (°C); the relative humidity is expressed as a percentage.

2.3 LCD Screen

LCD (liquid crystal display) is usually used to visually offer real -time data such as temperature, humidity or pressure in Arduino projects. It is usually connected to Arduino through a digital stick and shows sensor output, so users can monitor the climate variable on the site without a computer. In reference evaporation studies, LCD provides an effective and low power method to display the necessary environmental data in the area immediately.

The LCD interface is a form of in-field real-time monitoring that can operate without constant connection to a computer needed for serial monitoring. This reduces time required to transfer data, energy consumption, and is especially appropriate for long-term field applications and remote monitoring of data from sensors or devices.

2.4 The Block Diagram of The Current Work Screen

The block diagram of system Arduino is showing in Figure (2). The sensor was connected with Arduino Uno which power supplied with 5v. The sensor sensed the temperature and humidity to Arduino Uno and the values from the sensor were displayed on LCD screen.

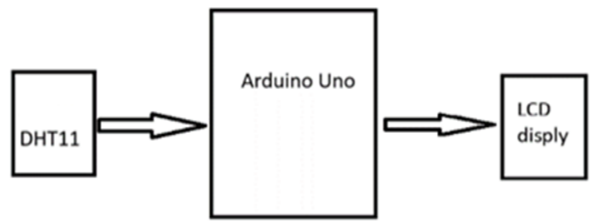

Figure 2. The Block Diagram of Arduino

2.5 Arduino System Connection

The diagram of connection electrical wire system Arduino is shown Figure (3).

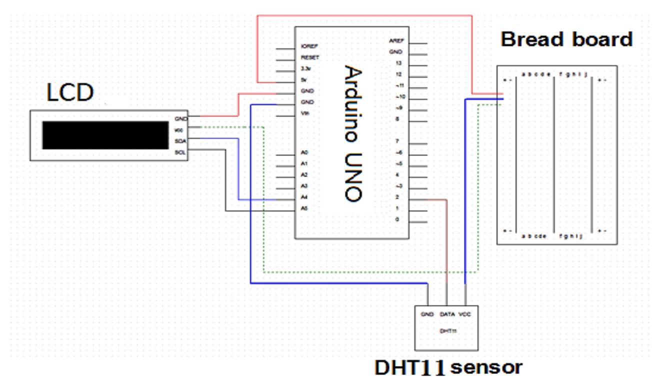

Figure 3. The Diagram of System Arduino Connection

2.6 The Temperature Model

The temperature model was a Hargreaves equation (Hargreaves and Samani ,1985; Hargreaves et al.,1985) as:

$$ETo = 0.0023 * \sqrt{TD} * (Ta + 17.8) * Ra$$

Where;

ETo: reference evapotranspiration mm/day,

TD: difference between maximum temperature Tmax and minimum temperature Tmin (Tmax-Tmin) oC,
Ta: average of temperature (Tmax+Tmin)/2 oC,
Ra: extraterrestrial of radiation mm/day.

The values of Ra depend on evaluation of weather station (latitude) and the day of year (Allen et al., 1998). The values of Ra were found for Mosul station by units' mm/day for Mosul station.

3. Validation & Reliability

The sensing unit was calibrated by comparing the output from the sensing unit with that of a standard industrial sensor that had been calibrated in the same NIST-certified water sample. An offset in the raw output was found, and the offset correction algorithm was inserted into the Arduino source code to compensate for this. By means of software calibration, we ensured that the device's output agreed with conventional measures, thus improving the range and precision of the device and establishing its credibility for field studies.

3.1 Root Mean Square Error

In order to evaluate the values of reading temperature from Arduino with reading from weather station, was used the root mean square error RMSE Willmot (1982) as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(yi - xi)^2}{n}}$$

Where:

yi: the values of temperature reading from the weather station for average climate data 1971-2000,
xi: the values of temperature reading from Arduino the three intervals at morning, noon, and night,
n: number of values.

4. Results and Discussion

4.1 Reading of Temperature

The monitoring period of 7 days also allows us to study diurnal" variation (day-night cycle). This allows us to take advantage of the difference between T_"max " (at noon) and T_"min " (at night/morning) to validate the response of the system to environmental changes. Hence, the comparison shows that the system can be a reasonable alternative for real-time monitoring. Even though current low cost prototypes do not deliver stable and verified data over a longer period of time, the long-term stability shown over the seven day period of this test can be used to verify our offset corrected and filtered measurements as shows in Table 1.

The system of Arduino was tested for siven days in three interval at morning, noon , and night inside of house. The temperaturae data at the time of noon will be consdeired Tmax , while The temperaturae data at the time of night will be consdeired Tmin. For accuracy of estimating reference evaptransipation ETo uses the system Arduino reading temperature for two hour interval and then chose the maxiuim Tmax and minimum temperature Tmin from data in agricultural fields then calcaleting the ETo. The the root mean square error RMSE were 11.3 % for temperature at morning , 11.8% for temperature at noon , and 11.4% for night .The highest performance of the values of temperaturae reading from Arduino the three interval at morning , noon , and night for being given a lower rate of root mean square error RMSE .

Table 1. Results of Measuring the Temperature for Seven Days.

Days	Temperature at morning oC	Temperature at noon oC	Temperature at night oC
23-5-2021	29	34	28
24-5-2021	30	33	30
25-5-2021	31	35	31
26-5-2021	30	34	30
27-5-2021	31	35	30
28-5-2021	30	34	31
29-5-2021	31	35	30

10.61704/pr.508

System's LCD interface is equipped for the real-time display of the temperature and humidity conditions obtained from the DHT11 (as shown in figure 4). This on-site monitoring method eliminates the need to be connected to a computer via a serial port, therefore allowing the conditions to be examined on site. The display will give immediate feedback about the environment and as a result, this system will become a practical tool for continuous monitoring.

Figure 4. Reading of Temperature and Humidity

4.2 The Reference Evapotranspiration from Weather Station

The values maximum and minimum of temperature, average and different between maximum and minimum temperature, and reference evapotranspiration ETo in mm/day for Mosul weather station for average climate data 1971-2000 were shown in Figures (5), (6), and (7).

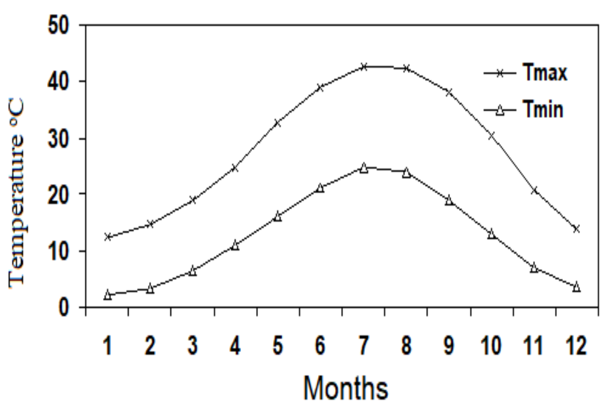

Figure 5. Maximum and Minimum Temperature of Mosul Weather Station

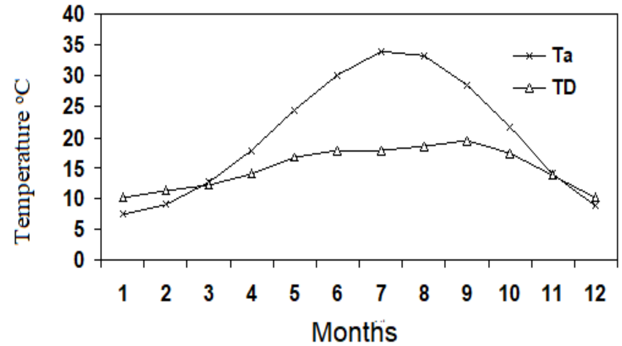

Figure 6. The Average and Difference of Temperature of Mosul Weather Station

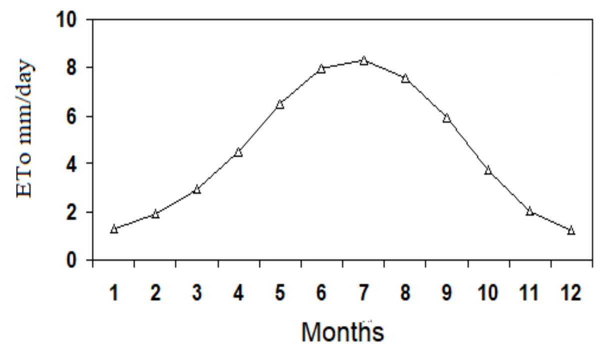

Figure 7. Reference evapotranspiration ETo of Mosul Weather Station

The Tmax maximum temperature, Tmin minimum temperature, Ta average of temperature, TD difference between maximum temperature Tmax and minimum temperature Tmin, and ETo reference evapotranspiration estimated by the Hargreaves equation curves were a low at start months of years and increase gradually with increase of months (2, 3, 4, 5 ,6 months) to reach to maximum value in July month. Then the curves gradually decrease to be end of year. These curves are low in the winter due to the cool and rainy season, and to the maximum value in summer due to hot season and then gradually decreases to be less at end year. The most factor in result of calculation the ETo by the Hargreaves equation is temperature. The temperature is little in winter the increase gradually in spring and the up the maximum value in summer, and then gradually least in the autumn to be less winter. The average monthly of values of Tmax, Tmin, and the ETo range from 12.4 to 42.7 oC, 2.3 to 24.9 oC, and 1.26 to 8.31 mm/day respectively for Mosul weather station.

5. Research Gap and Motivation

There are many low-cost environmental sensing platforms available, but few that have been validated to show that they are accurate and reliable enough to be used for serious science in the field. Prototypes are poorly calibrated and data may be processed poorly, leading to variable quality. This study tries to address the demand for the low-cost measurement equipment having scientific validation by applying an offset correction algorithm, as well as a moving average algorithm, to the measurements. The results show that the low-cost Arduino-based measurement system has comparable accuracy to that of industrial sensors, making it a viable option for long-term monitoring of water quality and other environmental parameters.

6. Study Limitations and Conclusion

6.1 Study Limitations

It should be noted that this study was performed in a short-duration and controlled indoor environment, which is a limitation of the current research.

- Indoor Environment: The measurements were only taken in an indoor environment and did not take into account some atmospheric factors such as solar radiation, wind speed or rainfall, which would affect climate conditions or parameters in an outdoor environment. Therefore, the findings cannot be generalized to other environments.
- Short duration: The collected dataset, although adequate for technical assessment and calibration, did not cover the timescale of the seasonal and annual range of variations and the results must be interpreted as a proof of concept rather than a climatological investigation.

6.2 Conclusion

The temperature model is a very easy to use and needs to minimum data maximum temperature. The reference evapotranspiration ETo curve is low in the starting of year due to the cool and rainy season. Then the ETo curve increases gradually to the maximum value in the July due to hot season and then gradually decreases to be less at end year. The Hargreaves method for the ETo is always used in limited climate data. The root mean square error RMSE were 11.3 % for temperature at morning, 11.8% for temperature at noon, and 11.4% for night. The system Arduino can be used a mini weather station with low cost and high performance.

References

A.Abdul Wahhab, I., Bierk, H., & Ahmed Aday, L. (2019). Humidity and temperature monitoring. International Journal of Engineering and Technology, 7(4), 5174-5177. https://doi.org/10.14419/ijet.v7i4.23225

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, rome, 300(9), D05109.

Al-Mahmood, S., & Hassan, H. (2021). Arduino-based mobile weather station for monitoring climate change within immediate environments. Environmental Monitoring and Assessment, 193(2), 1–12.

Al-Shaibani, A., Al-Mahmood, S., & Hassan, H. (2020). Development of an Arduino-based system for remote monitoring of temperature and humidity in Iraq. Journal of Environmental Science, 15(4), 234–242.

Atta, R., Boutraa, T., & Akhkha, A. (2011). Smart irrigation system for wheat in Saudi Arabia using wireless sensors network technology. International Journal of Water Resources and Arid Environments, 1(6), 478-482.

Das, S., Pal, B., Das, P., Sasmal, M., & Ghosh, P. (2017). Design and development of Arduino based automatic soil moisture monitoring system for optimum use of water in agricultural fields. International Journal of Engineering Research and Science, 3(5), 15-19.

Doorenbos, J., & Pruitt, W.O. (1977). Crop water requirements. FAO Irrigation and Drainage Paper 24, FAO, Rome.

Droogers, P., & Allen, R. G. (2002). Estimating reference evapotranspiration under inaccurate data conditions. Irrigation and drainage systems, 16(1), 33-45. https://doi.org/10.1023/A:1015508322413

Gupta, S., & Kaur, H. (2018). Low-cost Arduino based weather monitoring system. International Journal of Computer Applications, 180(8), 35–40.

Hargreaves, G. H., & Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. Applied engineering in agriculture, 1(2), 96-99. https://doi.org/10.13031/2013.26773

Hargreaves, G. L., Hargreaves, G. H., & Riley, J. P. (1985). Irrigation water requirements for Senegal River basin. Journal of Irrigation and Drainage Engineering, 111(3), 265-275. https://doi.org/10.1061/(ASCE)0733-9437(1985)111:3(265)

Hasan, S. S. M. (2016). Auto irrigation using Arduino [Bachelor of Engineering project report, Mumbai University, Anjuman-I-Islam's Kalsekar Technical Campus]

ME, J. (1990). Evapotranspiration and irrigation water requirements. American Society of Civil Engineers. Manuals and reports on engineering practice, 70, 25-41.

Kumar, A., Singh, R., & Soni, P. (2017). Development of a low-cost weather station using Arduino. International Journal of Advanced Research in Computer Science, 8(5), 100–104.

Kumar, A., Yadav, R., & Yadav, S. (2019). Mobile weather station based on Arduino and IoT. International Journal of Engineering and Advanced Technology, 8(6), 1379–1383.

Mishra, A., Kaur, H., & Singh, S. (2021). Low-cost climate monitoring with Arduino for agriculture. Journal of Agricultural Science and Technology, 23(1), 45–53.

Patel, S. D., & Dave, M. (2019). Arduino-based weather station for environmental monitoring. International Journal of Computer Applications, 178(12), 1–5.

Samani, Z. A., & Pessarakli, M. (1986). Estimating potential crop evapotranspiration with minimum data in Arizona. Transactions of the ASAE, 29(2), 522-524. https://doi.org/10.13031/2013.30184

Sharma, N., Gupta, R., & Arora, P. (2019). IoT based weather monitoring system using Arduino. International Journal of Computer Applications, 178(10), 6–11.

Singh, R., Sharma, P., & Bhardwaj, A. (2020). Arduino-based wireless weather monitoring system. International Journal of Innovative Research in Science, Engineering and Technology, 9(5), 4948–4952.

Ujoodha, M., Pultoo, A., & Oojorah, A. (2021). Climate monitoring using an arduino-based mobile weather station and open-source codes. JESS (Journal of Education on Social Science), 16(1), 105-114.

Willmott, C. J. (1982). Some comments on the evaluation of model performance. Bulletin of the American meteorological society, 63(11), 1309-1313. https://doi.org/10.1175/15200477(1982)063%3C1309:SCOTEO%3E2.0.CO;2

Yoder, R. E., Odhiambo, L. O., & Wright, W. C. (2005). Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid southeast United States. Applied engineering in agriculture, 21(2), 197-202. https://doi.org/10.13031/2013.18153

10.61704/pr.508