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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Measurement of Water Depth in a Class A Pan Using Ultrasonic Transducer and Programmable Logic Control (PLC)

Ultrasonik Algılayıcı ve Programlanabilir Lojik Kontrolü (PLC) Kullanarak A Sınıfı Buharlaşma Kabında Su Yükünün Ölçümü

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Abstract

The aim of this study is to compare water depths measured by manually and PLC from a Class A Pan in field conditions using ultrasonic transducer. The study was conducted in garden of Faculty of Agriculture, University of Kahramanmaras Sutcu Imam in the summer season of 2019. A steel meter was used to measure water depth manually in the evaporation pan. Using the ultrasonic transducer, PLC measured water depth from the evaporation pan between 140 and 223 mm water depth at 8:00 am. An ultrasonic transducer is attached one end of sliding buttress, at which was 50 cm above from its inner-bottom at the center of the evaporation pan. The ultrasonic transducer was set to be able to read water depth and calibrated using sliding buttress. A program was written in CODESYS-ST language to measure the water depth from a Class A Pan using PLC, which was connected the ultrasonic transducer and uploaded to PLC. With the program, digital water depths were converted to millimeter water depths. To be able to read the water depth more accurately, each depth value read by the PLC was determined by averaging 30 measurements made successively at 300 millisecond intervals. In this processes, moving average method was used. Water depth measured by PLC was saved on the SD (secure digital memory) card. In the manual water depth measurements, there were 26 observations. The water depths on the manual measurement dates were matched with the water depths measured by PLC. A regression analysis was performed between the water depths measured by the steel meter and PLC in the pan, and determination coefficient (R^2) was result as 0.96. The Mean Absolute Percent Error (MAPE) of these two data sets was calculated as 2.3%. The level of agreement between the two data sets; if the MAPE is below 10%, it is considered “very good”. The results of this study revealed that the PLC could measure the water depth close to the measured manually water depth in the evaporation pan with an ultrasonic transducer.

Keywords: Evaporation pan, Buttress, PLC, Ultrasound, Level.

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Öz

Bu çalışmanın amacı, ultrasonik algılayıcı ve PLC kullanarak arazi koşullarında A sınıfı buharlaşma kabından PLC ve elle ölçülen su derinliğini karşılaştırmaktır. Çalışma, Kahramanmaraş Sütçü İmam Üniversitesi Ziraat Fakültesi bahçesinde 2019 yaz sezonunda yapılmıştır. Buharlaşma kabı su derinliğinin elle ölçümlerinde, çelik metre kullanılmıştır. PLC ve çelik metre ile su derinliği ölçümleri, buharlaşma kabındaki su derinliğinin 140 ile 223 mm'lik su seviyesi arasında sabah saat 8:00'de yapılmıştır. Bir ultrasonik algılayıcı, bir hareketli payandanın bir ucuna bağlanmıştır. Hareketli payandaya tutturulan ultrasonik algılayıcı, anılan haraketli payandadan yararlanarak buharlaşma kabının ortasına ve iç-tabanından 50 cm yüksekliğe gelecek şekilde yerleştirilmiştir. Ultrasonik algılayıcının okuma ayarları yapılmış ve söz konusu algılayıcı, hareketli payandadan yararlanarak kalibre edilmiştir. PLC ve ultrasonik algılayıcı kullanarak A sınıfı buharlaşma kabından su derinliğini ölçmek için CODESYS-ST dilinde bir program yazılmış ve PLC'ye yüklenmiştir. Bu programla okunan sayısal değerler milimetre cinsinden su derinliğine dönüştürülmüştür. PLC tarafından ölçülen derinlik değerlerini daha doğru okumak için arka arkaya 300 mili saniyede bir 30 dijital değer alınmış ve anılan değerlerin ortalaması bulunmuştur. Bu işlemde hareketli ortalama yöntemi kullanılmıştır. PLC ile ölçülen su derinliği değerleri, SD (secure digital memory) karta kaydedilmiştir. Elle ölçümde toplam gözlem sayısı 26'dır. Elle ölçüm tarihlerindeki su derinlikleri, PLC ile ölçülen su derinlikleri ile eşleştirilmiştir. Bu iki su derinliği değerleri arasında regresyon analizi yapılmış ve belirleme katsayısı (R^2) 0.96 olarak belirlenmiştir. Anılan verilerin Ortalama Mutlak Yüzde Hata (MAPE)'sı %2.3 olarak hesaplanmıştır. İki veri değerleri arasındaki uyum düzeyi; MAPE %10'un altında ise "çok iyi" olarak değerlendirilmektedir. Bu çalışmanın sonuçları, PLC'nin ultrasonik algılayıcı ile buharlaşma kabındaki su derinliğini, doğruya yakın ölçebileceğini ortaya koymuştur.

Anahtar Kelimeler: Buharlaşma kabı, Payanda, PLC, Ultrason, Seviye.

1. Introduction

Class A pan is used in the preparation of irrigation scheduling for plants grown both in field and greenhouse conditions in the Faculties of Agriculture of the Universities and Agricultural Research Institutes. Evaporation from a Class A pan is called pan evaporation. In irrigation scheduling, Reference evapotranspiration (Eto) is calculated from pan evaporation by multiplying the pan coefficient (Ep) and plant evapotranspiration (Etc) is calculated from Eto by multiplying the crop coefficient (kc) (USDA, 1993; Gençoğlan et al., 2006; Gencoğlan and Kıraç, 2008).

In many countries on the world, Class A pan is used to create real-time irrigation program (Huang et al., 2001). In irrigation programming, Class A pan should be made, installed and managed in accordance with its technique. Besides, an appropriate pan coefficient should be selected (Huang et al., 2002). There are many studies carried out using Class A pan in irrigation scheduling of plants. Some of these are: Kanber et al. (1991); Yazar et al. (1991); Çevik et al. (1991); Ertek and Kanber, (2001); Gençoğlan et al., (2006); Ertek et al., (2006); Kıraç, (2007); Gençoğlan and Kıraç, (2008); Ünal, (2008); Ünlü et al., (2014); Gençoğlan et al., (2019); Yenigün and Erdem, (2019); Azder et al., (2020). In this respect, it is very important to accurately measure the water depth in the Class A pan in the creation of a real-time irrigation program.

Daily water depth measurements in Class A pans and refilling them with water up to a certain level are generally done by human hands in our country. In practice, the human errors in the measurements and the daily measurements by human being in Class A pan, which increases labor costs, could be seen as the negative aspects of it in irrigation programming. To decrease negative aspects of it and to increase usage in irrigation programming, the first automation studies of Class A pan started by Summer (1963) and continued by Phene and Campbell (1975), Burgess and Hanson (1981), Asrar et al. (1982), Van Haveren (1982), McKinion and Trent (1985), Boughton and McPhee (1987), Thibault and Savoie (1989), Phene et al. (1992), Mbajiorgu and Wilkie (1995), Caissie (2011), Gençoğlan et al. (2013), Fisher and Sui, (2013), Gençoğlan and Gençoğlan (2016), Yıldırım (2016), Sezer et al. (2017), Yahaya et al. (2018), Hasanuddin (2019) and Gençoğlan et al. (2021). Ultrasonic sensor started to use on automation of Class A pan since 2013. The ultrasonic sensor sends the ultrasonic wave towards an object at the speed of sound, and the echo that hits the object returns to the detector. The distance from the sensor to the object is calculated according to the time elapsed between sending the wave and returning the echo (Fisher and Sui, 2013). Ultrasonic sensors with many different features are sold in the market. Using ultrasonic sensor with different properties and methods, some researchers had measured the depth of water in Class A pan to determine pan evaporation (Gençoğlan et al., 2013; Fisher and Sui, 2013; Sezer et al., 2017). On the other hand, the water depth in the pan was measured using a pressure sensor in workshop and field conditions (Gençoğlan and Gençoğlan, 2016; Gençoğlan et al., 2021). In this study, the water depth in the pan was measured by attaching the ultrasonic sensor to one end of a buttress.

The aim of this study is to measure the water depth using an ultrasonic sensor and PLC in Class A pan under field conditions and compare it with the water depth values measured with a steel meter.

2. Materials and Methods

This study was carried out in the orchard (37°32'08" and 36°54'59" East and 700 meters above sea level) in Kahramanmaraş Sütçü İmam University, Faculty of Agriculture Research Area in order to compare the water depth values measured by PLC and steel meter from A Class evaporation pan. Water depth measurements in Class A pan were made in July and September 2019. During the study period, the monthly average wind speed varied between 0.9 (light) and 2.0 m s^{-1} (moderate).

Class A pan was placed on the wooden platform near the pear orchard, which was set and levelled on the ground in a grassy location, away from any obstacles which obstructed a natural air flow around the pan. To measure the water depth in the pan under field conditions, ultrasonic sensor and a steel meter were utilized. The ultrasonic sensor was placed in the centre of the evaporation pan by means of a buttress (*Figure 1*). On the other hand, to reduce the shading of the buttress on pan, it was attached to the northwest corner of the wooden platform (*Figure 2*). The dimensions of this buttress were given in *Figure 3*. The input of the ultrasonic sensor is 24 VDC and the output is 4-20 mA, and its sensing range is between 60-2000 mm, and adjustment range is between 90-2000 mm. The standard target plate of the sensor is 100x100 mm (Anonymous, 2022). A solenoid valve is used to automatically fill the Class A pan with water and its input is 24 VDC (*Figure 1*). In the study, a control system was used to measure the depth of water in Class A pan with an ultrasonic sensor (*Figure 4*). The control system consisted of circuit breaker power supply, PLC (CPU PM564), analog module (AX561), relays and clemens. Ultrasonic sensor output is connected to I0+ and R0 channels of analog module (AX561) and common terminal is connected to I0- channel (*Figures 5* and *6*). In the PLC, address of the I0+ channel is %IW0 and its channel input is selected as 4-20 mA. PLC converts 4-20 mA input analog values to 0-27648 (normal range) numerical values.

Since the distance between the ultrasonic sensor and the bottom of the Class a pan is approximately 500 mm, the sensing distance was taken as 500 mm. For this reason, the system given in Figure 7 was used to convert the sensing range of the ultrasonic sensor to 90-500 mm. In this system, there are an ultrasonic sensor-buttress and a board, and their distance between them was 500 mm. For this purpose, the ultrasonic sensor was connected to the buttress end. The method suggested by Anonymous (2022) and Tüysüz (2018) was used to change sensing rage of the ultrasonic sensor at a distance of at least 60 mm and at most 500 mm. Accordingly, ultrasonic sensor can send waves up to 500 mm. In the chancing sensing range, the target board was chosen larger than the standard size.

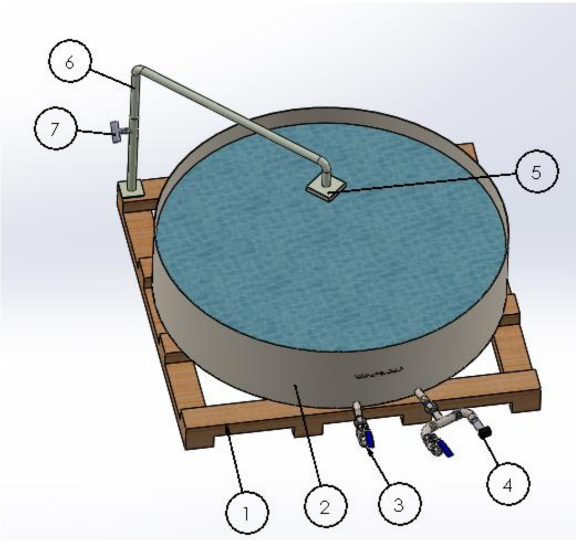

Figure 1. Class A pan and its elements (1-platform, 2-Pan, 3-Water supply, 4-Pressure sensor, 5-Ultrasonic sensor, 6-Buttress, 7-Clamping screw)

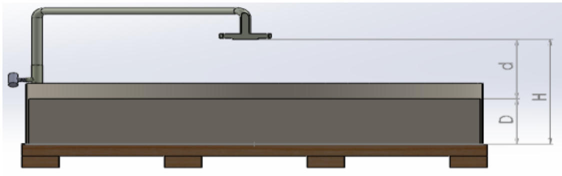

Figure 2. Location of the ultrasonic sensor on Class A pan

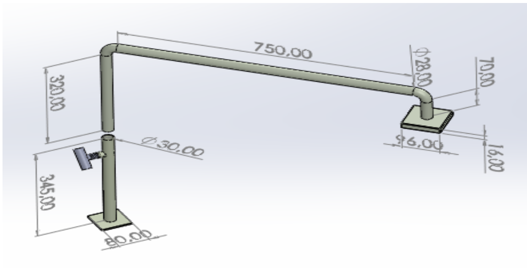

Figure 3. Buttress of ultrasonic sensor

Equation 1 was used to measure the depth of water in a Class A pan with an ultrasonic sensor (Gençoğlan and Tüysüz, 2018).

$$D=H-d \qquad \text{(Eq. 1)}$$

Where, D; Water depth in A class pan (mm), H; distance (mm) between the ultrasonic sensor and the bottom of the Class A pan, and d; distance from the ultrasonic sensor to the water surface (mm).

A program was written in CODESYS-ST language in order to measure the water depth in Class A pan with PLC using an ultrasonic sensor and the flow chart of the program is given in *Figure 8*. In this program, digital values are converted to water depth varying between 0-210 mm with the help of the LIN_TRAFO function. Each measurement value read by the PLC was determined by averaging 30 measurements made successively at 300 ms intervals. In this processes, moving average method was used (Tülücü, 2002). The water depth average was determined according to the moving average method. In addition, water depths measured by PLC were calibrated. For this reason, the pan was first filled with water at a depth varying between 150-200 mm. Then, the water depth in the pan was measured with a steel meter. Then, it was connected to the PLC online with the computer and at that moment the water depth in the pan was read, which value was compared with the value measured with the steel meter. By loosening the clamping screw of the buttress given in *Figures 1* and *3*, the upper part of the buttress was moved up and down until these two values are equal to each other. At the end of the calibration, the pan was filled with water to a depth of 200 mm, and water depth was recorded on the SD card at 8:00 am. When the water

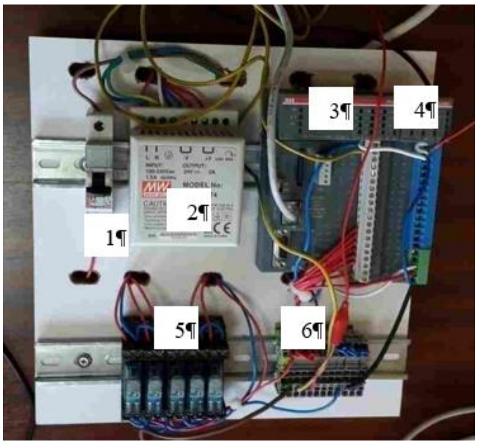

Figure 4. Control unit measuring water depth in Class A pan (1-circuit breaker 2-power supply, 3-PLC (CPU), 4-analog module, 5-relays and 6-clemens)

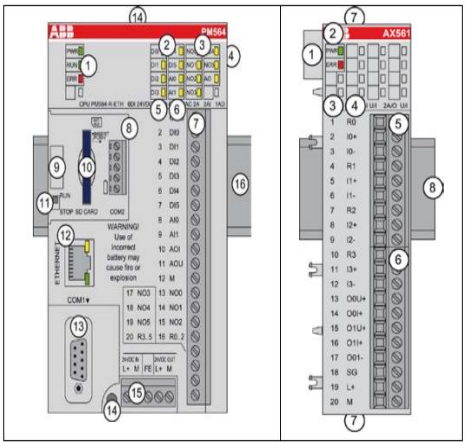

Figure 5. Detailed view of PLC's CPU and analog module (ABB, 2022)

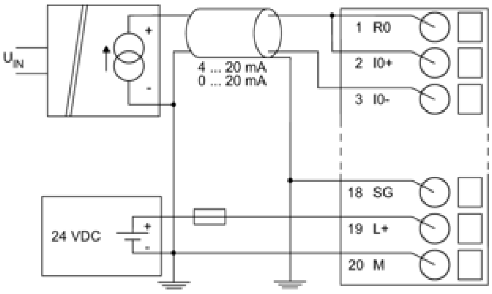

Figure 6. Connection of ultrasonic sensor to the analog module (ABB, 2022)

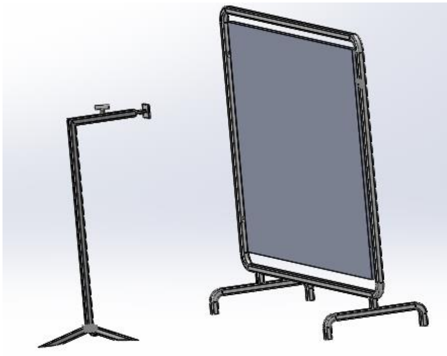

Figure 7. Sensing range adjustment board for ultrasonic sensor

depth in the pan decreased to 150 mm by evaporation, it was recorded at 8:00 on SD card and it was filled to a depth of 200 mm and recorded to the SD card at 8:05 again. It was waited for 5 minutes for the water ripple in the pan to stop. Water depth measurements with steel meter were made after PLC measurements. A total of 26 observations were taken in July and September in years of 2019. A regression analysis was performed between the water depths in the pan measured by the steel meter and PLC. On the other hand, Absolute Average Percentage Error (MAPE) (Lewis, 1982), which is an expression of the deviation of the water depth measured by the steel meter in the pan from the water depth measured by the PLC, was calculated from Equation 2.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|WDSM_i - WDUS_i|}{WDSM_i}100\right) \quad \text{(Eq.2)}$$

Where, WDSMi; water depth measured by steel meter (mm), WDUSi; water depth measured by ultrasonic sensor (mm), n; is the number of observations.

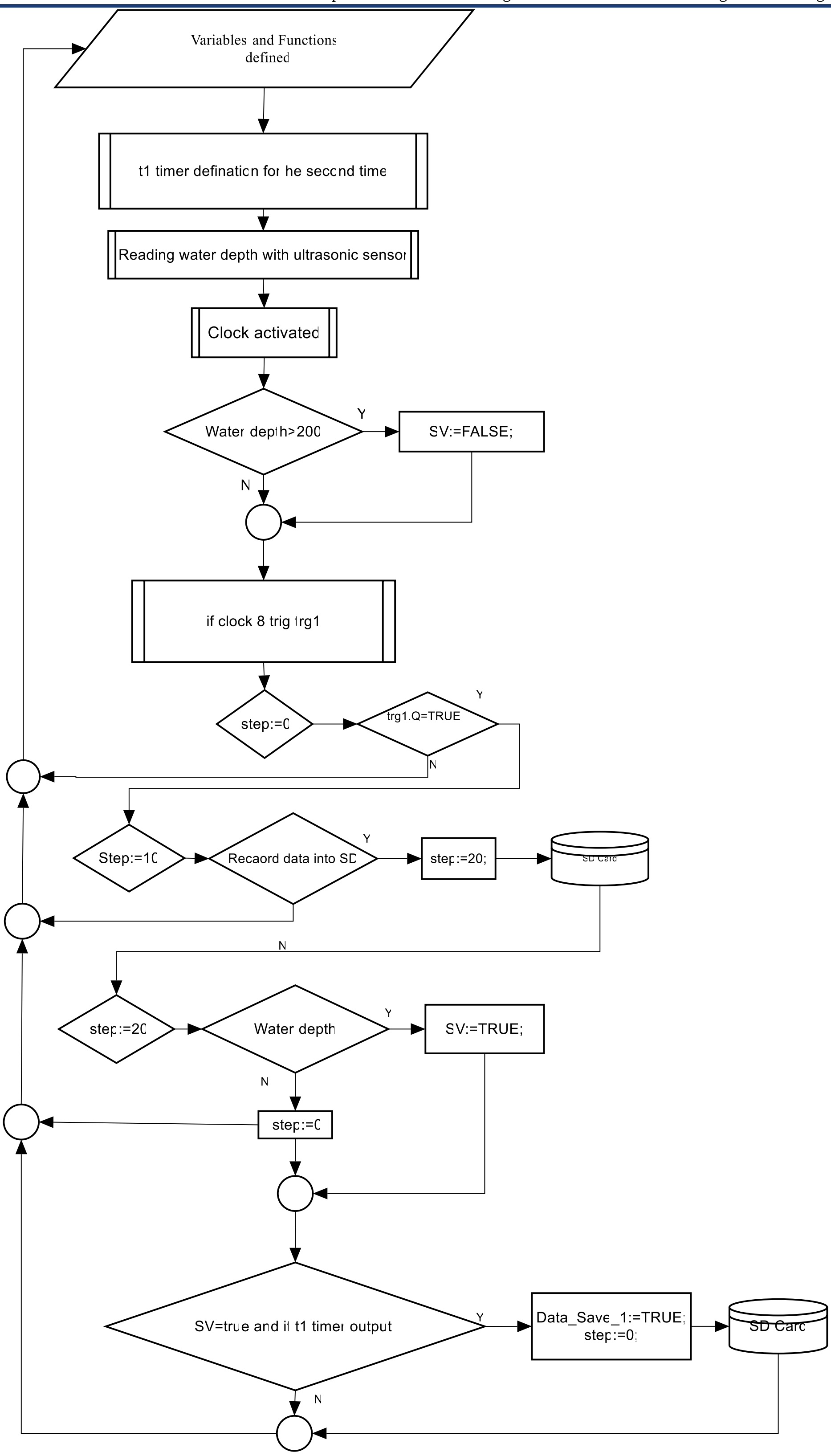

Figure 8. Flow chart of program of PLC used to measure water depth in Class A pan

3. Results and Discussion

This study was carried out to measure the water depth using an ultrasonic sensor and steel meter in the Class A pan under field conditions and to compare them. Water depths were measured 26 times from the pan at 8 o'clock in July and September (*Figure 9*). The averages of 26 water depth values measured by steel meter and ultrasonic sensor were 171.56±4.1 mm and 172.5±3.6 mm, respectively. The highest difference between these two water depth values is 8 mm and the average of the absolute differences is 3.85 mm. The standard error of water depth measured by ultrasonic sensor is lower than the standard error of water depth measured by steel meter. The regression equation between these two data sets was determined as WDUS = 0.88WDSM + 22.3 and the coefficient of determination (R^2) was 0.96. The slope of the equation and the intercept point on Y-axis approached 1 and 0 (zero), respectively. The ratio of representing water depth values measured with ultrasonic sensor to water depth values measured with steel meters is 96%. The level of agreement between the water depths measured by both the steel meter and the ultrasonic sensor in the pan was calculated as MAPE of 2.3%. The level of agreement between the two data sets; if MAPE is below 10%, it is considered as "very good", between 10-20% as "good", between 20-50% as "acceptable" and above 50% as "inconsistent" (Lewis, 1982). Both R^2 and MAPE demonstrated that ultrasonic sensor could read the water depth in the pan with very high accuracy.

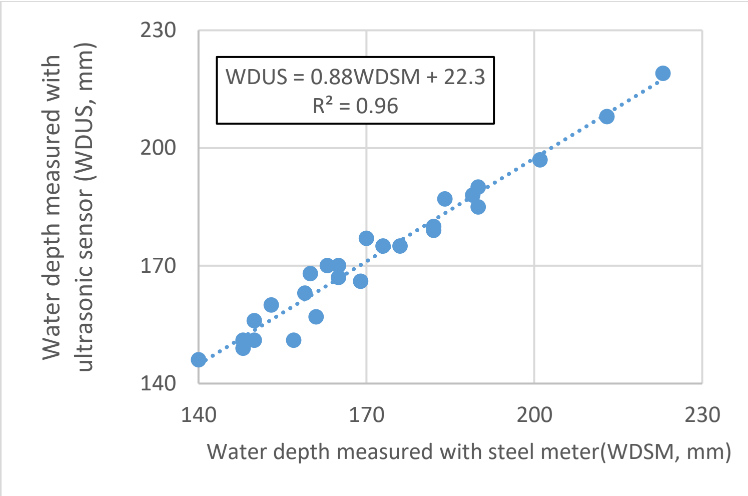

Figure 9. Water depth values measured in Class A pan with steel meter and ultrasonik sensor

In the study of Gençoğlan et al. (2013) stated that they could measure the depth of water in the Class A evaporation pan with an absolute error of less than 1 mm in both waveless and undulating conditions, in their study conducted under workshop conditions using a PLC and ultrasonic sensor. Fisher and Sui (2013) measured the water depth in the evaporation pan using an ultrasonic sensor and found values close to the hand-measured water depth. Sezer et al. (2017) stated that the accurate measurement of the amount of evaporation from a class A evaporation pan using an ultrasonic sensor varies depending on the evaporation amount. It was suggested usage of more sensitive ultrasonic sensor, and a floatable flat float on the surface of the water to be able to measure at higher depths in the metal pipe, and reducing diameter of the metal pipe as much as possible to affect evaporation minimum. Gençoğlan and Tüysüz (2018) measured the water depths and flow rates in the open channel using PLC, rating curve, pressure and ultrasonic sensor. On the other hand, they compared the water depth and flow rates measured with the electronic limnigraph with the water depth and flow rates measured by pressure and ultrasonic sensor. The researchers determined that the water depth and flow rates of the pressure and ultrasonic sensor were not statistically different from that of the electronic limnigraph's. They resulted that water depth and flow could be measured in an open channel using pressure and ultrasonic sensors.

The most important factor negatively affecting the water depth measurements in the Class a pan is the fluctuation of the water and noise. When the water in the evaporation pan fluctuates, the water depth in the pan changes. Accordingly, the water depth read by the PLC also changes. When the water fluctuation in the evaporation pan stops, the value read approaches the constant (Gençoğlan et al., 2013). On the other hand, there are signals called noise around. These signals change the numerical values determined by the PLC.

4. Conclusions

The water depths in the Class A pan were measured in field conditions using an ultrasonic sensor and compared with the water depth values measured with a steel meter. The standard error of the water depth measured with the ultrasonic sensor was found to be lower than the standard error of the water depth measured with the steel meter. The determination coefficient was acceptable level and the slope and intercept of the regression equation approached 1 and 0 (zero), respectively. On the other hand, it was determined that the conformity of MAPE between the water depths measured by the steel meter and the ultrasonic sensor in the pan was at a very good. It is concluded that the water depth in the pan can be measured with very high accuracy using an ultrasonic sensor.

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