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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Evaluation of Water Levels and Flow Rates Measured in Irrigation Canal Using Limnigraph, Pressure and Ultrasonic Sensors*

Sulama Kanalında Limnigraf, Basınç ve Ultrasonik Sensörler Kullanılarak Ölçülen Su Seviyeleri ve Debilerinin Değerlendirilmesi

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Abstract

Anything that cannot be measured cannot be managed. Based on the thought, the aims of this study are to evaluate water levels and flow rates measured by Limnigraph (OEL), pressure sensor (PS) and ultrasonic sensors (US) in the open irrigation canal. Limnigraph and pressure sensor sensed water levels and flow rates under un-fluctuating conditions in the Stilling Well and ultrasonic sensors directly measured them from water surface under fluctuating conditions at the Kartalkaya Dam in Kahramanmaraş. Assuming Limnigraph water level and flow rates readings correct and water levels and flow rates of Limnigraph were compared with that of pressure and ultrasonic sensor. Mean Absolute Percentage Error (MAPE) and ANOVA tests were done on 2454 observations. Average of water level and flow rates of limnigraph, pressure and ultrasonic sensor were 928±4.9 mm and 4.61±0.038 m^3s^{-1}, 927±4.9mm and 4.62±0.037 m^3s^{-1}, and 922±4.9 mm and 4.58±0.037 m^3s^{-1}, respectively. Differences between the average water levels and flow rates were 1 mm (928-927) and 0.01 m^3s^{-1} (4.61-4.62) under un-fluctuating and 6 mm (928-922) and 0.03 m^3s^{-1} (4.61-4.58) under fluctuating conditions. The fluctuation increased the differences between the average water levels and flow rates. MAPE of water levels and flow rates for pressure and ultrasonic sensor were calculated as 0.741% and 1.466% under un-fluctuation, and 1.453% and 2.490% under fluctuation conditions, respectively and since they were below 10%, the levels of agreement between the two data sets are considered as "very good". However, fluctuation conditions increased MAPEs from 0.741% to 1.453%, from 1.466% to 2.490%. The water levels and flow rates of both sensors were not statistically different from those of optic encoder Limnigraph. Accordingly, both sensors can be used to measure water levels and flow rates in open irrigation canal but un-fluctuating conditions should be preferred. In addition, ultrasonic sensors can be used in environments that block, corrode the pressure sensors and make it difficult to use by floating objects.

Keywords: PLC, Pressure and ultrasonic sensors, Stilling well, Water head, Rating curve.

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Öz

Ölçülemeyen hiçbir şey yönetilemez. Bu düşünceden hareketle, bu çalışmanın amacı, açık sulama kanalında Limnigraph (OEL), basınç sensörü (PS) ve ultrasonik sensör (US) ile ölçülen su seviyelerini ve debilerini değerlendirmektir. Kartalkaya Barajı'nda sol sahil sulama kanalında su seviyesi ve debiler, sulama mevsiminde akım gözlem istasyonunda (AGİ) ölçülmüştür. Akım gözlem istasyonunda limnigraf ve basınç sensörü, su seviyelerini dalgalanmayan koşullar altında ve ultrasonik sensörler ise dalgalı koşullar altında doğrudan su yüzeyinden ölçmüştür. Limnigraph'ın su seviyesi ve debi değerlerinin temel alınarak, basınç ve ultrasonik sensörün su seviyeleri ve debi değerleri ile karşılaştırılmıştır. Ortalama Mutlak Yüzde Hatası (MAPE) ve ANOVA testleri 2454 gözlem değeri üzerinde yapılmıştır. Limnigraf, basınç ve ultrasonik sensörün ortalama su seviyesi ve debisi sırasıyla 928±4.9 mm ve 4.61±0.038 m^3s^{-1}, 927±4.9 mm ve 4.62±0.037 m^3s^{-1}, 922±4.9 mm ve 4.58±0.037 m^3s^{-1}'dir. Ortalama su seviyeleri ve debiler arasındaki farklar, dalgasız ortamda 1 mm (928-927) ve 0.01 m^3s^{-1} (4.61-4.62), dalgalı koşullar altında 6 mm (928-922) ve 0.03 m^3s^{-1} (4.61-4.58)'dir. Basınç ve ultrasonik sensörün belirlediği su seviyeleri ve debilerinin MAPE'si dalgasız koşullarda sırasıyla %0.741 ve %1.466, dalgalı koşullarında ise %1.453 ve %2.490 olarak hesaplanmıştır. Bu değerler, %10'un altında oldukları için iki veri seti uyumu "çok iyi" olarak kabul edilmektedir. Dalgalanma koşullar, MAPE değerleri %0.741'den %1.453'e, %1.466'dan %2.490'a yükseltmiştir. Dalgalı koşullar ortalama su seviyesi ve debi değerleri arasındaki farkı ve MEPA değerlerini artırmıştır. Her iki sensörün su seviyeleri ve debileri, limnigrafın değerlerinden istatistiksel olarak farklı değildi. Buna göre, açık sulama kanalında su seviyelerini ve debileri ölçmek için her iki sensör de kullanılabilir ancak dalgalı olmayan koşullar tercih edilmelidir. Ayrıca ultrasonik sensörler, basınç sensörlerini tıkayan, aşındıran ve yüzen nesneler tarafından kullanılmasını zorlaştıran ortamlarda kullanılabilir.

Anahtar Kelimeler: PLC, Basınç ve ultrasonik sensör, AGİ, Su yükü, Anahtar eğrisi

1. Introduction

Since climate change is experienced and water is scarce on world, freshwater should be managed effectively (Li et al., 2020; Çetin et al., 2020; Ali et al., 2021). In Turkey, around 74% of fresh water is used in irrigation (Ministry of Development, 2018). The majority of the irrigation water is distributed through the open canal system with low efficiency in agricultural schemes (Çakmak and Tekiner, 2010). Especially in arid and semi-arid regions where water resources are scarce, the most efficient use and management of irrigation water has become a very important issue. As is mentioned by Garvin (1993), anything that cannot be measured cannot be managed. Therefore, the flow rates of irrigation water have been measured with a limnigraph or limnimeter using the rating curve at the beginning of the main irrigation canal. However, at the beginning of secondary and tertiary canal, it is measured using only limnimeter and rating curve (Acatay, 1996; Léonard et al., 2000). In addition, the water level in rivers, drainage canals, dams, lakes, flood controls and wastewater management are measured with limnigraph or limnimeter (Meral and Benli, 2013). Limnimeters are made of wooden or metal with different lengths and scaled in centimeters. Limnigraphs have different measurement systems such as float-optic encoder, magnetic encoder, radar, ultrasonic and pressure sensors. Of these, magnetic and float limnigraphs measure the water level mechanically. On the other hand, the rating curve is the function (Q=f(h)) of the water levels (h) measured in a certain cross-section of a stream (Chow et al., 1988; Léonard et al., 2000; Tülücü, 2002; Çetin et al., 2020).

The first water depth measuring instruments was limnimeters. Later, float limnigraphs (optic encoder limnigraph) were developed (Chow et al, 1988). The optic encoder limnigraphs have an LED light source, a light detector, a "code" disc/wheel mounted on the shaft, and output signal processor.

The sensor technology is the key for measurement and automation (Zhao and Wen, 2008). Therefore, in this study, pressure and ultrasonic sensors were used as limnigraph. A pressure sensor is a device that senses pressure and converts it into an electric signal where the amount depends upon the pressure applied (Trout, 1986; Huang et al., 2019). Pressure sensors are widely used in hydrogeological and hydrological sciences for monitoring water levels (Sorensen and Butcher, 2011) and water level could be measured with high accuracy (Yuliza et al., 2016). Pressure sensors have some advantages such as accurate measurement in low flow water, being suitable to be installed in river with steep slope elevation and less need for maintenance. They have some disadvantages such as accuracy drops in high flow condition, difficulty in maintaining as the sensor body may submerge in river sedimentation and susceptible to lightning surge problem (Hydrological Procedure, 2018). On the other hand, an 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; Varun et al., 2018). Ultrasonic sensors have some advantages such as accurate reading in both low and high flow conditions, no contact with water, making it easy for maintenance and no lightning surge problem and they have some disadvantages as fallows; susceptible to blockage of object which will result in reading error. Limitations such as deadband and bean angle, which require ultrasonic water level sensor to be installed at correct position. Ultrasonic wave is more sensitive, which may cause errors in reading, especially in water with debris. In addition, it is not suitable to be installed at area with high elevation riverbank (Hydrological Procedure, 2018).

To measure water levels and flow rates with float limnigraph (encoder optic limnigraph) in open irrigation canal it is needed a special expensive structure called stilling well, but no need it for pressure and ultrasonic sensors. Pressure sensors measure water levels directly since they are submergible, and ultrasonic sensors needs only a buttress. In addition, getting the accurate measurement in open canal is more difficult because there is an influence of external factors such as the formation of the wave, irregular channel structures and floating objects on the water surface (Rahman et al., 2017). In this context in the last 40 years, water level measurement studies have been carried out in laboratory conditions using pressure and ultrasonic sensors. However, studies that directly measure water level and flow rate in irrigation canals using these two sensors are very limited. In Turkey, PSs are used much less but USs much more in water level and flow rate measurement.

Using pressure sensor, the following studies were conducted. Trout (1986) measured water level in open canal. Harlan et al. (2021) determined flow rates in river. The water velocity in a rectangular canal was measured by integrating-float method under laboratory conditions and then the flow rate was calculated (Abed, 2021). In a study by Çetin et al. (2020), water levels and flow rates were measured using float limnigraph (encoder optic limnigraph) both in irrigation and drainage canals. Gençoğlan and Gençoğlan (2016) and Gençoğlan et al. (2021) measured water level in Class A pan in workshop and field conditions.

Flow rates in open canals were monitored using an ultrasonic sensor under laboratory conditions by Dusarlapudi et al. (2020) and Koshoeva et al. (2021), and the water levels were measured in open canals by Nirupam et al. (2015), Rahman et al. (2017), Sai (2017) and in tanks by Kumar and Verma (2015), Varun et al. (2018), Bello et al. (2018), Selvan et al. (2018), Mohammed et al. (2019) and in the rivers by Meral and Benli (2013), Machado, et al. (2021). For rivers, they also calculated flow rates using water level and rating curve. In Turkey, in recent years, water levels and flow rates have started to measure by using ultrasonic sensors in dams, irrigation regulators and main open irrigation channels. On the other hands, using ultrasonic sensor, some researchers had measured the water level in Class A pan to determine pan evaporation (Gençoğlan et al., 2013; Fisher and Sui, 2013; Sezer et al., 2017; Gençoğlan et al., 2022).

In accurate measurement for water level and flow rates in open irrigation canal, selection and use of the right measuring device and technique are important. With the development of technology, sensors such as PSs and USs and others have started to replace OEL because expensive structure like Stilling Well is needed to measure water levels and flow rates with OEL. PSs and USs do not need it and need only panel. In recent years, PSs and USs have been increasingly used in measuring water levels and flow rates in open irrigation canal.

The aim of this study is to evaluate the water levels and flow rates measured by OELs, PSs and USs in the open irrigation canal.

2. Materials and Methods

The study was carried out at the flow gauging station (FGS) located on the left bank main (conveyance) irrigation canal of the regulator of Kartalkaya Dam. Kartalkaya Dam is located 30 km southeast of Kahramanmaraş province. The measurements were done in the trapezoidal section, concrete-lined, left bank open irrigation canal in irrigation season in 2017.

At FGS, there was no collection of water, erosion and siltation since open canal was lined with the concrete. FGS had a Stilling Well of 80x80x240 cm and also 30 cm diameter and 3 m long pipe on which there was a shelter of 80x50x60 cm. The float limnigraph was available at the FGS. At FGS, a panel (50x50x80 cm) was placed under the shelter to measure the water levels and flow rates at cross-section of the open irrigation canal using pressure and ultrasonic sensor (*Figure 1*). In order to provide energy to the panel, the solar panel was installed on the guardrails of the observation bridge, in such an angle that it could receive the full sun, and the ultrasonic sensor was attached perpendicular to the water surface at the lower part and the middle point of the bridge (*Figure 2*). Inside the panel, there are circuit breaker, PLC, SD card module, analog module, solar regulator, inverter, power supply, router-modem with FTP, 3G vinn modem, and electrical outlet. The solar panel charged a battery, which was placed in the float limnigraph shelter, and it supplied power to the instruments in the panel.

In FGS, there was available float limnigraph (Optic Encoder Limnigraph, OEL). It was measuring the water level and flow rate mechanically by means of a float system and was configured to record them in 15 minutes interval by DSİ. Specification of OEL; accuracy is 1mm, tolerance ±1mm, logging time range 1, 5, 10, 15, 60....1440 minutes, output 4...20 mA, power 3.6V. The measured water level and calculated flow rates at FGS were recorded in the EEPROM of OEL. Computer was connected to OEL via the RS232 protocol using the interface program and the measured 2454 water level and flow rates were downloaded to the computer.

In the current study, measuring interval of pressure and ultrasonic sensor was selected 15 minutes since measuring interval of OEL was 15 minutes, and time was coincided.

The pressure sensor has input power 10-32 DCV and output 4-20 mA (Karabacak, 2003; Hashemian and Jiang, 2009). Its measurement capacity is 400 mBar, which is equal to water level of 4000 mm H_2O. Its standard accuracy is ≤±0.5% full scale (FS) or of span (Atek, 2020).

The input and output of the ultrasonic sensor is 24 VDC and 4-20 mA, and its sensing range is between 60-2000 mm, and adjustment range is between 90-2000 mm and repeat accuracy is ± 0.1 % of full-scale value (Pepperl and Fuchs, 2022).

The PLC has six digital inputs (DI, 24 VDC), six digital outputs (DO, 24 VDC, 0.5 A max., with transistor), 2 analog inputs (AI, voltage 0...10 V), 1 analog output (AO, voltage 0...10 V or current 0...20 mA/4...20 mA).

Analog (AI/AO) module had four configurable AI, 2 configurable AO, resolution 11 bits plus signal or 12 bits and measuring range from 0 to 27648 for 4-20 mA.

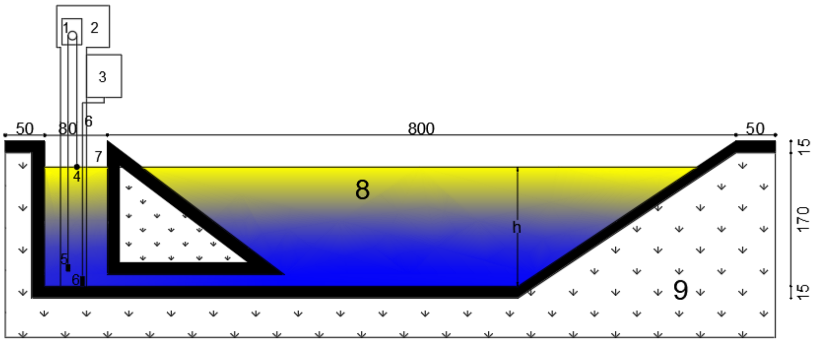

Figure 1. Cross section of trapezoidal type main irrigation canal and FGS (1-Limnigraph, 2-Limnigraph shelter, 3-PLC panel, 4-Limnigraph ball, 5-Limnigraph weight, 6- pipe, 7-FGS box, 8-Water cross-section, 9 -Canal fill section)

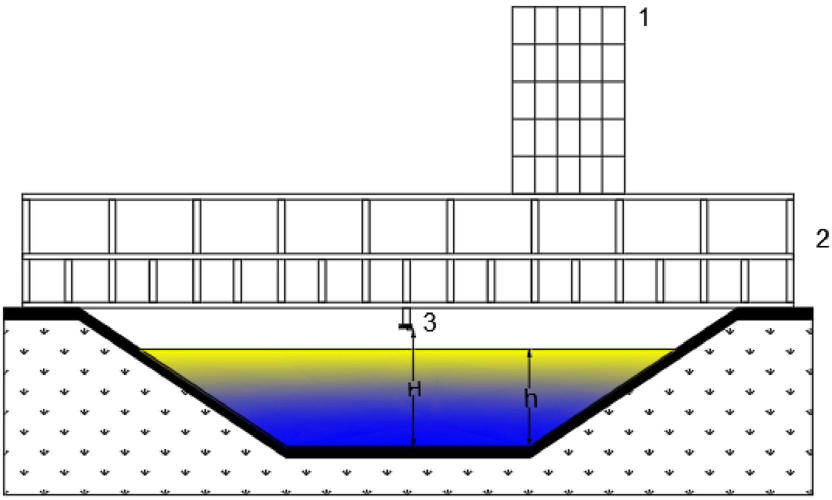

Figure 2 Trapezoidal main canal, bridge section and solar panel (1-solar panel, 2-bridge, 3-ultrasonic sensor)

Water levels and flow rates read by OEL were assumed to be correct and they were compared with water levels and flow rates of pressure and ultrasonic sensor. Measurement times of water levels and flow rates of pressure and ultrasonic sensor were coincided with the OEL's time, at 15-minute intervals. Since the water level in the open canal is affected by the fluctuation, in order to minimize its effect, successive 30 water levels were measured every 300 ms and their moving average was taken (Tülücü, 2002; Gençoğlan et al., 2013).

The digital water levels measured by pressure and ultrasonic sensor were converted to the water levels in millimeter using Equation 1 and 2, respectively.

$$h_{ps} = \frac{ps_{dv}x4000}{27648} \quad \text{(Eq. 1)}$$

$$h_{us} = H - \frac{us_{dv}x2000}{27648} \quad \text{(Eq. 2)}$$

Where, h_{ps}; water level measured with pressure sensor (mm) ve ps_{dv}; pressure sensor digital value, h_{us}; water level measured with ultrasonic sensor (mm), H; distance between canal floor and ultrasonic sensor (mm), us_{dv}; ultrasonic sensor digital value. The digital value of 27648 in Equation 1 and 2 corresponds to 4000 mm in pressure sensor and 2000 mm in ultrasonic sensor for 20 mA.

Since management of canal is under State Hydraulic Work (DSİ) and it was impossible to measure data of rating curve by us on the left bank of the regulator and therefore, the data of the rating curve was taken from DSİ (DSİ, 2017). Rating curve data consisted of independent (water levels) and dependent parameter (flow rates) (Alfa et al., 2018). The water level in the rating curve of the canal varies between 100-1610 mm and the flow rate between 0.2-12.050 m^3s^{-1}. To be able to use the key curve in the PLC program, a regression analysis was performed between 152 water levels and flow rates to establish polynomial rating curve. The curve was established as in Equation 3.

$$Q=ah^2+bh+c \qquad \text{(Eq. 3)}$$

Where, Q; flow rates (m^3sn^{-1}) and h water level (mm).

In irrigation canal, the flow rates were predicted directly by substituting h_{ps} and h_{us} for h in Equation 3.

A PLC project was created and then, a program was written in CODESYS-ST language to automatically determine the water levels and flow rates. This program consisted of two parts. The first section contained the program codes, and the second section is the visualization section, in which the instantaneous water levels and flow rates in the canal were directly visualized. In this project, an analog module was added to the PLC in order to read the pressure and ultrasonic sensor analog outputs. Since the pressure and ultrasonic sensor analog outputs are 4-20 mA, the input of the analog module was selected as 4-20 mA. The addresses of these inputs are %IW0 and %IW1. The types of these addresses are INT. IP numbers should be the same group in order to establish the network connection between the computer and the PLC. Web and FTP servers were activated for remote connection. Web port is taken as 80 and FTP as 21. Water levels and flow rates were recorded in SD card in every 15 minutes (Machado et al., 2021). The second section visual display interface was made in order to instantly monitor the water levels and flow rates in the open canal on the visual screen via the web browser.

Mean Absolute Percentage Error (MAPE) (Lewis, 1982) for the water depth and flow rates of PS and US were calculated from Equation 4. It is an expression of the deviation of the water depth and flow rates measured by OEL in the irrigation canal from the water depth measured by pressure and ultrasonic sensor.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|WD_{OELi}-WD|}{WD_{OELi}}100\right) \qquad \text{(Eq. 4)}$$

Where, WD_{OELi}; water depth measured by pressure sensor (mm), WD; water depth measured by pressure and ultrasonic sensor (mm), n; the number of observations (2454 times).

In addition, the ANOVA tests were performed in the Minitab program to determine whether there is a difference among the water levels and flow rates measured by the EOL, PS and US.

3. Results and Discussion

In this study, the water level and flow rates were measured by Optic Encoder Limnigraph (OEL), pressure (PS) and ultrasonic sensor (US) in open irrigation canal at FGS in the Kartalkaya Dam. Water levels and flow rates read by OEL were assumed to be correct and they were compared with water levels and flow rates of pressure and ultrasonic sensor. OEL and PS measured them in Stilling Well (under un-fluctuating) and US directly from water surface (under fluctuating).

At FGS, a quadratic rating curve equation was determined as $Q=3*10^{-6}h^2+0.0021h+0.0134$ ($R^2=0.9995$). A close relationship was determined between the water levels and the flow rates and it means that the water levels represent 99.95% flow rates. Accordingly, the flow rates in FGS show that it is highly dependent on the water levels. Clarke (1999) reports that R^2 of rating curves is often close to 1, which means that the estimated flow rates will have high accuracy. Meral and Benli (2013) found rating curve equation as $Q=3.0523h-0.5569$ ($R^2=0.8563$). The researchers found first-order equations between the water level and flow rate, measured in the Aksu river. Kukul (2008) determined rating curve as $Q= 8.786h^2+91.855h-95.990$. In the study by Ardıçlıoğlu and İlkentapar (2015), the rating curve was determined as Q=7.09h3.42 ($R^2=0.99$). Generally, the degree of the rating curves varies according to the cross-sectional area and the water velocity.

The variance analysis was performed for OEL, PS and US water levels and flow rates and its results were found to be insignificant ($P>0.05$). According to these results, there is no statistical difference among OEL, PS and US water levels and flow rates. These results show that water levels and flow rates using the rating curve can be measured by PS and US in a trapezoidal main irrigation canals.

The levels of agreement between the water levels of OEL and PS, and OEL and US were calculated as MAPE of 0.741% and 1.453%. They are considered as "very good" since MAPE is below 10% (Lewis, 1982). The averages of 2454 water levels were determined as 928±4.9 mm for OEL, 927±4.9 mm for PS, and 922±4.9 mm for US, respectively (*Table 1*). As seen in the figures, differences between the average water levels of OEL and PS, and OEL and US were 1 and 6 mm, respectively. The average 6 mm difference in water levels may be due to the fact that OEL measured the water level in un-fluctuating conditions but US in fluctuating conditions. Under un-fluctuating conditions, difference between average levels measured by OEL and PS was found as 1 mm. Although sensitivity of PS is higher than that of US (Nirupam et al., 2015), difference in water level read by PS was lower than that of US. Accordingly, the average water level difference measured in the Stilling Well (un-fluctuating) conditions decreased. The results were supported by MAPE since MAPE of 0.741% under un-fluctuating conditions was less than that of 1.453% under fluctuating conditions. There was a difference between the water level measured in un-fluctuating and the water level measured in fluctuating conditions, but it was not statistically significant.

The lowest water levels measured by OEL, PS and US were 250 mm, 181.7 mm and 154.8 mm and the highest 1270 mm, 1266 mm and 1276 mm, respectively. In addition, it was observed that the OEL's, PS's and US's water levels distributed on and around the diagonal line in *Figure 3* and *4*. It was sighted that PS's and US's water levels were lower than that of OEL when the water levels were below about 600 mm. The slope and determination coefficient between OEL and PS, and OEL and US were found to be S=0.9981 and R^2=0.9992, and S=0.9934 and R^2=0.9969, respectively and they were close to each other's (*Figure 3* and *4*). Water levels measured using by US (Gençoğlan et al., 2013) and by PS (Gençoğlan and Gençoğlan, 2016) in Class A pan resulted acceptable under fluctuation and un-fluctuation conditions. In studies by Kumar and Verma (2015), Yuliza et al. (2016), Rahman et al. (2017), Prayash (2017), Bello et al. (2018) and Selvan et al. (2018), it was concluded that performance of US was at the desired accuracy. Dusarlapudi et al. (2020) proposed that US was cost effective and highly accurate with an accuracy range of 96 – 98%. When results of water levels sensed by PS and US were compared, the results of this study correlate with the water levels ranges reported in the existing studies.

Table 1. Average water levels and flow rates measured by OEL, PS and US, and results of MEPA

	Average water levels (mm)	**Average flow rates (m^3 s^{-1})**	**MEPA for water levels**	**MEPA for flow rates**
OEL	928±4.9	4.61±0.038		
PS	927±4.9	4.62±0.037	0.741	1.466
US	922±4.9	4.58±0.037	1.453	2.490

The levels of agreement between the flow rates of OEL and PS, and OEL and US were calculated as MAPE of 1.466% and 2.490%. The levels of agreement between the two data sets are considered as "very good" since MAPE is below 10% (Lewis, 1982). Using the rating curve, Ardıçlıoğlu et al. (2010) found flow rate of 9.4% error in rivers, and Ardıçlıoğlu and İlkentapar (2015) found flow rate of 3.8% error in open canal.

The flow rates were calculated by substituting the water levels in $Q=3*10^{-6}h^2+0.0021h+0.0134$ rating curve. The averages of 2454 flow rates for OEL, PS and US were 4.61±0.038 m^3s^{-1}, 4.62±0.037 m^3 s^{-1} and 4.58±0.037 m^3 s^{-1}, respectively (*Table 1*). Difference between OEL and PS, and OEL and US flow rates was found as to be 0.01 m^3 s^{-1} and 0.03 m^3 s^{-1}, respectively. The average flow rate difference of 0.03 m^3 s^{-1} determined for US under fluctuating conditions was higher than that of 0.01 m^3 s^{-1} for PS under un-fluctuating conditions. Therefore, the average flow rates difference measured under open irrigation conditions decreased (Pereira et al., 2022). The results were supported by MAPE since MAPE of 1.466% under un-fluctuating was less than that of 2.490% under fluctuating conditions. There was a difference between the flow rates under un-fluctuating and fluctuating conditions, but it was not statistically significant.

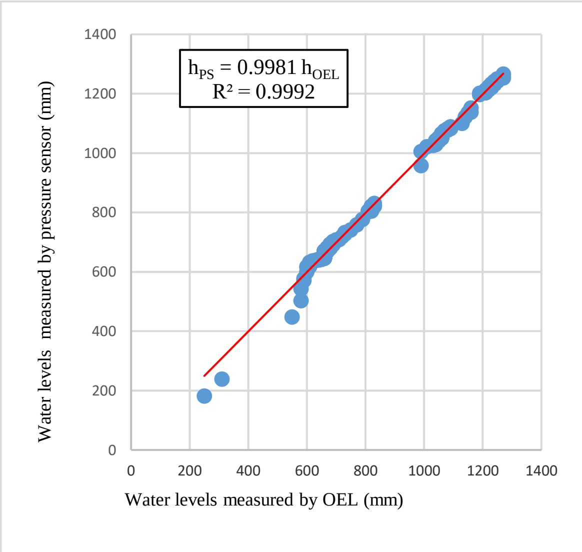

Figure 3. Optic encoder limnigraph-pressure sensor water levels

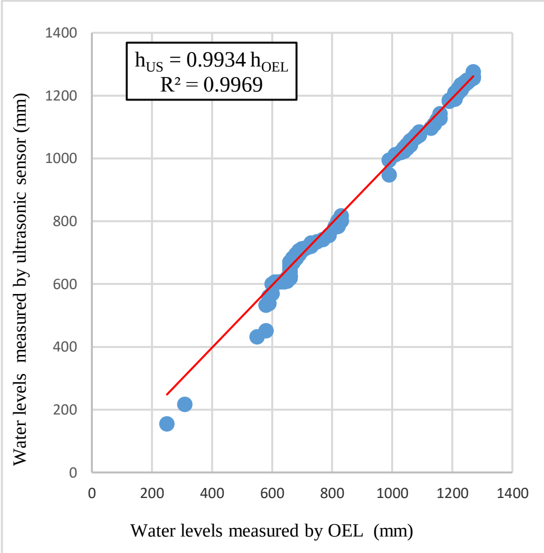

Figure 4. Optic encoder limnigraph -ultrasonic sensor water levels

The lowest and highest flow rates of OEL, PS and US were 0.61 m^3 s^{-1} and 7.41 m^3 s^{-1}, 0.475 m^3 $s^{-1}$and 7.358 m^3 s^{-1} and 0.394 m3 s-1 and 7.453 m^3 s^{-1}, respectively (*Figure 5* and *6*). As seen the figure, OEL, PS and US flow rates are distributed on and around the diagonal line and PS and US flow rates were lower than OEL values when the flow rates fell below about 1.4 m^3 s^{-1}. Slope and R^2 were determined between OEL and PS, and OEL and US flow rates as S=0.9983 and R^2=0.9986, S=0.9921 and R^2=0.997, respectively (*Figure 5* and *6*). Their slopes and determination coefficient were very close to each other's. In the US study conducted by Koshoeva et. al (2021), it was reported that result of flow rates was of high accuracy. When flow rates read by PS and US were compared, the results of this study correlate with the flow rates ranges reported in the existing study.

As can be seen from the studies given above, the number of water level studies conducted using US is large but limited for PS and many of them were conducted under laboratory conditions. Results of this study shows that both sensors, no needing expensive structure, needing only panel, can be used to measure water levels and flow rates in open irrigation canal but un-fluctuating conditions should be preferred. In addition, ultrasonic sensors can be used in environments that block, corrode the pressure sensor and make it difficult to use by floating objects.

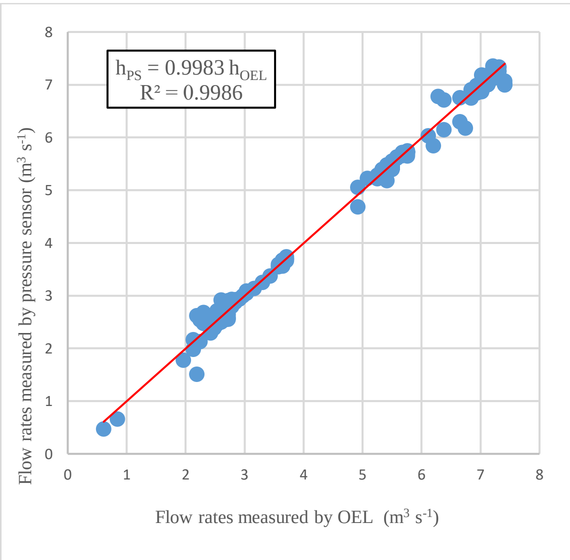

Figure 5. Optic encoder limnigraph-pressure sensor flow rates

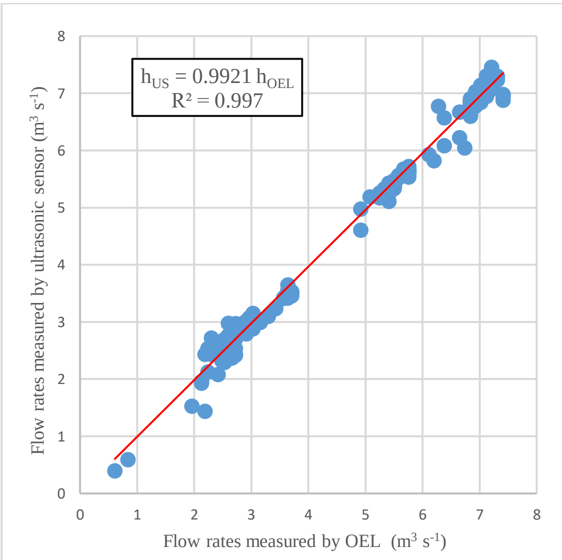

Figure 6. Optic encoder limnigraph -ultrasonic sensor flow rates

4. Conclusions

The study was conducted to measure water levels and flow rates using pressure sensor (PS) and ultrasonic sensors (US) in the open irrigation canal, and to compare water level and flow rates measured by optic encoder limnigraph (OEL) with that of pressure sensor and ultrasonic sensors in the flow gauging station (FGS).

In accurate measurement for water level and flow rates in open irrigation canal, selection and use of the right measuring device and technique are important. With the development of technology, sensors such as PSs and USs and others have started to replace OEL because expensive structure like Stilling Well is needed to measure water levels and flow rates with OEL.

Pressure sensor water levels were measured under waveless (un-fluctuating) conditions in the Stilling Well. The ultrasonic sensors water level was measured directly from the irrigation canal water surface in fluctuating conditions. Optic encoder limnigraph water levels and flow rates were taken as the baseline values in comparison with water levels and flow rates of pressure sensor and ultrasonic sensors. MAPE and ANOVA tests were done in observation of 2454 water levels and flow rates. The Averages of water level and flow rates of optic encoder limnigraph, pressure and ultrasonic sensor were 928±4.9 mm and 4.61±0.038 m^3s^{-1}, 927±4.9 mm and 4.62±0.037 m^3s^{-1}, and 922±4.9 mm and 4.58±0.037 m^3s^{-1}, respectively. Differences between the average water levels, and flow rates of OEL and PS, and OEL and US were 1 mm and 0.01 m^3s^{-1} under non-fluctuating and 6mm and 0.03 m^3s^{-1} under fluctuating conditions. MAPE of water levels and flow rates of pressure and ultrasonic sensor were calculated as 0.741% and 1.466% under un-fluctuation, and 1.453% and 2.490% under fluctuation conditions, respectively. The fluctuation increased the differences between the average water levels and flow rates of OEL and PS and which of OEL and US. Under un-fluctuation conditions, MAPEs are lower than that of fluctuation and since they are below 10%, the levels of agreement between the two data sets are considered as “very good”. The water levels and flow rates of PS and US were not statistically different from that of OEL. Using both PS and US, water level and flow rate can be measured in open irrigation canal but it should be preferred to measure water levels and flow rates at FGSs in which water is non-fluctuating. In addition, ultrasonic sensors can be used in environments that block, corrode the pressure sensor and make it difficult to use by floating objects.

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