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DEVELOPMENT OF AN ARDUINO-BASED LOW-COST TURBIDITY AND ELECTRIC CONDUCTIVITY METER FOR WASTEWATER CHARACTERIZATION

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ABSTRACT

The turbidity and electrical conductivity of a wastewater stream are undeniably essential parameters in the characterization of wastewater. The primary objective of this study was to design a low-cost, efficient device for monitoring turbidity and electric conductivity of wastewater and to compare its performance against commercially available meters. The results indicated that the developed turbidity model sensor and electric conductivity probe provided a comparable turbidity value (ranging from 20-200 NTU) and EC (ranging from 0-50 mS/cm) compared to commercial meters at almost 10 times lower cost (12.87 US dollars for turbidimeter and 13.52 US dollars for electrical conductivity meter). The error percentage of the developed prototype was less than 5 % for both tested parameters. Therefore, the study concludes that this prototype can be used as an accurate and exact water quality measurement device that is capable of being applied in a wide variety of water quality applications, especially in low-income countries.

Keywords: Arduino, electric conductivity, conductivity meter, turbidity, wastewater.

INTRODUCTION

The characterization of wastewater is an initial requirement in selecting and designing water and wastewater treatment processes for different purposes, as it provides valuable information on the type and concentration of impurities or pollutants present, along with their distribution (Deblonde et al., 2011). Wastewater treatment, agricultural practices, and industrial discharges all contribute to water pollution and release many substances into wastewater flows (Rosal et al., 2010). Approximately 80 % of all wastewater is currently dumped into the world's waterways, creating threats to human health, environmental stability, and the climate (Duong and Saphores, 2015). Moreover, urbanization exacerbates the generation of wastewater flow and the consumption of globally scarce resources. However, knowledge and understanding of wastewater characterization furnish an opportunity to recover water, energy, nutrients, useful organics, phosphates, nitrogen, cellulose, rare earth, and other resources (Akpor et al., 2014; Shan et al., 2016).

The identification of pollutants in wastewater, as well as the treatment process, is extremely important to initiate and/or implement proper handling and design to safeguard the assimilative capacity of surface waters, shellfish, finfish, and wildlife, as well as to preserve or restore the aesthetic and recreational value of surface waters and to protect humans from adverse water quality conditions (Munter, 2003). In such an approach for wastewater characterization, two basic water quality characteristics, namely, turbidity and conductivity, receive more attention.

A measure of the clarity or haziness of water that is dependent on the presence of suspended insoluble particles is called turbidity (Parra et al., 2018; Alimoron et al., 2020). Turbidity helps to determine the amount of light passage hindered by suspended solid matter and is used widely as an indirect measurement of the quality of wastewater (Diamant, 2013). On the other hand, electrical conductivity (EC) relates to how well or poorly water conducts electricity, depending on the circumstances, primarily on the presence of certain ions (Ramos, 2008; De Sousa et al., 2014). The greater the EC is, the greater the dissociated ion concentration in the water. The conductivity of pure water is exceedingly low in the absence of contaminants (Mccleskey et al., 2012).

Increased turbidity can be associated with poorer coagulation and flocculation, malfunctioning of the biological reactor (either aerobic or anaerobic), low disinfection efficiency and increased bacterial levels (E-coli and coliforms) at particular times. However, the majority of distribution systems exhibit only a minor association between bacteriological parameters and turbidity (Mccoy and Olson, 1986). On the other hand, conductivity is a reliable parameter for characterizing dissolved ions and solids in water, including anions such as nitrate, chloride, phosphate, and sulfate, as well as cations such as calcium, aluminum, iron, magnesium, and sodium (Stevens et al., 1995; Harikumar et al., 2017). Additionally, conductivity has been discovered as a potential indicator characteristic for detecting unauthorized discharges, which are primarily associated with industrial processes (Pitt, 2004). However, it has a moderate capability for wastewater detection (Atekwana et al., 2004; Panasiuk et al., 2015).

The electrical conductivity of a material is determined using a probe and a meter (Alimoron et al., 2020; De Sousa et al., 2014; Mccleskey et al., 2012). A voltage is applied between two electrodes on the tip of a probe dipped in a water sample and converts the probe reading to micro siemens per centimeter. The turbidity of the water samples was determined using a nephelometer (Parra et al., 2018). Optical sensors are widely employed tools for monitoring turbidity, and many commercial types are available on the market. In those turbidity meters, an optical sensor measures the amount of scattered light that reaches the detector after it is emitted. Depending on the measurement angle, there are three methods for optical sensing, including nephelometric, absorb meters, and backscattering, which are all terms for measuring the angle between the nephelometric angle and the absorbimetric angle (Omar and Matjafri, 2009).

Even though scientific advancements have been made in wastewater characterization, the accessibility of testing technologies and instruments for that purpose continues to be a limiting factor for Sri Lanka, similar to many developing countries, compared to industrialized nations. Because the use of commercially available meters for measuring turbidity and EC is not economically feasible due to the high cost of the sensor, which may become prohibitively expensive for many applications (Parra et al., 2018), the frequent characterization of water in a variety of applications is hindered by this existing gap. Therefore, this project aimed to address this gap by designing and developing a low-cost smart turbidimeter and electric conductivity meter. Both smart meters will be capable of identifying different types of wastewater based on their turbidity and electrical conductivity when they are properly constructed.

MATERIALS AND METHODS

This research was funded and carried out at the Joint Research Demonstration Center for water technology (JRDC) located in Peradeniya, Sri Lanka.

Design concept

Various sections and/or parts required for the design and fabrication of the device comprise a DC power supply unit, microcontroller unit, sensing unit, and data transferring unit from the microcontroller unit to the (Gibb, 2010). The open-source microcontroller board based on the Microchip ATmega328P, Arduino Uno (Fig. 1), was used as a microcontroller board that is in charge of operating the probes linked to it and relaying data to the computer host (Alimoron et al., 2020). The Light-Dependent Photo Resistor (LDR) was attached to an Arduino analog pin as a sensor for turbidity measurements. LED (NIR-650 nm wavelength) was used as a light transmitter, and a 9 V battery and a 7805-voltage regulating IC were utilized to maintain a steady 5 V voltage to 16x2 cm LCD attached to the microcontroller unit. The display's backlight and contrast were controlled using a potentiometer in the i2C module. The primary housing components, a two-part casing and a turbidity/EC sensor meter, were constructed from black-colored plastic enclosure.

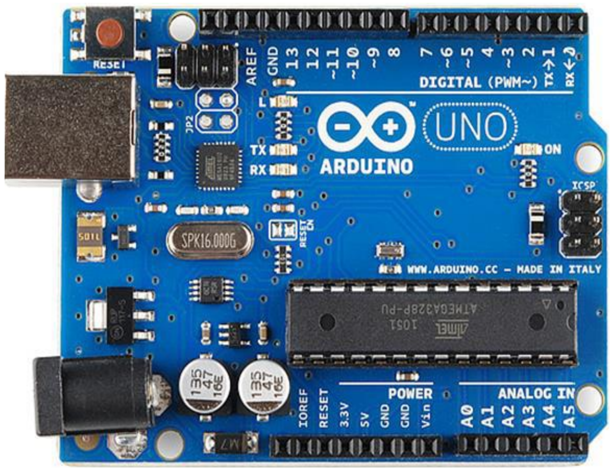

Figure 1: The open-source microcontroller board - Arduino Uno

Turbidity Sensor

An LED light source was directed through a water sample in a chamber, into which a photodetector LDR was placed at a 90° angle to the LED light beam (Fig. 2). The scattered light-generated resistivity was exclusively measured by this single-beam turbidimeter arrangement. In complete darkness, the sensor system comprising light sources and the light receiver was placed inside a black-colored plastic box. The LED (NIR-650 nm wavelength) was given a direct 5 V supply, and the LDR was connected to the ground wire. Analog signals for each sample were collected via the A0 pin between 10-second intervals and averaged before inclusion in the calibration sequence as well as for the sample turbidity value calculations. Finally, the LCD was linked to the Arduino board using the i2C module to display the results. The PCF8574 chip in this i2C module converts serial data to parallel data for LCD. To reset the program, a push button was mounted separately from the device, allowing the operator to calibrate the samples. Fig. 3 shows the circuit diagram in detail. The Arduino IDE program was used for coding the fabricated devices (Badamasi, 2014). The block diagram for the coding sequence is described in Fig. 4.

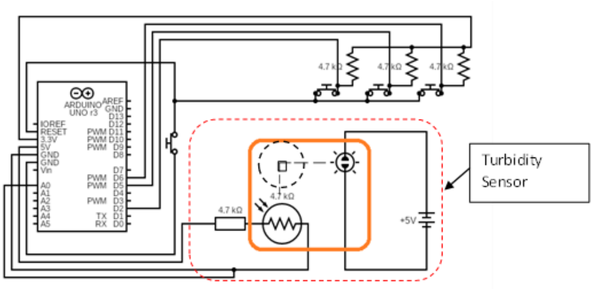

Figure 2: Circuit diagram of the turbidity meter

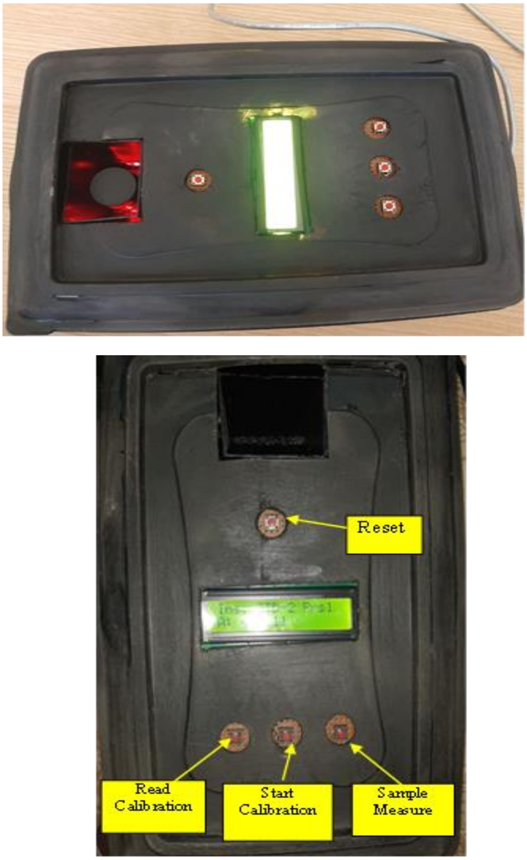

Figure 3: Fabricated turbidity meter

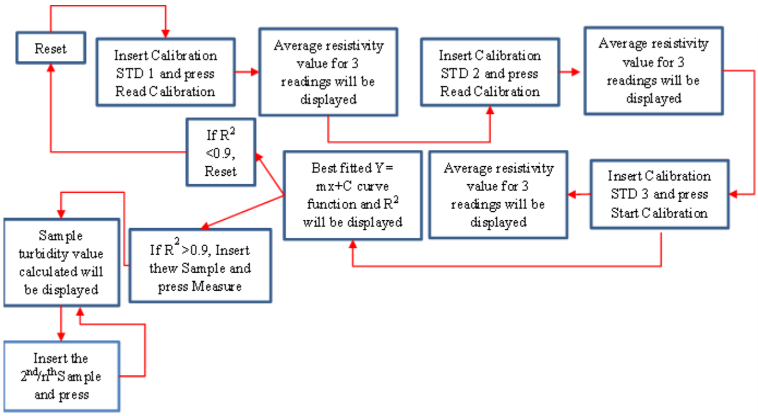

Figure 4: Turbidity meter coding sequence

Conductivity Sensor

A probe for measuring electrical conductivity (EC) was fabricated by using stainless steel wires and connecting them as a voltage divider circuit. For the same probe, a temperature sensor (Thermistor) was included and then connected to the A5 pin of Arduino UNO (Fig. 4). The circuit diagram for the fabricated EC devices is shown in Fig. 5. The Arduino IDE program was used for coding the fabricated devices (Apha, 2017). The EC meter operation block diagram was also similar to the coding sequence described in Fig. 4.

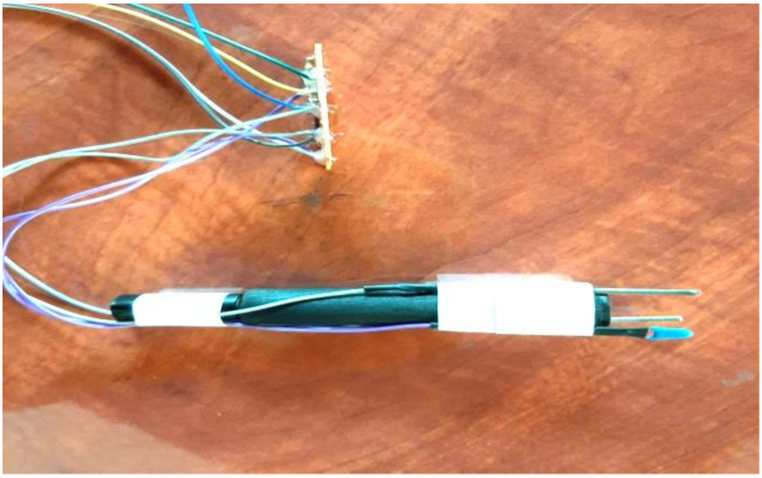

Figure 5: Fabricated electric conductivity probe

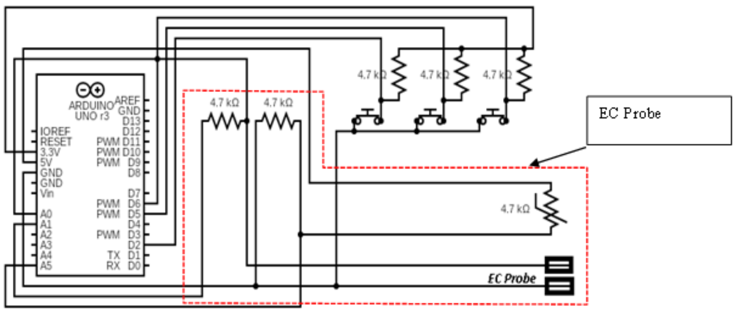

Figure 6: Circuit Diagram of the EC meter

RESULTS AND DISCUSSION

Turbidity Meter

To evaluate the device's performance, several standard solutions with varying turbidity values (20, 100, and 200 NTU) were prepared as per the standard method 2130B (Apha, 2017). The resistivity values of scattered light were determined for those standard solution turbidities for instrument calibration. Each value was measured three times and averaged and used to determine the best fit regression curve ($y = mx + c$). Accordingly, the turbidity level of the calibration samples was determined first, and then the turbidity of the samples was determined again using the designed model as per the sequence given in Fig. 4. Five trials for each parameter using both the designed sensor and a borrowed commercial sensor meter (LFWCS-2008, LIHERO, and China) were conducted from the lab. The percentage error was calculated to identify the variation between both commercial sensors and designed sensors.

As illustrated in Fig. 7, the linear regression value calculated for the calibration was:

$$y = -449.75x + 148286 \tag{1}$$

where x is the NTU value; y is the sensor's averaged resistivity value, the linear regression coefficient of determination R^2 was found to be 0.9726, and the correlation was acceptable.

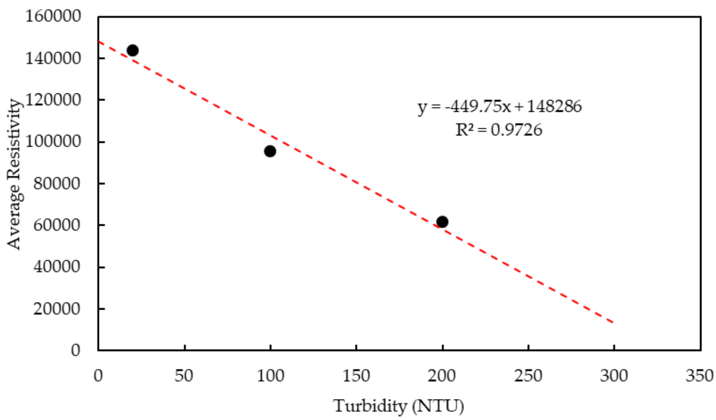

Figure 7: Calibration plot turbidity

The results show that there were no significant differences in turbidity readings between the commercial turbidity meter and the open-source turbidimeter. The model turbidimeter provides a reasonable approximation of the results compared to commercial handheld models over the range of 20–200 NTU (Table 1). Meanwhile, comparing the results of both the commercially available turbidity meter and the model one, all of the error percentages were under the 4.6 % range, which is still reliable given the 5 % tolerance used in this investigation.

Table 1: Turbidity values of the model and commercial turbidity meter

Sample No	Model turbidity meter value (NTU)	Commercial meter value (NTU)	Percentage error (%)
1	29	28.98	0.07
2	36	34.99	2.89
3	37	35.98	2.83
4	31	30.99	0.03
5	43	41.11	4.60
6	60	58.28	2.95
7	50	48.01	4.14
8	40	39.85	0.38
9	22	21.83	0.77
10	48	46.08	4.16

Electrical conductivity (EC) meter

The conductivity probe was made by two stainless steel conductors attached to an LM35 temperature sensor. Two separate conductors were the same length and accomplished with hot glue and rubber sleeves that only conductors would touch the water. Additionally, the conductors were 1 cm apart and were close enough to be exposed to the solution, increasing the accuracy.

A voltage divider circuit (applied voltage Vin) was used to calculate the resistance (Eq. 2) created by the EC electrode (RE) by measuring the output DC voltage across the EC probe (VP) attached to 4.7 kΩ resistors. Since RE was measured across a 1 cm electrode, it can be directly converted to the conductivity units of microSiemens (µS) (Eq. The measured DC voltage was converted with an analog to a digital converter.

$$RE = \left(1000\ \frac{4.7VP}{Vin}\right)\left(1+\frac{VP}{Vin}\right) \tag{2}$$

$$RE \times 1cm = RE\,\Omega m = 1000\ RE\,(\mu S/m) \tag{3}$$

For calibration of the EC probe, three standard (KCl) solutions were used (Fig. 8). When calibrating and analyzing the sample, the probe temperature should be within the range of 24 °C – 28 °C. Calibration readings are shown on the LCD screen of the instrument.

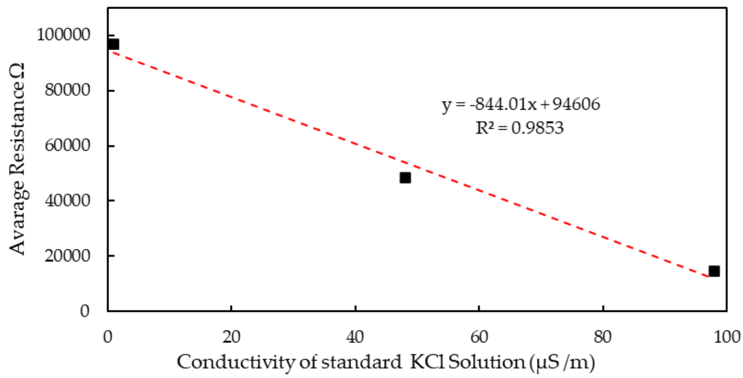

Figure 8: Calibration Plot-Electrical Conductivity

As illustrated in Figure 8, the linear regression value calculated for the calibration was:

$$y = -844.01\,x + 94606 \tag{4}$$

where *x* is the µS/m value, *y* is the sensor's averaged resistance Ω value, the linear regression coefficient of determination R^2 was found to be 0.9853, and the correlation was acceptable. Most electric conductivity probes can be used for wastewater characterization and hydroponic agriculture.

The results show that there were no significant differences in EC readings between the commercial EC meter and the open-source EC. Model EC provides a reasonable approximation of results compared to commercial handheld models over the range of 1–

50 µS/m (Table 2). Meanwhile, comparing the results of both the commercially available turbidity meter and model one, all of the error percentages were under the 4.7 % range, which is still reliable given the 5 % tolerance used in this investigation.

Table 2: EC value comparison

Sample No.	Model EC meter value (µs/cm)	Commercial meter value (µs/cm)	Percentage error (%)	Temperature	
				Model EC meter (°C)	Commercial meter (°C)
1	1	0.98	2.04	25	25
2	21	20.98	0.09	25	25
3	35	35.08	0.22	25	25
4	28	26.84	4.32	25	25
5	42	41.31	1.67	25	25
6	37	35.60	3.93	25	25
7	24	23.81	0.79	25	25
8	39	37.38	4.33	25	25
9	51	50.03	1.93	25	25

Cost analysis for turbidity and electric conductivity meters

The components for the whole system prototype cost approximately $18.732 US dollars, which is a factor of at least ten times less than commercially available. Table 3 describes the cost for each component used for fabrication works.

Table 3: Description of the cost for the components

No	Components	Description	Quantity	Price in USD for Turbidity meter	Price in USD for EC meter
1	Arduino Uno	ATmega328P	1	3.45	3.45
2	Resistor	10k	1	0.025	-
3	Resistor	4.7k	3	0.025	0.025
4	Switch	Push	4	0.099	0.009
5	LCD screen	2x16, Green	1	1.48	1.48
6	LDR	5 mm	1	0.099	-
7	I2c	PCF8574 I2C	1	0.49	0.49
8	LED laser	650 nm	1	1.97	-
9	Wires	2 m	1	0.99	0.99
10	Battery	9v	1	0.74	0.74
11	Power cable	With adapter	1	1.23	1.23
12	Dot board	20 cmx30 cm	1	0.3	0.3
13	Plastic box/casing	Dark color	1	1.97	-

14	Plastic sleeves	10 cm	1	-	0.15
15	LM 35	5 V	1	-	0.69
16	Wires	1 m	1	-	0.50
17	Stainless steel wire	20 cm	1	-	0.50
18	Probe casing	Plastic black	1	-	2.00
19	Glue stick	White color	1	-	0.97
	Total			**12.868**	**13.524**

CONCLUSION

The focus of this paper was to present the concept of designing a low-cost system for real-time monitoring of wastewater turbidity and conductivity. Contrary to commercially available analyzers, the designed system is 10 times cheaper, lightweight and capable of data processing and logging. This implementation is suitable for large deployments, enabling a sensor network strategy for providing spatiotemporally rich data in wastewater characterization and treatment processes carried out by water customers, water businesses, and governments. In the future, we intend to add additional parameters to the fusion algorithm for intentional contaminants and to deploy the system in multiple locations throughout the water distribution network to collect spatiotemporally rich water quality data and characterize the system's response in real-world field deployments.

REFERENCES

AKPOR O.B., OTOHINOYI D.A., OLAOLU T.D., ADERIYE B.I. (2014). Pollutants in wastewater: Impacts and remediation process, Journal of the Hellenic Veterinary Medical Society, Vol. 65, Issue 2, pp. 115–120.

ALIMORON G.F.M.L.S., APACIONADO H.A.D., VILLAVERDE J.F. (2020). Arduino-based Multiple Aquatic Parameter Sensor Device for Evaluating pH, Turbidity, Conductivity and Temperature. 2020 IEEE 12th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, HNICEM 2020. https://doi.org/10.1109/HNICEM51456.2020.9400145

APHA (2017). Standard Methods for the examination of water and waste water American Public Health Association, pp. 2-12.

ATEKWANA E.A., ATEKWANA E.A., ROWE R.S., WERKEMA D.D., LEGALL F.D. (2004). The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon, Journal of Applied Geophysics, Vol. 56, Issue 4, pp. 281–294. https://doi.org/10.1016/j.jappgeo.2004.08.003.

BADAMASI Y.A. (2014). The working principle of an Arduino. Proceedings of the 11th International Conference on Electronics, Computer and Computation, ICECCO 2014. https://doi.org/10.1109/ICECCO.2014.6997578

DE SOUSA D.N.R., MOZETO A.A., CARNEIRO R.L., FADINI P.S. (2014). Electrical conductivity and emerging contaminant as markers of surface freshwater contamination by wastewater, Science of the Total Environment, Vol. 484, Issue 1, pp. 19–26. https://doi.org/10.1016/j.scitotenv.2014.02.135

DEBLONDE T., COSSU-LEGUILLE C., HARTEMANN P. (2011). Emerging pollutants in wastewater: A review of the literature, International Journal of Hygiene and Environmental Health, Vol. 214, Issue 6, pp. 442–448. https://doi.org/10.1016/j.ijheh.2011.08.002

DIAMANT S. (2013). The importance of monitoring turbidity in industrial water treatment, Water Technology. https://www.watertechonline.com/wastewater/article/15543707/the-importance-of-monitoring-turbidity-in-industrial-water-treatment

DUONG K., SAPHORES J.M. (2015). Obstacles to wastewater reuse: an overview, WIREs Water, Vol. 2, Issue 3, pp. 199–214. https://doi.org/10.1002/wat2.1074

GIBB A.M. (2010). New-Media-Art-Design-and-the-Arduino-Microcontroller: A Malleable Tool, A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Pratt Institute, New York, USA. http://aliciagibb.com/wp-content/uploads/2013/01/New-Media-Art-Design-and-the-Arduino-Microcontroller-2.pdf

HARIKUMAR P.S., ARAVIND A., VASUDEVAN S. (2017). Assessment of Water Quality Status of Guruvayur Municipality. Journal of Environmental Protection, Vol. 8, Issue 2, pp. 159–170. https://doi.org/10.4236/jep.2017.82013

MCCLESKEY R.B., NORDSTROM D.K., RYAN J.N., BALL J.W. (2012). A new method of calculating electrical conductivity with applications to natural waters, Geochimica et Cosmochimica Acta, Vol. 77, pp. 369–382.

MCCOY W.F., OLSON B.H. (1986). Relationship among turbidity, particle counts and bacteriological quality within water distribution lines, Water Research, Vol. 20, Issue 8, pp. 1023–1029. https://doi.org/10.1016/0043-1354(86)90045-X

MUNTER R. (2003). Industrial wastewater characteristics, The Baltic University Programme (BUP), Sweden, pp. 185–194.

OMAR A.F.B., MATJAFRI M.Z. B. (2009). Turbidimeter design and analysis: A review on optical fiber sensors for the measurement of water turbidity, Sensors, Vol. 9, Issue 10, pp. 8311–8335. https://doi.org/10.3390/s91008311

PANASIUK O., HEDSTRÖM A., MARSALEK J., ASHLEY R.M., VIKLANDER M. (2015). Contamination of stormwater by wastewater: A review of detection methods, Journal of Environmental Management, Vol. 152, pp. 241–250. https://doi.org/10.1016/j.jenvman.2015.01.050

PARRA L., ROCHER J., ESCRIVA J., LLORET J. (2018). Design and development of low-cost smart turbidity sensor for water quality monitoring in fish farms, Aquacultural Engineering, Vol. 81, pp. 10–18.

PITT R. (2004). Illicit Discharge Detection and Elimination - A Guidance Manual for Program Development and Technical Assessments, Center for Watershed protection, University of Alabama, October.

RAMOS P.M., PEREIRA J.M.D., MEMBER S., RAMOS H.M.G., MEMBER S., RIBEIRO A.L. (2008). A Four-Terminal Water-Quality-Monitoring Conductivity, Sensor, Vol. 57, Issue 3, pp. 577–583.

ROSAL R., RODRÍGUEZ A., PERDIGÓN-MELÓN J.A., PETRE A., GARCÍA-CALVO E., GÓMEZ M.J., AGÜERA A., FERNÁNDEZ-ALBA A.R. (2010). Occurrence of emerging pollutants in urban wastewater and their removal through biological treatment followed by ozonation, Water Research, Vol. 44, Issue 2, pp. 578–588. https://doi.org/10.1016/j.watres.2009.07.004

SHAN Y., GUAN D., LIU J., LIU Z., LIU J., SCHROEDER H., CHEN Y., SHAO S., MI Z., ZHANG Q. (2016). CO2 emissions inventory of Chinese cities, Atmospheric Chemistry and Physics Discussions, pp. 1-26. https://doi.org/10.5194/acp-2016-176

STEVENS R.J., O'BRIC C.J., CARTON O.T. (1995). Estimating nutrient content of animal slurries using electrical conductivity. The Journal of Agricultural Science, Vol. 125, Issue 2, pp. 233–238. https://doi.org/10.1017/S0021859600084367.