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Use of geothermal fluid for agricultural irrigation: preliminary studies in Balçova-Narlıdere Geothermal Field (Turkey)

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Abstract: Balçova-Narlıdere Geothermal Field (BNGF) hosts the largest geothermal district heating system of Turkey and several geothermal wells used for district heating and thermal tourism activities. This study assesses the use of BNGF geothermal fluid for agricultural activities. The spent geothermal brine was treated using nanofiltration and reverse osmosis membranes on a pilot-scale membrane test system. The qualities of the product were evaluated in terms of agricultural irrigation integrated with the implemented innovative wireless sensor network. It is important to use geothermal fluid, which is consists of valuable minerals, for irrigation. But when using geothermal fluid in irrigation, the chemical composition of the water must be carefully monitored to prevent damage to the plants. Nevertheless, the first result shows that the use of geothermal fluid to irrigate is proving to be a promising and economically viable option in BNGF.

Key words: Arsenic, boron, drip irrigation, geothermal water, membrane process, wireless sensor network

1. Introduction

Energy obtained from conventional fossil fuels has been currently the leading player in global energy resources, produced and used by various countries. That being said, with rising concerns about global warming, states and businesses are turning to renewable and environmentally friendly energy sources (Bongole et al., 2021). Geothermal energy is a renewable and reliable energy resource that is environmentally friendly and has a large amount of energy potential stored beneath the earth surface (Tester et al., 2007). Water is perhaps the most commonly used transfer heat fluid medium in low-enthalpy geothermal exploitation systems due to its high thermal capacity (Chu et al., 2021). Nevertheless, two issues may arise during geothermal water production: a reservoir pressure shortfall and the negative effects of geothermal water disposal upon heat usage. Geothermal power plants use significant quantities of geothermal fluids to produce electricity (EPAUS, 2008). Disposing of spent geothermal fluid to flowing rivers was thought to be one option for removing wastewater after the energy was extracted (Haklıdır et al., 2021). However, this method is not environmentally friendly. Based on long-term findings, it was mentioned that used geothermal fluid discharged to a river has a much higher concentration of major ions than water flowing in the surface water (Wątor and Zdechlik, 2021). Another approach to dealing with spent geothermal fluid is reinjection back into the reservoir. Both theories and practices have shown that geothermal fluid reinjection is the most effective approach for these problems (Liu, 2003; Kaya et al., 2011). One critical aspect is how to ensure the flow safety and injectivity of the wellbore, particularly corrosion risk, which can limit the effective and economical usage of geothermal energy (Knipe and Rafferty, 1985; Zhang et al., 2021). Some ion concentrations in the production well fluids increased after reinjection into similar lithology and fault zones (Haklıdır et al., 2021). Thus, spent geothermal fluid finds its way into cold groundwater resources, thereby contaminating the groundwater resources. Alternatively, water shortages are now becoming critical issues across all living creatures and environmental health across the globe. This key problem compels authority to seek new possible future sources of

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water that can be used efficiently both for drinking and irrigation purposes. Hence, after the extraction of energy from geothermal fluids, some part spent geothermal fluid can reasonably be viewed as a promising alternative for industrial use and agricultural irrigation, livestock farming, wildlife watering, as well as for drinking water sources. This would surely reduce the pressure on current existing freshwater sources. It is also good to keep in mind that recharging of the aquifer is also of paramount importance for the sustainable use of geothermal energy (Melikoglu, 2017). However, due to the high salt content of the spent geothermal fluid, its discharge to the surroundings or direct use for agricultural irrigation would surely result in the soil salinity and modification of agricultural areas (Ozbey-Unal et al., 2018). Besides, geothermal water has high boron and arsenic concentrations depending on the geological properties of the region. Although boron is an essential nutrient in plant nutrition, this high boron poses a risk in plant production. Boron toxicity is considered a significant problem in limiting plant growth, especially in low rainfall and highly alkaline and saline soils. The phytotoxicity of boron is manifested by physiological disturbances such as short shoots, reduction of root growth and decrease of stem cell division, RNA content, leaf chlorophyll, and photosynthetic rate (Roessner et al., 2006). Also, boron forms complexes with heavy metals such as Pb, Ni, Cd, and Cu in groundwater resources, posing a greater threat to drinking water sources of heavy metals (Gallup, 2007; Cengeloglu et al., 2008). Therefore, it is critical to keep boron concentrations below the World Health Organization (WHO) limit of 0.5 mg/L and the European Union (EU) limit of 1 mg/L for drinking water (Kalaitzidou et al., 2018, Ozbey-Unal, et al., 2020). Similarly, arsenic can also be categorized as a toxic drinking water substance across the globe due to its numerous adverse effects on environmental sustainability and human health. Arsenic's posing effects pose serious harm to human metabolism (Bundschuh et al., 2010). Due to the global significance of arsenic danger to human health and its high concentrations in geothermal fluid, the World Health Organization (WHO) established a permissible level of arsenic in drinking water is not to be greater than 10 µg/L (WHO). Therefore, it is of paramount importance to treat geothermal fluid before its disposal. There are so many studies that have highlighted the potential of fresh and spent geothermal fluid from different parts of Turkey also as a potential source of irrigation water (Koseoglu et al., 2010; Yavuz et al., 2013; Samatya et al., 2015; Ozbey-Unal et al., 2018; Jarma et al., 2021). There are also large numbers of publications that show the potentials and importance of using spent geothermal fluid (Tomaszewska et al., 2013, 2017, 2020). However, these studies were conducted in various minipilot studies.

Irrigation is responsible for consuming about 70% of global freshwater resources, including rivers, lakes, aquifers. With the effect of climate change, population growth, and urbanization, competition between agriculture and other water-consuming sectors regarding water allocation is increasing day by day. Under these stresses, agriculture must also be more productive, resource-efficient, and sustainable (WB, 2021). For this reason, much innovative technology has been used for irrigation. For example, a wireless sensor network (WSN) is a group of network nodes having sensing, processing, transmitting, and receiving capabilities (Akyildiz et al., 2002). Sensor nodes are distributed over the field within the constraint of topographic conditions. The collected data are usually sent to the central unit directly or via routers. The central unit also transmits information from the outside world to the sensor nodes (Hamami and Nassereddine, 2020).

In irrigation, efficient management of water helps reduce yield losses, water stress, and nutrient leaching (Kim and Evans, 2009). Today, it is already well known that pressurized irrigation systems such as drip irrigation increase the effectiveness of irrigation. However, by the integration of recently emerging technologies such as wireless sensor network, efficiency of irrigation can be further increased by precise monitoring of soil water content with advanced soil sensors and sensor-activated valve controllers, which help determine the correct timing of irrigation and the amount of irrigation water volume (Balendonck et al., 2009; Lea-Cox, 2012; Hamami and Nassereddine, 2021).

Additionally, this study will investigate the preliminary treatment of spent geothermal fluid using large pilot-scale nanofiltration (NF) and reverse osmosis (RO) membrane system to apply the treated spent geothermal water for irrigation of tomato plants at geothermal heating center.

2. Materials and methods

2.1. Study area

Balçova-Narlıdere Geothermal Field (BNGF) is located 7 km west of İzmir city and covers a total area of approximately 3.5 km^2 (Figure 1). The reconnaissance and exploration studies were initiated in 1963, and Turkey's first downhole heat exchanger was applied in 1982. Then Balçova Geothermal District Heating System was commissioned in 1996. The district energy system has been in operation for four decades (Erdogmus et al., 2006). Izmir Geothermal Company provides district heating services. At that time, 85% residential area of Balçova and 15% residential area of Narlıdere is heated. The total population benefited approximately 90,000 people. The total current capacity is 145 MWth. The actual capacity of the district heating system is about 37,500 R.E. The installed capacity of the geothermal system from wells is 50,500 R.E. Other users are agricultural (greenhouses) and

Figure 1. Study area and geothermal wells.

spas in tourist facilities. As of May 2021, the field houses the largest geothermal district heating system of Turkey, a modern spa complex with a total capacity of 1000 persons/day, and approximately 10 ha greenhouse heating with 15 production and 5 reinjection wells. Besides geothermal production and reinjection wells, the field contains numerous groundwater wells used for irrigation of the agricultural fields and greenhouses. The annual reinjection rate is 96%.

2.2. Hydrogeochemical properties of the geothermal fluid

The study area is situated on an east-west directed plain where the Upper Cretaceous flysch formation, which consists of siltstone, sandstone, and mudstone units, are crop out, named the Bornova mélange by Erdogan (1990). The hydrogeological unit is highly fractured and weathered (Baba and Güngör, 2002). The geological formation has low permeability and porosity. Two geothermal reservoirs have been seen in the study. All geothermal wells are planned to cut faults. The depth of wells ranges from 200 to 1100 m. The resource temperature changes from 96 to 141 °C. Also, the reinjection temperature ranges from 55 to 60 °C (Figure 2). The pH of the geothermal fluid ranges from 6.68 to 8.6, and the electrical conductivity (EC) is the change between 1742 and 2025 µS/cm (Figures 3 and 4) (Baba and Sözbilir, 2016).

The chemical characteristics of geothermal fluid, based on major ion concentrations, were evaluated on the Piper and Schoeller diagram (Figure 5). It can readily be seen that geothermal fluid is relatively rich in $Na\text{-}HCO_3$ (sodium bicarbonate type). Geothermal fluids have higher B concentrations. The concentration of boron ranges from 10 to 15 mg/L in the study area (Figure 6). The high amounts of boron (B) content result from the formation of the phyllite. B concentrations are high in thermal water in Turkey. The high B concentration is related to sedimentary and volcanic rocks but may also be controlled by the degassing of magma intrusive (Baba and Armannsson, 2006).

2.3. Innovative wireless sensor network application for irrigation in the study area

A WSN, operating at 868 MHz ISM frequency band, was integrated into the installed drip irrigation system to reuse of geothermal wastewater or treated geothermal fluid for the irrigation of tomato plants. A concentrator, soil monitoring, and valve control nodes were implemented in terms of hardware and firmware in WSN. A GSM modem (HE910, Telit) connected to the WSN concentrator with RS232 serial communication provided the data transmission from WSN to the server and vice versa.

LE70-868 (Telit) short-range transceivers, i.e. RF module, formed the physical layer of the WSN. Modules

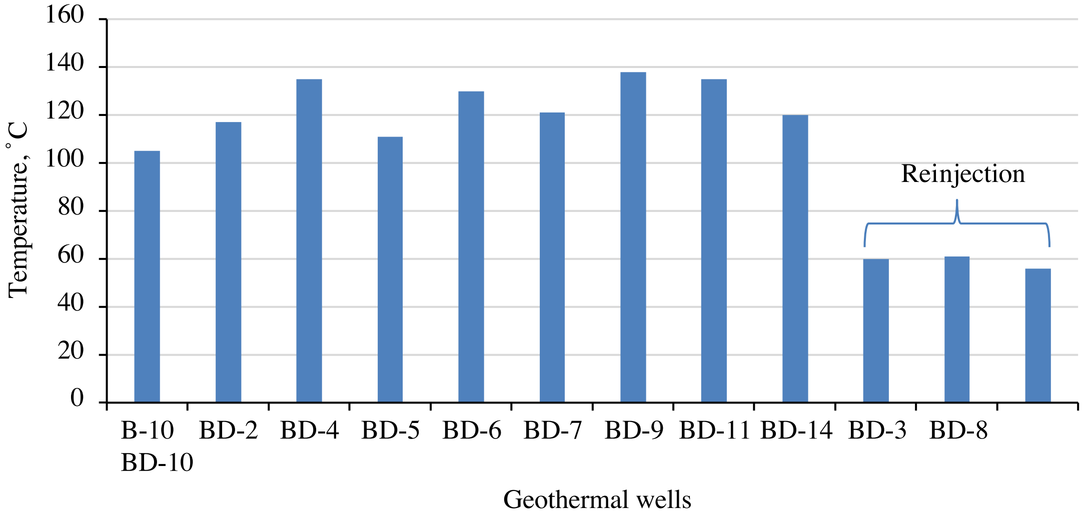

Figure 2. Distribution of reservoir temperature of the geothermal fluid in the study area.

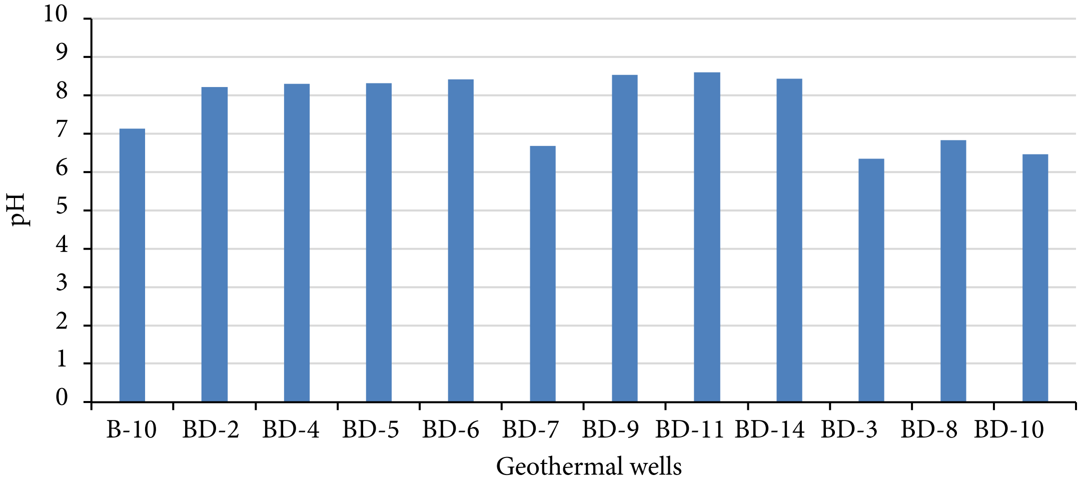

Figure 3. Distribution of pH of the geothermal fluid in the study area.

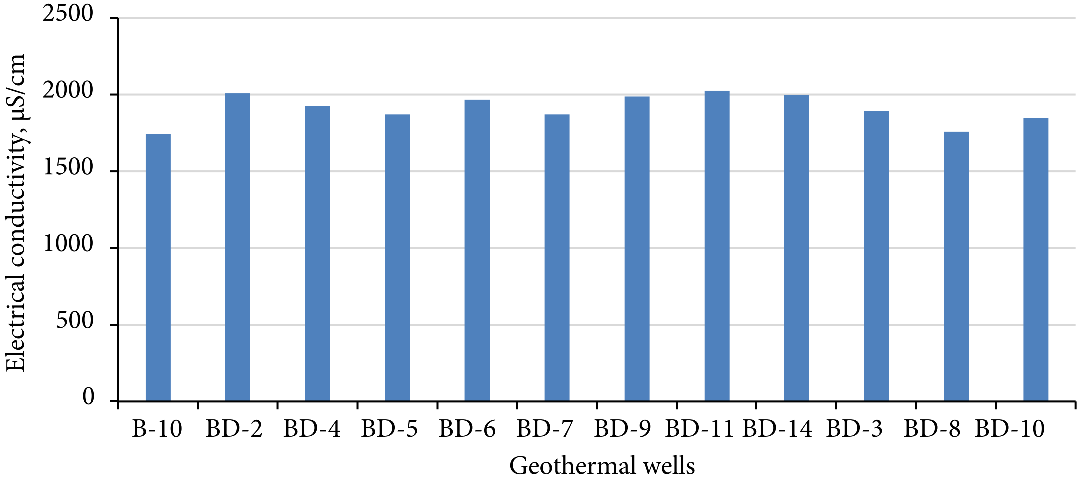

Figure 4. Distribution of electrical conductivity (EC) of the geothermal fluid in the study area.

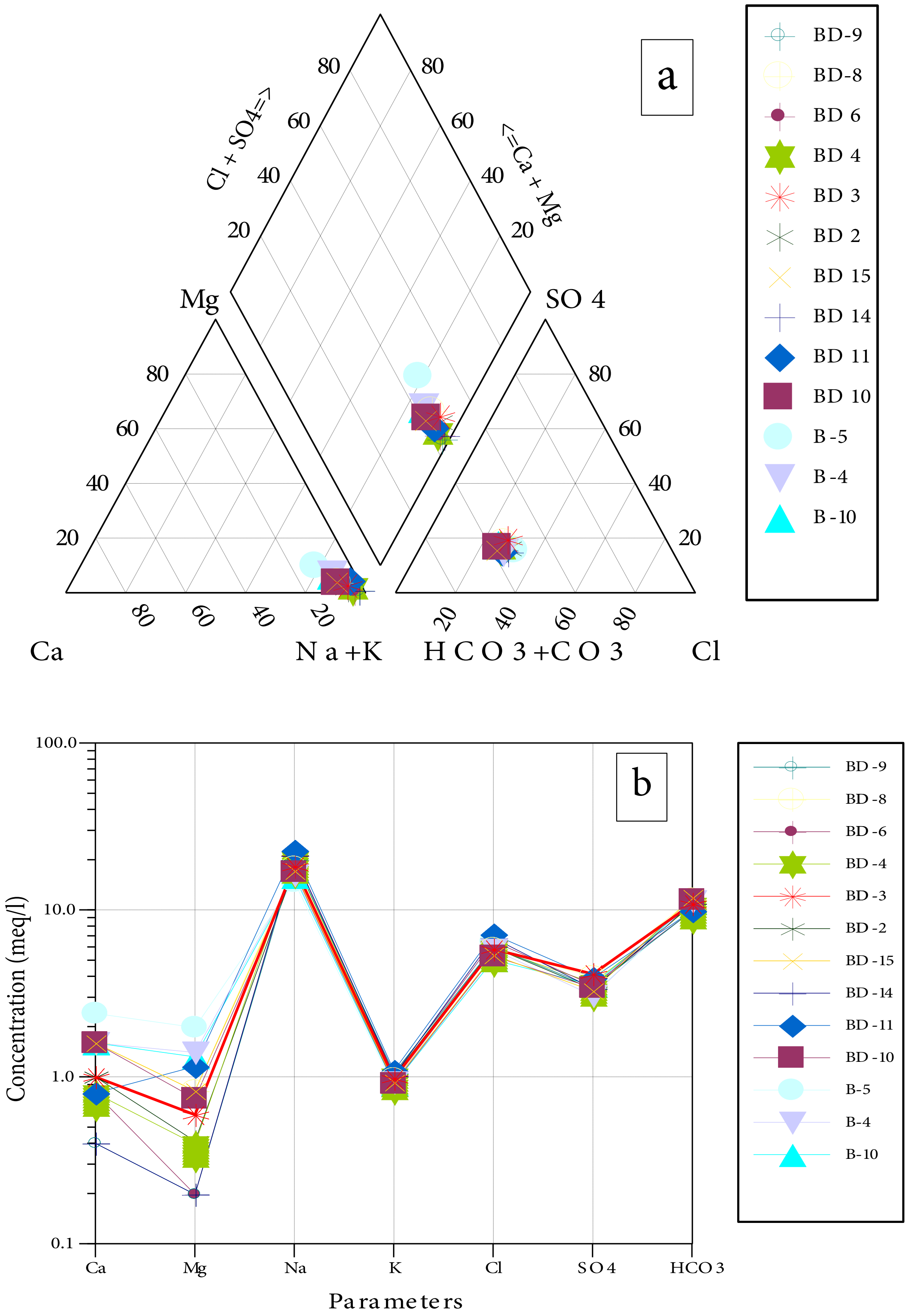

Figure 5. Chemical analysis of geothermal fluid of the study area plotted on a) Piper and b) Schoeller diagram.

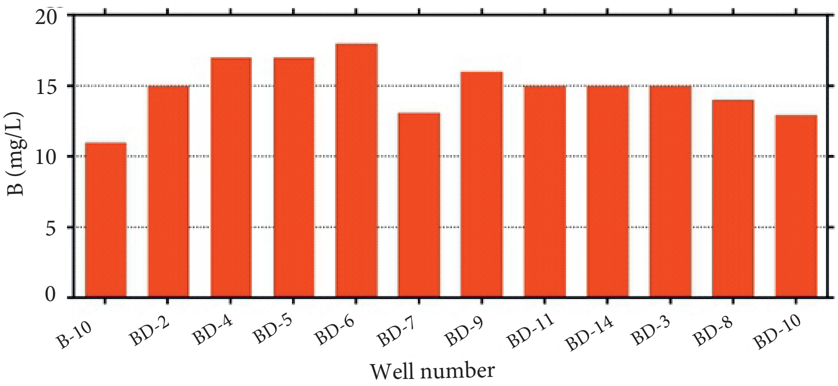

Figure 6. Distribution of boron concentration in the geothermal fluid in the study area.

were configured to operate in a star network with smart repeater mode. This mode allows the leaf-like network design with some advantages and restrictions (TSNPS, 2015).

In addition to the rules of star network mentioned above, the following two rules have been set on system design in terms of drip irrigation.

· Valve nodes can only be represented by nodes or routers of the network.

· Soil monitoring nodes can only be represented by subnodes of the network.

2.3.1. Hardware design

Regardless of their role, both nodes are designed and manufactured as two hardware layers, namely, top and bottom. While power components, analog/digital inputs and outputs, and other electronic components such as motor driver (DRV8800, Texas Instruments) are placed on the bottom layer, microcontroller (MCU), RF module, eeprom, and external antenna connection are placed on the top layer.

A 32-bit ARM Cortex-M4 MCU with floating-point support running at 84 MHz (STM32F401RET6, ST Microelectronics) is selected as MCU. Communication between MCU and RF module is established with UART at TTL level. To save the user-defined configuration parameters, an external eeprom (AT24C512, Atmel) was connected to MCU via I2C connection.

The bottom layer includes a 12–24 VDC power input, 9 analog inputs for soil moisture sensors and pressure sensor, 1 digital input/output line for the SDI-12 communication of digital soil moisture-EC-temperature sensors, 1 digital input for a water meter connection, and 1 digital output for 9VDC latch solenoid valve.

2.3.2. Sensors and other peripherals

Teros-10 and Teros-12 (Meter Group) sensors are selected for soil moisture and soil electrical conductivity measurements. Volumetric water content (VWC) range of Teros-10 and 12 is 0–0.64 and 0–0.70 m^3/m^3 and in mineral soils with standard calibration, respectively. Both sensors have ±0.03 m^3/m^3 accuracy in mineral soils that has solution EC is lower than 8 dS/m. The output of the Teros-10 is between 1000 and 2500 mV regardless of 3 to 15 VDC supply voltage. By using the sensor output, VWC is calculated using Equation 1.

$$VWC = 4.824 \times 10^{-10} \times mV^3 - 2.278 \times 10^{-6} \times mV^2 + 3.898 \times 10^{-3} \times mV - 2.154 \qquad (1)$$

where mV is Teros-10 sensor output as millivolt, VWC is the volumetric water content of the soil as m^3/m^3.

The bulk electrical conductivity (EC) range of Teros-12 is 0–20 dS/m. The accuracy of the sensor between 0 and 10 dS/m is ±(5%+0.01 dS/m). The supply voltage is 4–15 VDC. This sensor communicates with MCU over SDI-12 protocol (SDI-12 Support Group, 2021) that allows the placement of more than one Teros-12 sensor on a data line and provides the measured values directly. According to this protocol, each sensor must have a different ID. Therefore, ID of each sensor has been changed before insertion into the soil.

Both sensors were supplied with 5 VDC and were awakened by toggling the power line from an MCU pin at the time of measurement.

Applied irrigation water volume was measured by a pulse water-meter (Baylan Watermeters, 1 pulse/liter). An additional 12VDC latch solenoid valve (Rainbird) was installed before the water-meter to initiate the irrigation. This valve was powered up at 50 ms duration by firmware to turn on and off.

2.3.3. Firmware and software design

The firmware was developed with C/C++ by Med OS 5.0 bare-metal profile. Interrupt driven control algorithm was implemented to acquire sensor data, measure the water-meter pulses and control the solenoid valve.

Data transmission interval and irrigation water volume to be applied can be configured and adjusted by the user on the web-based graphical user interface (GUI). To start the irrigation, the special command, including desired water volume (liter) was sent to the valve node over the internet and RF by the user through the browser (i.e. Google Chrome, etc.).

2.4. Field tests

2.4.1. Experimental design

Developed WSN was integrated into the drip irrigation system installed at the experimental field of İzmir Geothermal A.Ş. Yenikale Heat Center (38°23'45.95"N, 27°00'40.85"E). Dripper spacing is 20 cm, dripped flowrate is 2 l/h (Figures 7 and 8).

Three irrigation treatments; T1: Irrigation with freshwater, T2: Irrigation with low boron concentration (treated geothermal water + freshwater mix, 2–4 ppm), T3: Irrigation with high boron concentration (treated geothermal water + freshwater mix, 4–6 ppm) with three repetitions were planned to irrigate tomato plants.

A pair of soil monitoring nodes and valve control nodes were attached to each treatment. Four Teros-10 and four Teros-12 soil sensors were connected to each soil monitoring node and inserted into the soil at 25, 40, 50, and 70 cm depths (Figure 7). The data transmission interval was 20 min.

A 5 m^3 tank was used to store fresh water (T1) and treated geothermal fluid + freshwater mix (T2 and T3) for each treatment. A submersible pump was placed into each tank to supply irrigation water to plants.

Tomato seedlings were planted with a density of 40 × 80 cm (3.125 plants/m^2 or 0.32 m^2/plant) in 04.20.2021. Each treatment has 186 plants (59.52 m^2). Low and high boron concentration treatments have not been initiated immediately so that the plant seedlings can adapt to the existing soil and climate conditions. All treatments were irrigated with fresh water until the plants were shown healthy root and shoot development.

2.4.2. Irrigation methodology

Ten days before planting, a basin was created on the surface of the soil at the point where the sensors were placed, and the soil profile was saturated up to approximately 100 cm in each treatment. The soil moisture values read by Teros-10 moisture sensors in each soil layer were observed for

Figure 7. General view of wireless sensor network soil monitoring node (left) and Teros-10 and Teros-12 sensors (right) for tomato production.

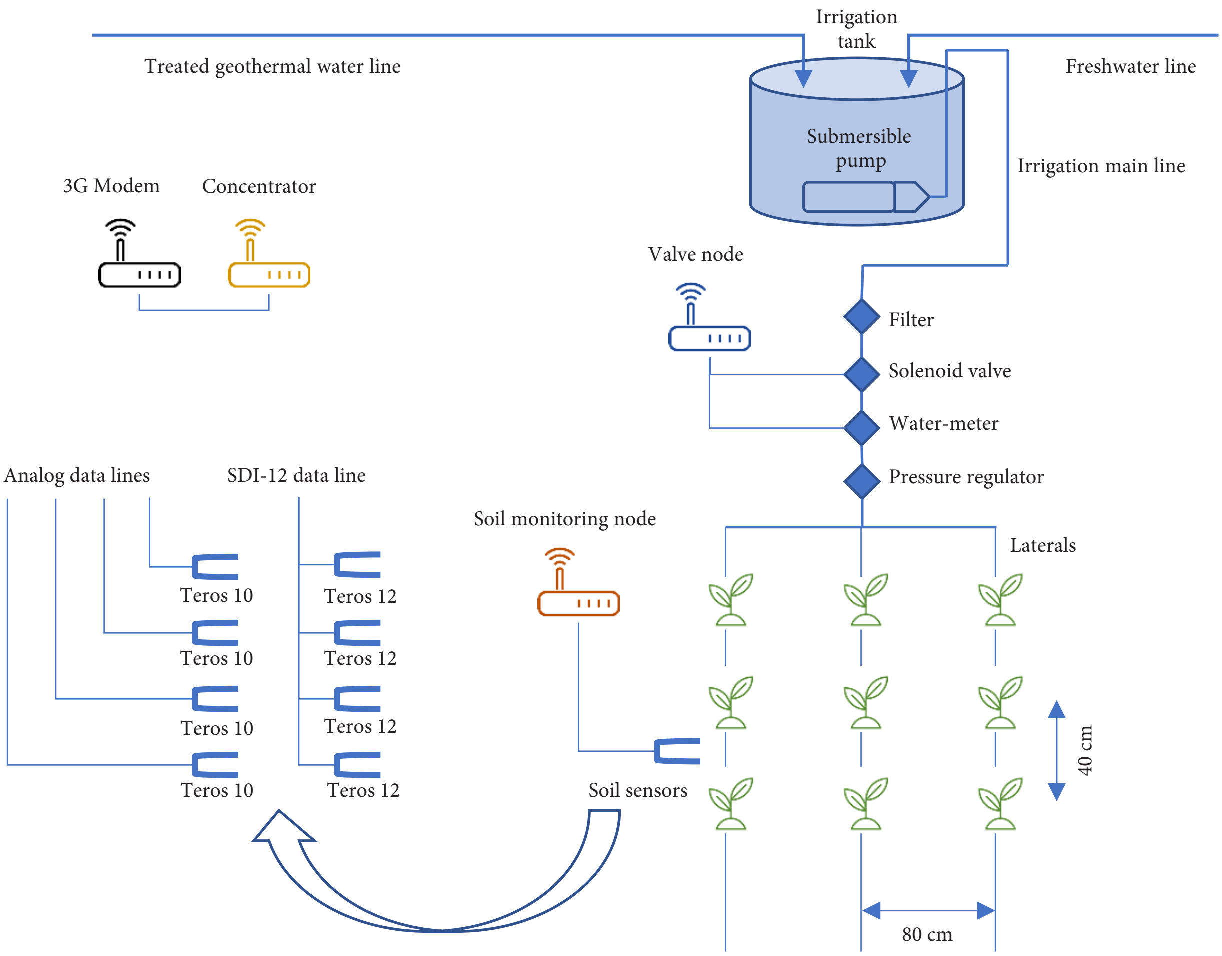

Figure 8. Schematic representation of an irrigation treatment (Treated geothermal water line has been installed only for low (T2) and high (T3) boron concentration treatments).

approximately three days to determine the field capacity of the soil. This test was repeated twice. Field capacity values determined according to this test are given in Table 1.

Irrigation was managed by Teros-10 sensor readings. The total amount of irrigation water to be applied is calculated as the sum of the irrigation water amounts calculated using Equation 2 separately for each soil layer remaining within the soil depth to be wetted. Wetted soil depth was considered 300 mm until 05.05.2021, 600 mm in 05.05.2021, 750 mm after 05.05.2021.

$$I = (FC - M) \times D \times PD \times N \tag{2}$$

where, I is the irrigation water volume (liter), FC is the soil moisture at field capacity of the relevant soil layer (m^3/m^3), M is the soil moisture before irrigation (m^3/m^3), D is the thickness of the soil layer (mm), PD is the surface area per plant (0.32 plant/m^2), N is the total plant number per treatment (186 plants).

The irrigation interval was between 2 and 3 days until 05.05.2021 and planned as 7 days after 05.05.2021, due to capacity of the membrane treatment system, time required to cool down the spent geothermal water and to reduce the labor required to fill the tanks.

2.4.3. Large pilot-scale membrane tests

A pilot-scale NF/RO membrane system was installed in the geothermal heating center, İzmir, Turkey, to treat spent geothermal fluid for agricultural irrigation water production. The spent geothermal brine was taken from the geothermal heating center after the energy has been extracted for the heating of the residential area. The spent geothermal water having a temperature of 50–55 °C was first taken into two PE containers of 5 m^3 to cool down to ambient temperature before its treatment by a pilot-scale NF/RO membrane treatment system. Cooling of spent geothermal fluid is necessary because the membranes intended to be used for treating the spent geothermal water are made of polymeric materials. Therefore, they can only accommodate temperatures up to 45 °C as recommended by the manufacturers. After the spent geothermal fluid is cooled down to ambient temperature, it was first pumped through sand and carbon filters to remove large particles, H_2S, etc. before NF/RO inlets, the system is equipped with 5 µm cartridge filters to remove smaller particles that might be passed through carbon and sand filters. Furthermore, the system is equipped with an antiscalant dosage pump. Because the spent geothermal fluid contains some inorganic scalants such as Ca^{2+} and Mg^{2+} that can have a serious threat to the productivity of the system when they form a scaling on the surface of the membranes. The antiscalant used in this study was Ropur (PRI-3000 A) type, while the antiscalant concentration was maintained constant at 5 g antiscalant/m^3 of the spent geothermal water to be treated. The pilot-scale NF/RO membrane system is equipped with a control panel where parameters like permeate and concentrate flow rates, pressure at the inlet, and the exit of the membranes are monitored. The PID controller in the automation system allows us to set a desired operational pressure and water recovery without difficulties (Figure 9). For the course of

Table 1. Field capacity of different soil layers determined by Teros-10 soil moisture measurements.

Treatment	Sensor depth (cm)	Representative soil depth to be wetted (or irrigated) (cm)	Layer thickness (mm)	Field capacity (FC) (m^3/m^3)
T1	25	0–30	300	0.28
	40	30–45	150	0.23
	50	45–60	150	0.24
	70	60–75	150	0.19
T2	25	0–30	300	0.29
	40	30–45	150	0.26
	50	45–60	150	0.32
	70	60–75	150	0.23
T3	25	0–30	300	0.28
	40	30–45	150	0.27
	50	45–60	150	0.25
	70	60–75	150	0.23

Figure 9. Large pilot-scale NF/RO treatment system.

this study, 1 NF (NF8040-70) and 1 RO (TM720D-400) commercially available membranes were used. Properties of the membranes used in this study are given in Table 2. The membrane treatment system was operated in a closed-loop mode, an applied pressure of 15 bar was maintained throughout 4 h of experimental time. Water recovery was maintained at 60%.

During each membrane test, samples from the feed, permeate, and concentrate streams were collected for further quality analysis. At every test, a Hach-Lange HQ14D model multimeter was used to measure conductivity, pH, total dissolved substances (TDS), as well as salinity. The curcumin technique was used to measure boron concentrations in the feed, permeate, and concentrate samples using a Jasco SSE-343 V-530 UV/Vis spectrophotometer.

Total-As, Na, K, Mg, Ca, SiO_2, Ba, Fe, Si, Sr, and Li concentrations were determined using inductively coupled plasma SM 3120 B (ICP) method for the full analysis of spent geothermal fluid taken directly from the reinjection stream. The standard method 2320B was used to determine the total alkalinity (mg $CaCO_3$/L), HCO_3 (mg/L), as well as CO_3 (mg/L). SO_4^{2-} and F^- ion concentrations were determined using standard methods with chemical kits, whereas Cl^- ion concentration was measured using the standard iodometric method (4500-Cl B) for spent geothermal water taken directly from the reinjection stream. Properties of the spent geothermal water used in this study are given in Table 3.

3. Results and discussion

3.1. Preliminary results of irrigation test

To demonstrate the operational success of the WSN, irrigations on 05.12.2021 and 05.17.2021 in T1 treatment selected as an example. Soil moisture sensor readings before irrigation are given in Table 4. On those dates, 1400 and 1680 liters of water calculated according to Equation 2 were applied to plants. Because of these applications, changes in soil moisture and EC readings of Teros-10 and Teros-12 sensors within 75 cm soil depth are given in Figures 10 and 11.

With the start of the irrigation, soil moisture end EC readings increased up to 0.29 m^3/m^3 and 240 μmhos/cm in the upper soil layer. Integrated WSN system successfully captured and sent data to the database located on the server at 20 min intervals. Due to the higher evaporative demand of the atmosphere and the correspondingly more water intake by the plants in daytime hours, sharper decreases were observed in the soil moisture, especially in Teros-10 sensor located at 25 cm depth. Alternatively, soil EC increased with the penetration of irrigation water into the soil and changed between 125–250 μmhos/cm in 75 cm soil profile. Increases in sensor readings after irrigation water application are indicated that the water has reached the soil depth where the sensor was installed.

In recent years various similar studies were successfully conducted to demonstrate the application of WSNs for different crops such as tomato (Cambra et al., 2018), lettuce (Cambra et al., 2018), container crops (Rahim Khan et al., 2013), citrus (Sawant et al., 2017); with different communication technologies such as Zigbee (Angelopoulos et al., 2011; Nikolidakis et al., 2015), bluetooth (Kim et al., 2008; Kim and Evans, 2009) and GPRS (Gutiérrez et al., 2014). Besides various soils/growing mediums (Navarro-Hellín et al., 2015; Cambra et al., 2018; Dursun and Ozden, 2011) tested and drip irrigation strategy mentioned (Dursun and Ozden, 2011; Chikankar et al., 2015; Sawant et al., 2017).

3.2. Preliminary test results of pilot-scale membrane tests

Treatment of spent geothermal fluid by employing pressure-driven membrane separation processes was investigated as the preliminary study. Two membranes (NF and RO) were employed for this task. An applied pressure of 15 bar and 60% water recovery was maintained constant throughout permeate collection while the mode of operation was a closed loop. Permeate obtained was assessed before irrigation of tomato.

Based on the results obtained, it was observed that the quality of the produced water in terms of electrical conductivity (EC) has complied with irrigation water standards given by the Republic of Turkey Ministry of Environment and Urbanisation (TPDWTP, 2010).

Table 2. Membrane properties of large pilot-scale membrane treatment system.

Membrane	Producer	pH range	Active area (m^2)	Maximum pressure (bar)	Maximum temperature (°C)
NF	Toray[1]	2–11	37.2	41.4	45
RO	Toray[2]	2–11	37.0	41.4	45

[1] Lenntech (2021). Toray Membranes CSM-NE8040-70-L. https://www.lenntech.com/Data-sheets/CSM-NE8040-70-L.pdf [accessed 23 May 2021].

[2] Lenntech (2021). Toray Membranes TM720D-400 https://www.lenntech.com/products/membrane/toray.htm [accessed 23 May 2021].

Table 3. Spent geothermal fluid characteristics.

Parameter	**Spent geothermal fluid**
pH	8.52
Electrical conductivity (µS/cm)	1807
TDS (mg/L)	1230
HCO_3 (mg/L)	580
Cl (mg/L)	199
SO_4 (mg/L)	164
F (mg/L)	7.0
Na (mg/L)	411
K (mg/L)	32
Mg (mg/L)	7.7
Ca (mg/L)	25
B (mg/L)	12
SiO_2 (mg/L)	118
As (mg/L)	0.17

Table 4. Soil moisture readings of Teros-10 sensors before the irrigations on 05.12.2021 and 05.17.2021.

Irrigation date	**Sensor depth (cm)**	**Teros-10 sensor readings before irrigations (m^3/m^3)**
05.12.2021	25	0.230
	40	0.202
	50	0.213
	70	0.178
05.172021	25	0.227
	40	0.199
	50	0.211
	70	0.176

However, the produced water did not comply with irrigation water in terms of boron concentration in both the membranes tested (NF and RO). Furthermore, the arsenic concentration in NF permeates was higher than the irrigation water standard (<10 µg/L). Likewise, the pH of the produced water by RO membrane was found to be lower than the irrigation water standard (> 6.0) as shown in Table 5. It is good to keep in mind that different crops require different irrigation water quality (Yilmaz et al., 2008). For that reason, some strategies need to be developed to tailor the produced water for it to be suitable for the irrigation of tomato plants.

Hence, various approaches are needed to use treated spent geothermal fluid for irrigation. Many ways are proposed in the literature regarding the treatment of spent geothermal fluid. For example, the pH of the spent geothermal fluid can be increased for the removal of boron to irrigation water standards as recommended by Tomaszewska and Bodzek (2013) and Yavuz et al. (2010). So that, limiting factors of boron toxicity in plant production such as reduction of root growth and decrease of stem cell division, RNA content, leaf chlorophyll, and photosynthetic rate will be excluded (Roessner et al., 2006).

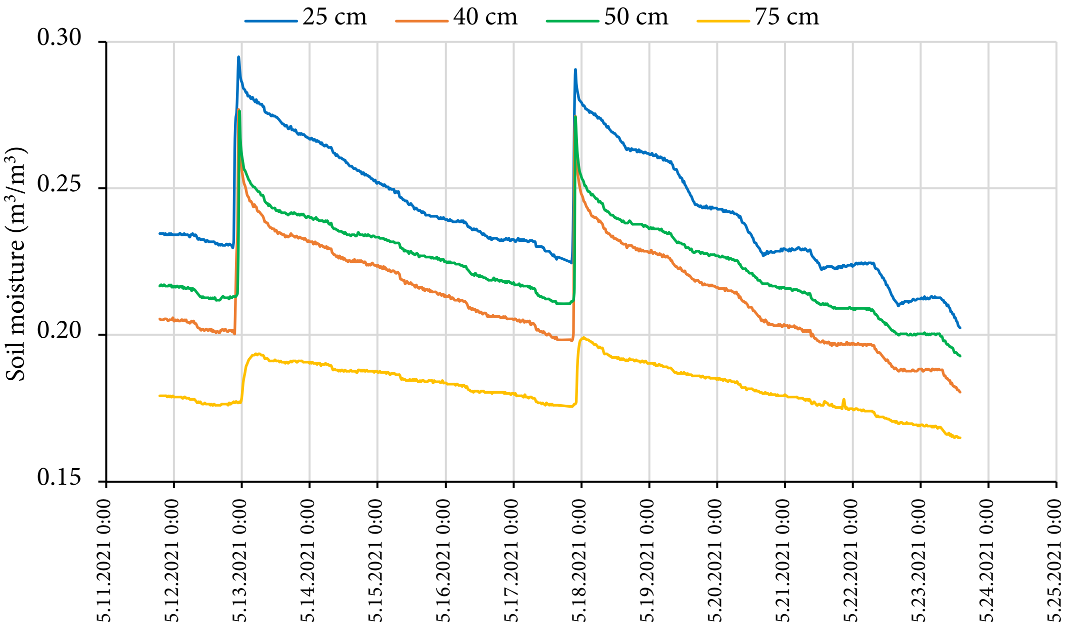

Figure 10. Soil moisture readings of Teros-10 sensors in T1 treatment between 05.12.2021 and 05.23.2021.

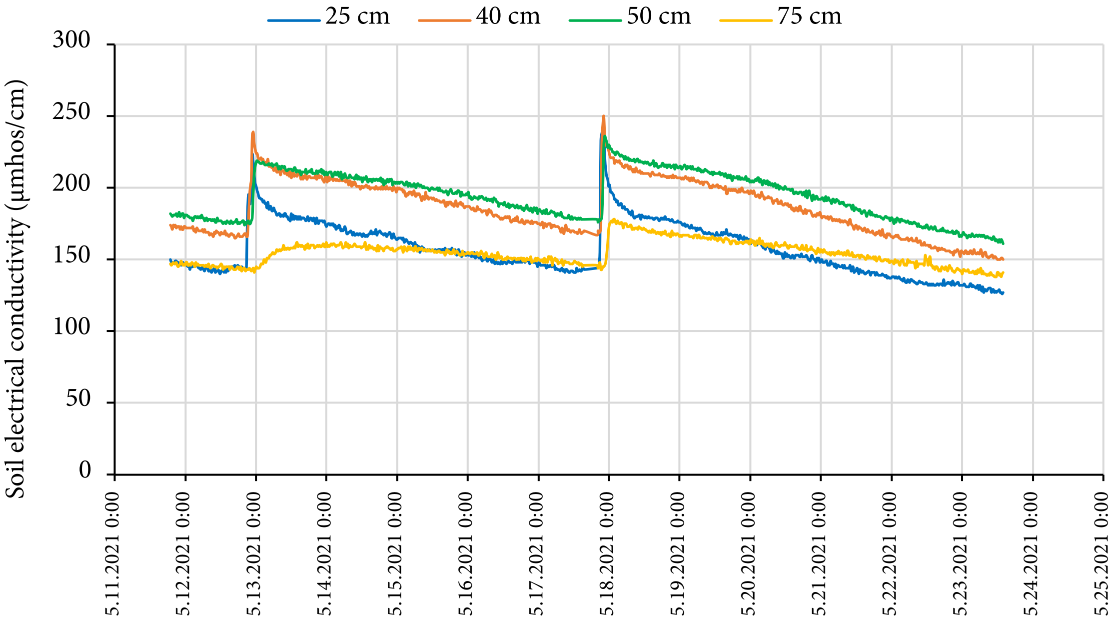

Figure 11. Soil EC readings of Teros-12 sensors in T1 treatment between 05.12.2021 and 05.23.2021.

Table 5. Evaluation of chemical quality of product water after NF/RO treatment for agricultural irrigation purpose.

Parameter	**Unit**	**NF**	**RO**
Salinity	‰	0.34	0.01
EC	µS/cm	856	23.4
TDS	mg/L	346	8.77
Boron	mg/L	8.72	5.50
Arsenic	µg/L	30	< 10
pH	-	6.90	5.30

Another approach is to pass the treated spent geothermal fluid through a fixed-bed column containing boron selective chelating ion exchange resins. Another problem that needs to be addressed is the absence of minerals needed for a plant grown in permeate of NF/RO membranes. Therefore, after NF/RO process, there is a need to adjust the product water quality to be suitable for the crop that is intended to be irrigated. This can be done by either directly adding the missing elements or mixing the produced permeates with a rich mineral-rich water source (free of boron and arsenic) at an optimum ratio.

4. Conclusion

Geothermal fluid can be used for heating, cooling, greenhouses, fish, etc. It is also can be used for irrigation. In this study preliminary results of the operational efficiency of an innovative WSN and a pilot-scale NF/RO membrane system integrated to drip irrigation system was demonstrated for irrigation of tomato plants with treated geothermal water. Obtained data showed that irrigations could be successfully monitored and managed remotely by the WSN, in terms of soil moisture and electrical conductivity, during the test period.

When using geothermal fluid in irrigation, the chemical composition of the water must be carefully monitored. Some geothermal fluids consist of a high concentration of boron. In these cases, the fluid needs to be treated. Treatment of spent geothermal fluid by employing pressure-driven membrane (NF and RO) separation processes in a pilot scale was investigated as preliminary studies. It was found that the boron concentration was still higher than the irrigation water standard. It was concluded that more additional separation strategies like an increase in feed spent geothermal fluid, coupling of pressure-driven separation process with boron selective ion exchange fixed bed, two or more pass membrane units must bring boron to irrigation water standard.

It was clearly seen that spent geothermal fluid is a promising potential irrigation water source when proper treatment strategies alone or in combination with innovative WSN are put in place. Additionally, long-term studies are also necessary to better assess the opportunities and risks for soil and plants.

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