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Assessment of Effluent Water Quality in the Al-Hammar Marsh, Thi-Qar Province, Iraq: A Spatiotemporal Statistical Analysis (2012–2014 vs. 2019–2021)

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ABSTRACT

Water resources in Iraq, particularly its marshes, are increasingly threatened by pollution caused by diminished flow volumes, agricultural runoff, and unregulated domestic and industrial discharges. This study assesses the water quality of the effluents of the Al-Hammar Marsh in Thi-Qar Province using spatial and temporal statistical analyses. Monthly monitoring data for four key parameters—electrical conductivity, pH, total dissolved solids, and water temperature—were collected from 12 sites over two separate periods: 2012–2014 and 2019–2021. Trend analysis and the evaluation of the best-fitted models were also performed. The results indicate a variation in water quality standards across the periods studied. At all locations, the values of electrical conductivity coefficient and total dissolved solids fluctuated during the studied periods. The observed monthly values of the pH coefficient at all sites indicated a decrease over time, i.e., from the first period to the second period. For temperature, the results showed that the time series of observed monthly values in the 12 sites did not change significantly during the study periods. In general, the values of temperature ranged from a minimum of approximately 8°C to a maximum of 35°C. This reflects the deterioration of water quality in the effluents of the marsh and indicates that the water quality in Al-Hammar Marsh has been unstable over time due to changes in water quality and quantity, driven by water scarcity and climate change in the region.

1. INTRODUCTION

The Iraqi marshes, which are known as the “Garden of Eden”, are considered one of the richest regions in the world in terms of the diversity of wildlife and aquatic life and their unique geographical advantages. These marshes, or what is locally called “Ahwar”, located in the south of Iraq, are natural reservoirs of fresh water. The water of the marshes can be used for municipal uses as well as for other sectors such as agriculture and navigation, and a multitude of ecosystem services, all essential for economic growth in the region [1]. The marshland is part of the area of the lower and middle basins of the Tigris and Euphrates Rivers. It creates one of the most widespread ecosystems of wetlands in the Middle East. These two rivers created a large network of wetlands called the "Mesopotamian marshes". The wetlands consist of several natural interconnected lakes that contain fresh water as well as swamps and plains that are flooded seasonally, i.e., water levels in marshes can reach their maximum levels in early spring and then decrease during the summer season [2].

One of the most important and largest marshes in Iraq is the Al-Hammar Marsh, which is a large complex of wetlands in southeastern Iraq. Al-Hammar Marsh is located specifically in the governorates of Thi-Qar and Basra. It is bordered from the north by Al-Qurnah city, from the southeast by Basra city, and from the northeast by the Euphrates River, while from the south it is bordered by the Western Desert and salt lakes, and finally from the west and north, it is bounded by urban regions represented by Nasiriyah city and Al-Chibayish city. The main water sources for Al-Hammar Marsh are the Euphrates River and its tributaries, in addition to the water that comes from the Tigris River through the surplus in the central marshes. Approximately until the 1970s, these wetlands extended for more than 120 km by 25 km, covering an area of 2800 km^2 and reaching 4500 km^2 during the flood seasons [3].

Many studies with a variety of essential topics about marshes and wetlands have been conducted worldwide. These studies covered the temporal and spatial variation of the chemical and physical properties of water, seasonal changes in water quality, water quality measurement, and environmental assessment of the water of the marshes. Most of the topics were related to the Iraqi marshes, including the Al-Hammar Marsh and some other waterbodies in the world.

Al-Musawi et al. [4] presented a study to assess the water quality of the Al-Hammar Marsh at the station (M1), which is also called Al-Hamedy. This station was located in the middle of the marshes in Basra city from 2011 to 2015. The study dealt with 12 parameters such as potential of hydrogen (pH), nitrate (NO_3), phosphate (PO_4), calcium (Ca), magnesium (Mg), total hardness (TH), sulfate (SO_4), sodium (Na), chloride (Cl), total dissolved solids (TDS), alkalinity (Alk.), and electrical conductivity (EC). The Water Quality Index

(WQI) was also calculated to ensure the water quality of the Al-Hammar Marsh. Then, the results were linked with the program ArcGIS 10.4.1 to obtain layers representing the spatial distribution of WQIs indicators as color maps. The study found that the water quality of the marshes was lower than the category of poor water quality; in addition, the salinity of the marshes' water was low.

Al-Saad et al. [5] implemented and designed water quality surveys for the period from November 2005 to September 2006 in six locations, four of which are Al-Nagara, Al-Barga, and Al-Baghdadia 1 and 2 in Al-Hammar Marsh, and two locations, Um Al-Neiach and Um Al-Warid in Al-Hwaaiza Marsh. Several physical and chemical parameters, such as dissolved oxygen (DO), turbidity, biological oxygen demand (BOD), total suspended solids (TSS), EC, TDS, temperature, and TH, were studied, as well as salinity, pH, and nutrients. The results showed that there are wide variations in the seasonal values of all the studied parameters in all the examined sites of the marshes.

Mashkhool [6] studied the concentrations of heavy metals such as copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), and cadmium (Cd) in both particulate and dissolved phases in water and sediments. The study examined and analyzed the physical and chemical properties of water, such as salinity, temperature, pH, electrical conductivity, the percentage of organic carbon in the sediments, and the texture of the sediments. This study was conducted in two stations within the Al-Chibayish marshlands in Thi-Qar province during the summer and winter seasons of 2011 to assess the water quality of the marshes. The results showed that the average concentration of heavy metals in water and sediments for all phases was high in the first station compared to the second station. The study stated that human activities through sewage discharge and the impact of oil spilled from boats and chemicals used in fishing had the greatest impact on increasing the concentrations of heavy metals in the first station compared to the second station.

Al-Shammary et al. [7] assessed water quality in eastern Al-Hammar Marsh after restoration using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), based on CCME Water Life Guidelines, as a body and historical data for two stations within the Al-Hammar Marsh for the period from September 2008 to September 2009. Thirteen factors were studied, such as oxygen demand, water temperature, salinity, BOD_5, NO_3, pH, NO_2, Sil, PO_4, TSS, TDS, turbidity, and transparency. The results showed that the value of WQI was under fair evaluation in the two stations, respectively.

Al-Rikabi and Abed [8] evaluated the improvement of hydraulic performance and water quality of the Al-Chibayish Marsh to determine the best sites for drainage outlets. Field measurements and laboratory tests were conducted for the two periods of November 2020 and February 2021 to determine the concentrations of TDS for nine sites. Some physical and chemical parameters, such as electrical conductivity, pH, turbidity, dissolved oxygen, and temperature, were also examined. The simulation of hydraulic performance and water quality was carried out using programs (RMA4 and SMS-RMA2). The results showed that the use of these outlets will improve water quality significantly.

Charkhabi and Sakizadeh [9] studied the spatial variation of water quality parameters in nine stations located along the Anzali wetland, in northern Iran. The studied water parameters are pH, TDS, DO, chemical oxygen demand (COD), BOD, temperature, total organic carbon (TOC), total phosphorus (TP), Total Nitrogen, Ammonium (NH_4^+), and Nitrate (NO_3^-). The results indicated that TDS values increased in some parts due to residential and agricultural activities. While the values of NH_4^+ were high due to the addition of fertilizers in the nearby agricultural fields. The results of the levels of phosphorus and total nitrogen were within the organic form.

Hong et al. [10] assessed the temporal and spatial variability of water quality and heavy metal concentrations in wetlands along the Yellow River using the Heavy Metal Pollution Index (HPI), the WQI, redundancy analysis, and hierarchical clustering analysis. Analysis of the results showed that the average WQI was highest during the flood season, while the average HPI was lowest during the same period. Also, both dissolved oxygen and chemical demand significantly influenced heavy metal concentrations. They concluded that if this trend continues unaddressed, the wetlands are likely to lose their vital social and ecological functions.

Al-Seedi and Al-Aboudy [11] presented a study about three sites in the marshes of Thi-Qar Province, namely Abu-Zurik, Al-Adel, and Al-Sanaf, to examine the chemical and physical properties and to determine the changes that occurred in their waters. The study was conducted for the period from January to December 2010. The results showed that the properties of the water of one marsh vary during the months of the year. Also, the results showed that the marsh water, which is of relatively high salinity, tends to be alkaline and is semi-hardened, and thus it is not suitable for drinking and other human uses, because the concentrations of the studied parameters were higher than the standard levels for human use.

Gupta et al. [12] conducted a study to evaluate the temporal and spatial distribution of the main ions of water samples for the Kabar Tal wetland "Ramsar site", Bihar, in India. The samples were collected during the winter, summer, and monsoon seasons. The analytical and Geographic Information Systems (GIS) results obtained showed that the electrical conductivity, nitrate, and chloride concentrations were higher in summer compared to winter and monsoons. In contrast, concentrations of sodium, calcium, potassium, and magnesium were higher in winter compared to summer and monsoons. In contrast, phosphate and sulfate concentrations were high during monsoons compared to summer and winter.

Merceline et al. [13] studied the temporal and spatial changes of the chemical and physical properties that occur as a result of human activities and their impact on the water quality of the Kapkatet Wetland, Kericho County, in Kenya. The physical and chemical parameters were measured by a multimeter probe (model no. YS1 15B) at three stations for a period of 6 months from February to July 2019. The data were examined by analysis of variance to verify the existence of statistically significant differences between months and sites. The results showed that human activities have a significant impact on wetlands and their water quality at the study site.

Tabassum et al. [14] evaluated the groundwater quality in Rajshahi, Bangladesh, through regional mapping. Data were collected from 7,388 wells in nine districts in collaboration with the Department of Public Health Engineering. The obtained water quality results were evaluated against the Bangladesh standards and the WHO. Spatial analysis was performed to model contaminant levels, and machine learning was applied. After corrections, improvements, and error handling of the initial model, an increase in the R^2 values of iron, arsenic, and chloride was observed. Finally, a comprehensive map was produced that includes water quality risks for the region.

Roy et al. [15] explored the potential of algae and fungi for wastewater treatment. Four genera of organisms-two algae (Gloeocapsa rupicoig and Spirogyra maxima) and two fungi (Trichoderma asperallum and Phanerochaete chrysosporium) were used for the reaction. After that, concentrations of iron, sulfate, copper, and bicarbonate ions were measured. The results showed improved wastewater treatment using these organisms compared to separate treatments.

Abed et al. [16] conducted a study to simulate turbidity in the Al-Saray area distribution network due to the increase in daily water consumption demand and high discharge rates. The Prediction of the Discoloration in Distribution Systems (PODDS) model was used, which is based on colour change in distribution systems. Flow rate values (522 and 5870 m^3/d) were adopted. The study results showed that the turbidity response increased at a flow rate of (5870 m^3/d) and that the shear stresses exceeded the layer's shear strength due to the increase in water demand.

Makki et al. [17] studied the suitability of the main outfall drain water of Al-Hammar Marsh through the comprehensive pollution index (CPI), twenty chemical and physical parameters were adopted, namely, PH, turbidity, EC, DO, PO_4, TDS, Ca, Mg, Cl, K, SO_4, NO_2, Pb, Mn, Cr, NH_4, Na, Ni, Zn, and Ba. This research was adopted in evaluating Artificial Neural Network (ANN) and Multiple Linear Regression (MLR) models to predict pollution indicators. Through the results, it was shown that the water of the Al-Khamissiya canal is very polluted, depending on the CPI, and that the models of both MLR and ANN are very effective in predicting pollution. It was also concluded that the neural network model is highly accurate in prediction due to the high level of accuracy of the results.

Wang et al. [18] assessed the sedimentary waters of Lake Bosten in Xinjiang, collecting 22 sediment samples to determine the concentrations of eight heavy metals: arsenic (As), chromium (Cr), mercury (Hg), Pb, Cu, Cd, Ni, and Zn. To evaluate sediment contamination with these metals, they used the Potential Environmental Hazard Index (RI) and the Pollution Burden Index (PLI). They concluded that the sediment showed significant cadmium contamination, slight zinc, lead, and chromium contamination, moderate nickel and copper contamination, and no levels of arsenic.

Melnyk and Brunn [19] assessed long-term seasonal (spring and summer) trends (2017–2024) in the water surface condition of Cheremsky Nature Reserve, a wetland of significant international importance. Using data from Google Earth Engine and Sentinel-2, 14 spectral indices for the reserve's waters were calculated. The data were then analyzed using Sen's method, and based on standard weights and trends, a Composite Index (CI) was developed. The results revealed seasonal variations in the indices, which can inform management and conservation efforts.

Iraq suffers from a deficit in water resources due to climate change and limited water levels in the Tigris and Euphrates Rivers, resulting in the construction of several big dams on these rivers upstream, such as those in Turkey and Iran, where more than 75% of the available water of Iraq comes from outside the country. Thus, the discharges of the Tigris and Euphrates Rivers have been estimated to continue to decrease with time, and they will be completely dry by the middle of this century. The Iraqi marshes and wetlands depend on the remaining waters that come from these rivers after several sectors, such as agriculture and industry, take their adequate amount of water for use in the upstream. Therefore, the problem arises with the reduction of the quality of the water that feeds these wetlands, which have been lived with people with their animals since the earliest times. The quality of the water supply to the marshes changes with time based on these limitations and inconsequence affect the life in the marshes and wetlands, and the restoration of the marshes becomes a necessary issue to put life back into this ecosystem. Thus, it is essential to study the water quality over time to conduct further investigations. The present study aims to determine the changes that affect the quality of the water supplying the Al-Hammar Marsh, southern Iraq. This is due to several reasons, including the great importance of the marshes in Iraq from an environmental and tourism perspective, and the lack of studies that have focused on the quality of the marsh water and how to treat it. This was done by studying some water quality parameters, such as EC, pH, TDS, and temperature in twelve sites feeding the marshes of southern Iraq. The analysis involved spatial analysis and time series for these water quality parameters using statistical methods used (e.g., Sen's slope, histogram frequency analysis). These sites are: Euphrates/Nasiriyah, Abu-Lahya, AZ24, Al-Abra, Middle the marsh/M4, Umm Al-Wadaa, Middle the marsh/M5, BC3, BC4, Abu-Sobat, Al-Hamidi River, and the Railway/M2.

2. DESCRIPTION OF THE STUDY AREA

Marshes and swamps are generally spread in the southern part of the sedimentary plain in southern Iraq. The marshes are characterized by the diversity of their environmental system of plants, fish, birds, and other organisms related to the aquatic environment. The marshes, including the Al-Hammar Marsh, spread in the south of the study area (Thi-Qar Governorate), as in Figure 1, and extending in a west-east direction through Universal Transverse Mercator (UTM) zones 38N, and between two latitudes ($30^{\circ},46' – 31^{\circ},60'$), in the north, and between two longitudinal arcs ($46^{\circ},27'–47^{\circ},80'$) to the east.

Table 1. Geographic coordinates of the study sites according to Universal Transverse Mercator system

Site No.	Site Name	Geographic Coordinates	
		Easting (m)	Northing (m)
Site 1	Abulihya	652485	3449513
Site 2	AZ24	664600	3424134
Site 3	Abusobat	694652	3427937
Site 4	Al-Abrat	658625	3426263
Site 5	Euphrates/Nasiriya	618380	3435451
Site 6	Al-Hamidi River	658980	3421354
Site 7	BC3	688291	3424170
Site 8	BC4	677360	3424551
Site 9	M5/Middle the Marshe	659794	3411700
Site 10	M4/Marsh	653035	3409755
Site 11	M2/Railway	649705	3409977
Site 12	Um Al-Wada	645850	3409250

The drought conditions prevailing in the study area and the accompanying lack of water revenue in the Tigris and Euphrates Rivers, resulting from the expansion of control and storage projects in the upstream countries (Turkey and Iran), contributed to reducing large areas of Iraq's marshes in general, especially in the study area. The area of the marshes decreased from 2850 km^2 in 1973 to 1181 km^2 in 2010, but at present, their area does not exceed 881 km^2, represented by the

Al-Hammar Marsh. This marsh is a shared water body between the governorates of Basra and Thi-Qar, and is one of the areas rich in vegetation and wealth, animals, fish, and birds. Thus, its great role in improving environmental conditions and developing tourism in the region. It is important to mention here that the data used in this study were collected periodically from 12 sites. These sites represent the effluents of the Al-Hammar Marsh that are distributed throughout the study area, as shown in Figure 1. Table 1 represents the geographical coordinates of these sites in the study area.

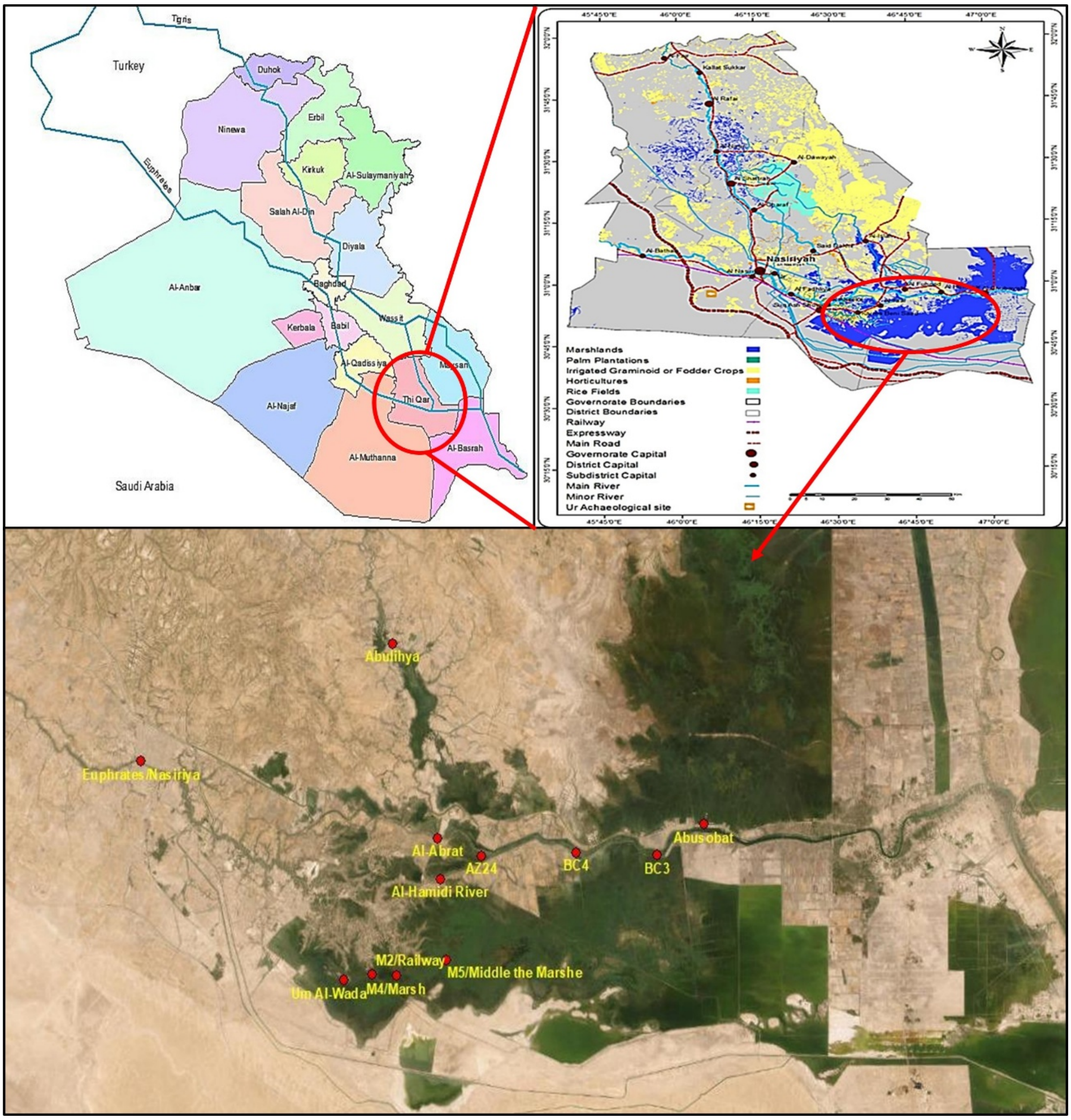


Figure 1. The locations of Al-Hammar Marsh and its effluents in the study area

3. METHODOLOGY AND DATA COLLECTIONS

In this study, an analysis of some water quality parameters was conducted in the Al-Hammar Marsh within Thi-Qar Governorate, southern Iraq. These parameters included EC, pH, TDS, and temperature in the twelve sites that feed the Al-Hammar Marsh within Thi-Qar Governorate, as shown in Table 1. The temperature of water is an essential physical parameter that impacts water quality. It also affects the chemical quality of water due to the dissolution of gases and increment of metabolic activity. pH is also an important parameter, especially for marshes, because it reflects numerous biological and chemical processes in the water body. EC represents the water's ability to connect electrical fields due to the presence of salts. The purpose here is to study the changes in water quality and compare them with time. Thus, data were collected for two different periods: the first period was extended from 2012 to 2014, and the second period from 2019 to 2021. The obtained data represent the mean monthly value of the studied parameters, and it was provided by Thi-Qar Marshlands and the Lands Management Projects, affiliated with the Center for Restoration of Iraqi Marshland and the Wetlands, one of the formations of the Ministry of Water Resources, Iraq. Statistical models of spatial analysis and time series were used in the analysis of the water quality parameters of the effluents of the marsh. The analysis also involved the histogram frequency for time series data of observed values for the parameters and the best probability distributions for the sites and the two studied periods. The histogram is a popular data analysis tool and is used to determine how the actual data distribution matches known distributions, such as Weibull, normal, and lognormal distribution etc. Moreover, an evaluation of trend magnitude was carried out based on Sen's slope of the time series data for the measured parameters to obtain the best-fitting trend models. The choice of Sen's slope and associated parametric trend analysis methods is due to their robustness and suitability for real-world data often found in environmental and hydrological studies, and they match the data used in this study.

4. RESULTS AND DISCUSSION

The time series plots of the observed monthly values for the 12 sites and both EC, as in Figure 2, and pH, as in Figure 3, and for TDS, as in Figure 4, while temperatures are shown in Figure 5. The blue line represents the first period (2012–2014), while the black line represents the second period (2019–2021). For the EC parameter, the results showed that the variation in EC in site 1 was small and fluctuated between 1000 and 1500 US cm^{-1} during the first period (2012–2014). A slight increase in EC from the first period to the second period. During the second period, the EC parameters have high fluctuation at the beginning of the period, then the change becomes slight till the end of the period. In contrast, for site 12, the results showed there is a reduction in EC values from the first period to the second period. For the rest sites, the variation in EC during the studied periods fluctuated for both periods (see Figure 2). There were several reasons for the fluctuation in the electrical conductivity of water, including agricultural runoff, sewage, and industrial wastewater, in addition to geological variation.

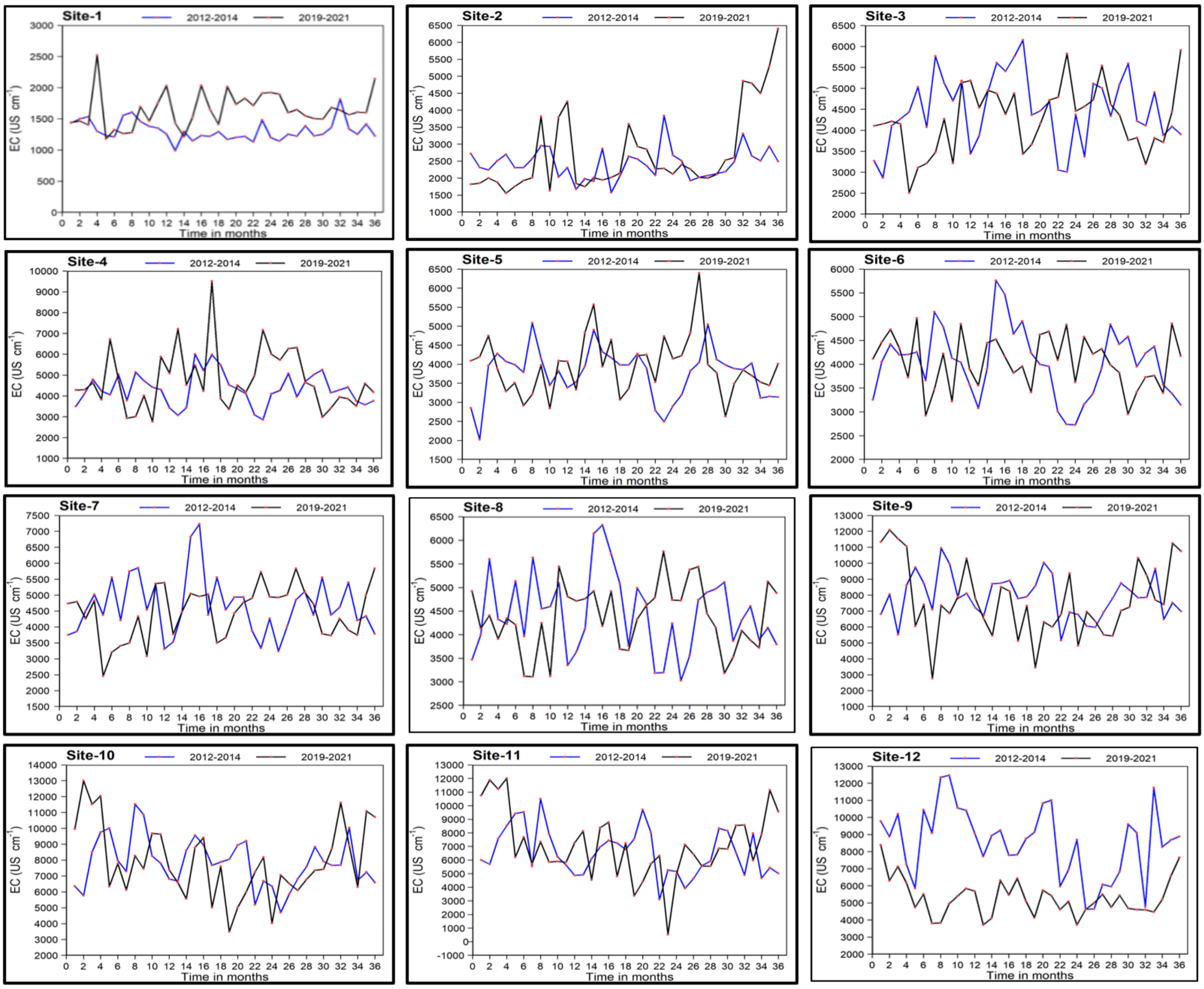
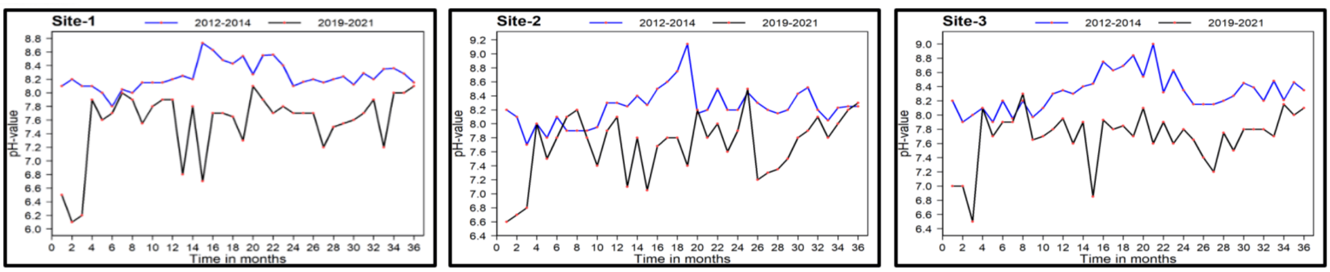


Figure 2. The time series plots of the observed monthly values for the electrical conductivity (EC) parameter in the 12 sites



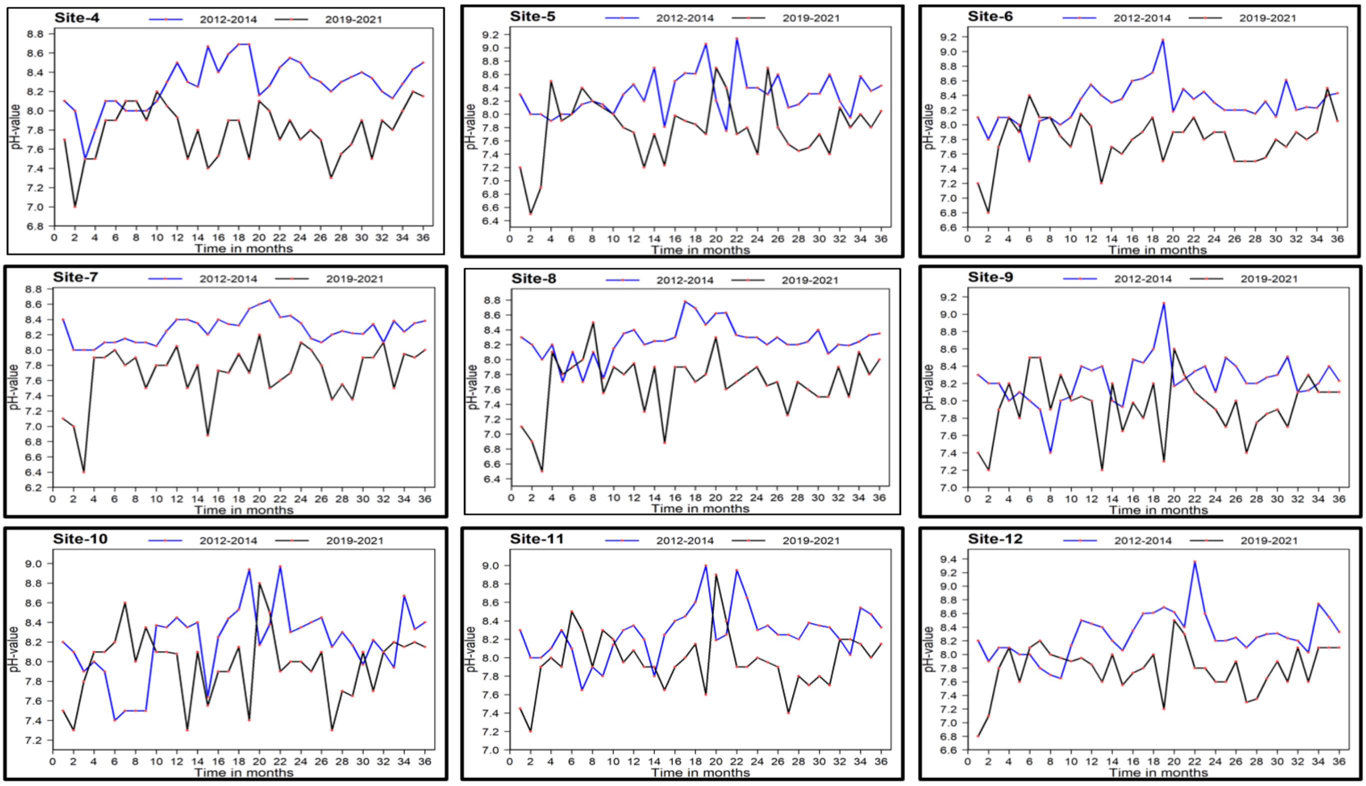


Figure 3. The time series plots of the observed monthly values for the potential of hydrogen (pH) parameter in the 12 sites

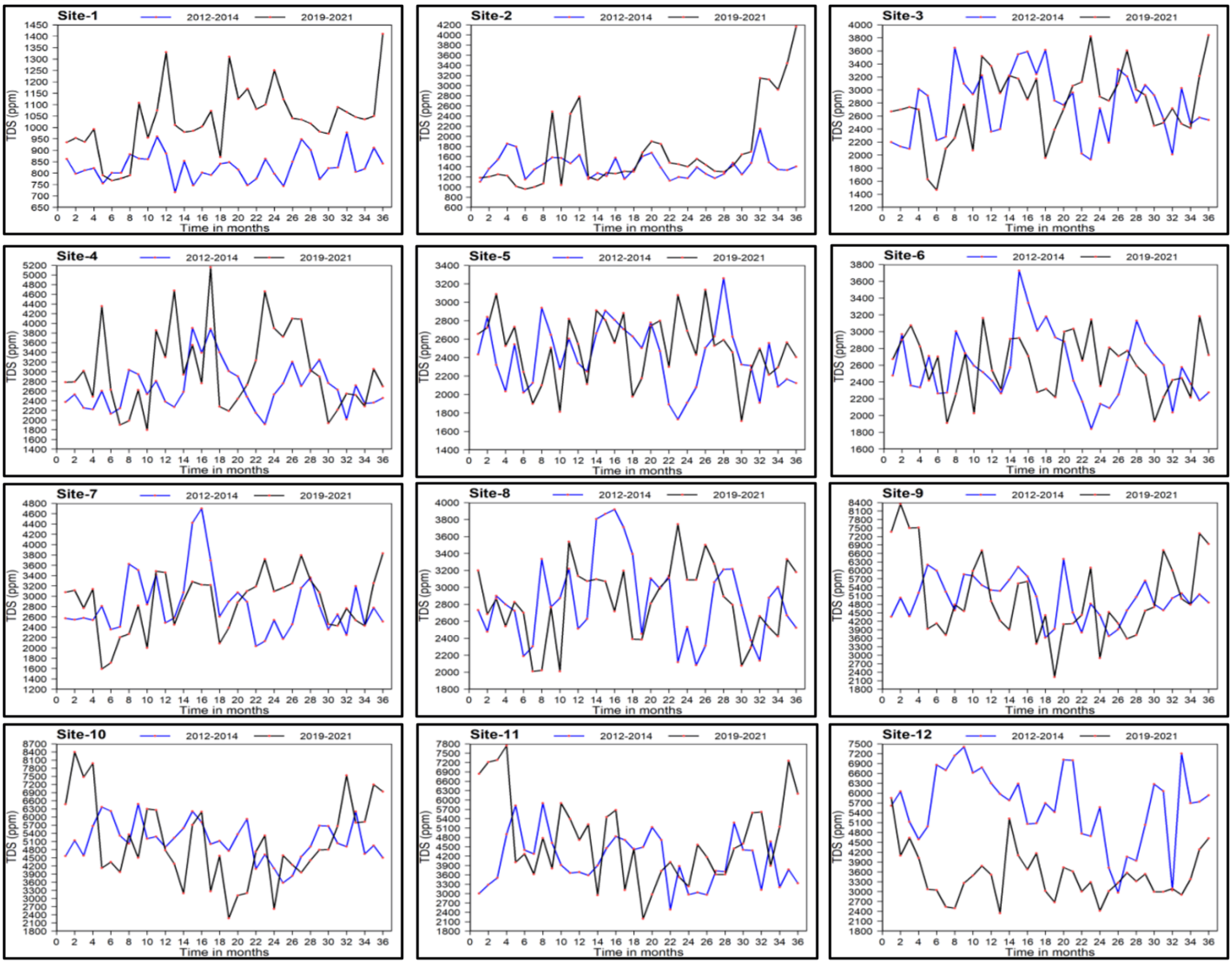


Figure 4. The time series plots of the observed monthly values for the total dissolved solids (TDS) parameter in the 12 sites

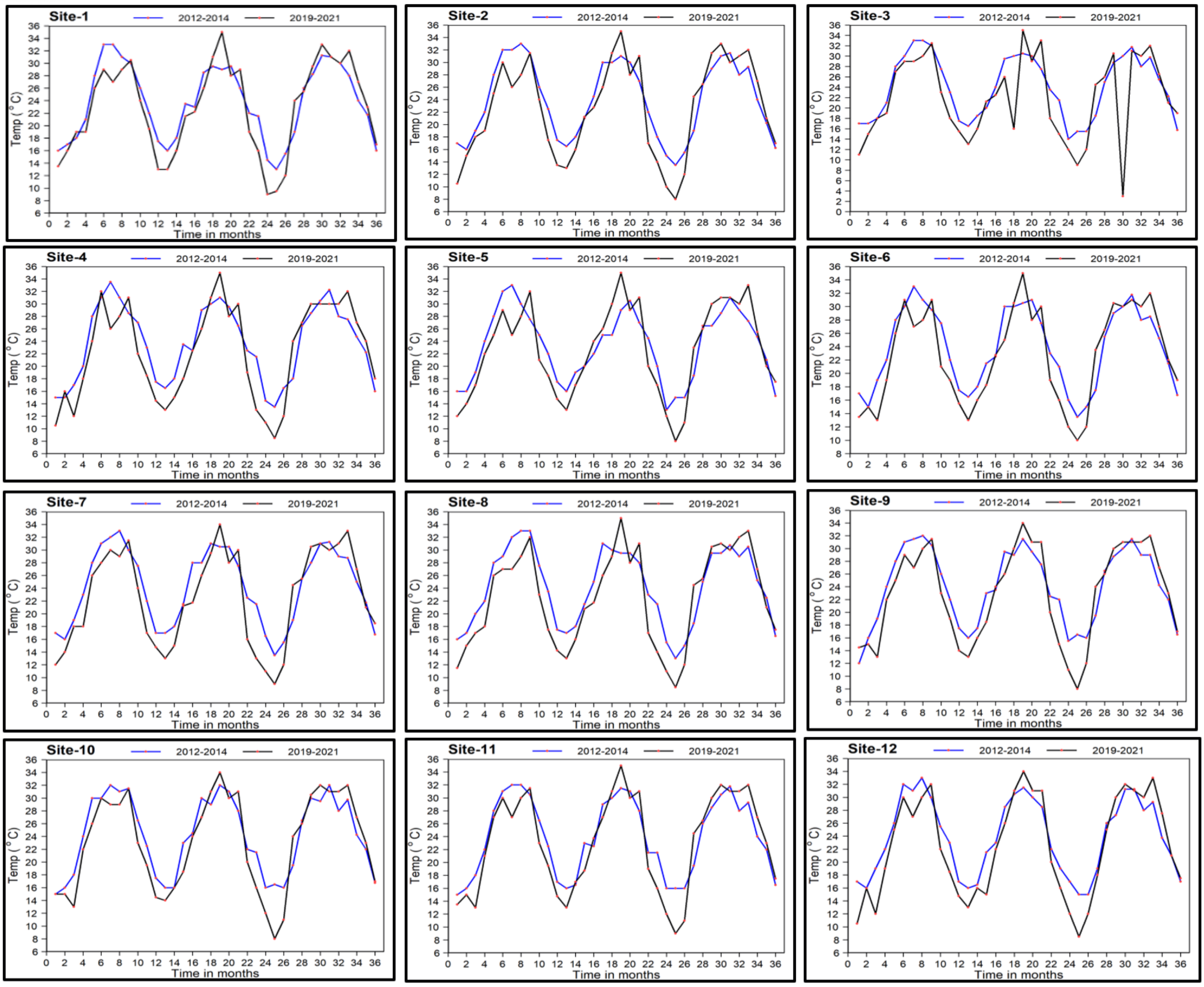


Figure 5. The time series plots of the observed monthly values for temperature parameters in the 12 sites

These reasons led to an increase in dissolved organic and inorganic materials, which in turn led to an increase in ions in the water, and this in turn changed the values of electrical conductivity. The time series results of the observed monthly values for the pH parameter in the all 12 sites indicated that there was a reduction in pH value over time, i.e., from the first period to the second period, as shown in Figure 3. The pH of a body of water can decrease due to several natural and human factors, such as an increase in CO_2 and the presence of organic acids. Figure 4 presents the time series plots of the observed monthly values for the TDS parameter in the 12 sites. At the site 1, there was an increase in TDS values with time from the first period to the second period, while there was a reduction in TDS values from the first period to the second period at the site 12. For the rest sites, it is clear that from the results, there is a fluctuation in TDS values in both periods. The fluctuation in TDS values is due to the fluctuation in water inflow values between different seasons, as the relationship between them is inverse. There are several sources of TDS, including soil water rich in clay, agricultural and urban runoff, and polluted water from water and sewage treatment plants. For the temperature parameters, the results showed that the time series of the observed monthly values for temperature parameters in the 12 sites did not change much during the observed periods (see Figure 5). In general, the values of the temperatures changed from about 8°C as a minimum value to 35°C as a maximum. The highest peaks occurred during the second period.

Table 2. Best probability distributions for parameters (EC, pH, TDS, and Temp.) and for the two time periods (2012–2014) and (2019–2021)

Site No.	Period (2012–2014)		Period (2019–2021)	
	Parameter	**Distribution**	**Parameter**	**Distribution**
Site 1	EC	Log-Logistic (3P)	EC	Log-Logistic (3P)
	pH	Log-Logistic (3P)	pH	Log-Logistic (3P)
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Weibull	Temp.	Weibull (3P)

Site 2	EC	Weibull	EC	Weibull
	pH	Log-Logistic (3P)	pH	Weibull (3P)
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Beta	Temp.	Power function
Site 3	EC	Weibull (3P)	EC	Weibull (3P)
	pH	Lognormal (3P)	pH	Weibull (3P)
	TDS	Weibull	TDS	Weibull
	Temp.	Beta	Temp.	Beta
Site 4	EC	Lognormal (3P)	EC	Lognormal (3P)
	pH	Log-Logistic (3P)	pH	Weibull
	TDS	Gamma (3P)	TDS	Gamma (3P)
	Temp.	Uniform	Temp.	Beta
Site 5	EC	Lognormal (3P)	EC	Lognormal (3P)
	pH	Log-Logistic	pH	Log-Logistic (3P)
	TDS	Normal	TDS	Normal
	Temp.	Power function	Temp.	Weibull
Site 6	EC	Logistic	EC	Logistic
	pH	Logistic	pH	Log-Logistic (3P)
	TDS	Weibull (3P)	TDS	Weibull (3P)
	Temp.	Weibull	Temp.	Power function
Site 7	EC	Log-Logistic (3P)	EC	Log-Logistic (3P)
	pH	Weibull	pH	Weibull (3P)
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Weibull	Temp.	Power function
Site 8	EC	Gamma	EC	Gamma
	pH	Log-Logistic (3P)	pH	Log-Logistic (3P)
	TDS	Lognormal (3P)	TDS	Lognormal (3P)
	Temp.	Weibull	Temp.	Power function
Site 9	EC	Normal	EC	Normal
	pH	Log-Logistic (3P)	pH	Log-Logistic (3P)
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Beta	Temp.	Weibull
Site 10	EC	Gamma	EC	Gamma
	pH	Log-Logistic (3P)	pH	Weibull
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Beta	Temp.	Power function
Site 11	EC	Log-Gamma	EC	Log-Gamma
	pH	Log-Logistic (3P)	pH	Log-Logistic (3P)
	TDS	Weibull (3P)	TDS	Weibull (3P)
	Temp.	Beta	Temp.	Power function
Site 12	EC	Log-Logistic (3P)	EC	Log-Logistic (3P)
	pH	Log-Logistic (3P)	pH	Weibull (3P)
	TDS	Log-Logistic (3P)	TDS	Log-Logistic (3P)
	Temp.	Uniform	Temp.	Beta

Note: EC: electrical conductivity; pH: potential of hydrogen; TDS: total dissolved solids; Temp.: temperature.

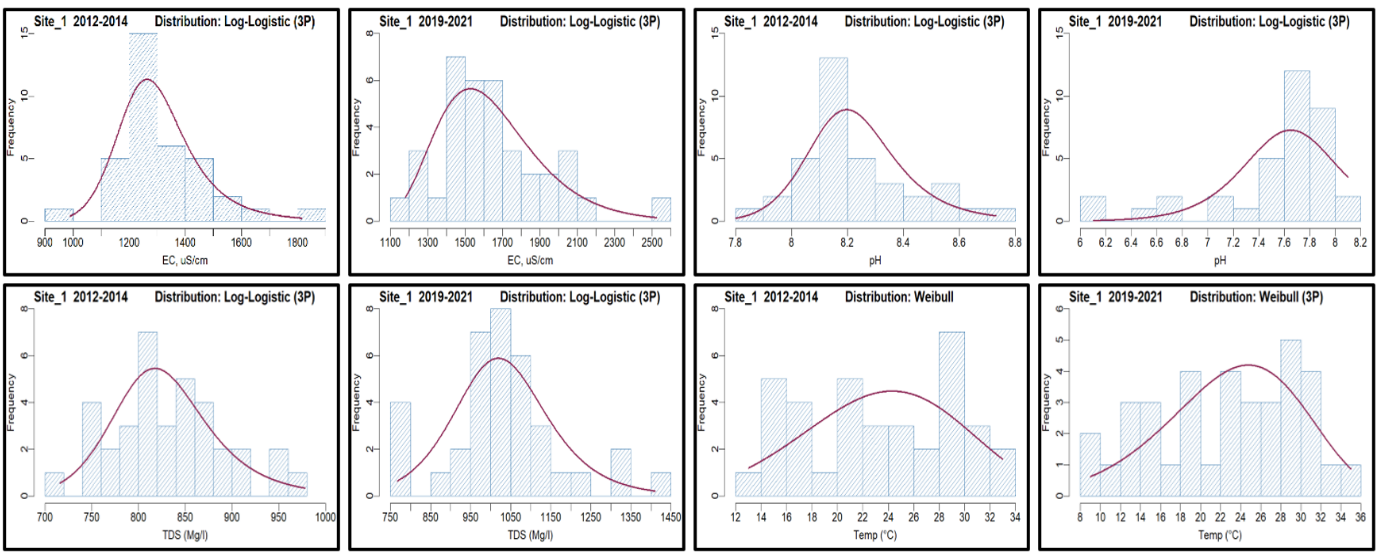


Figure 6. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 1

Note: EC: electrical conductivity; pH: potential of hydrogen; TDS: total dissolved solids; Temp.: temperature.

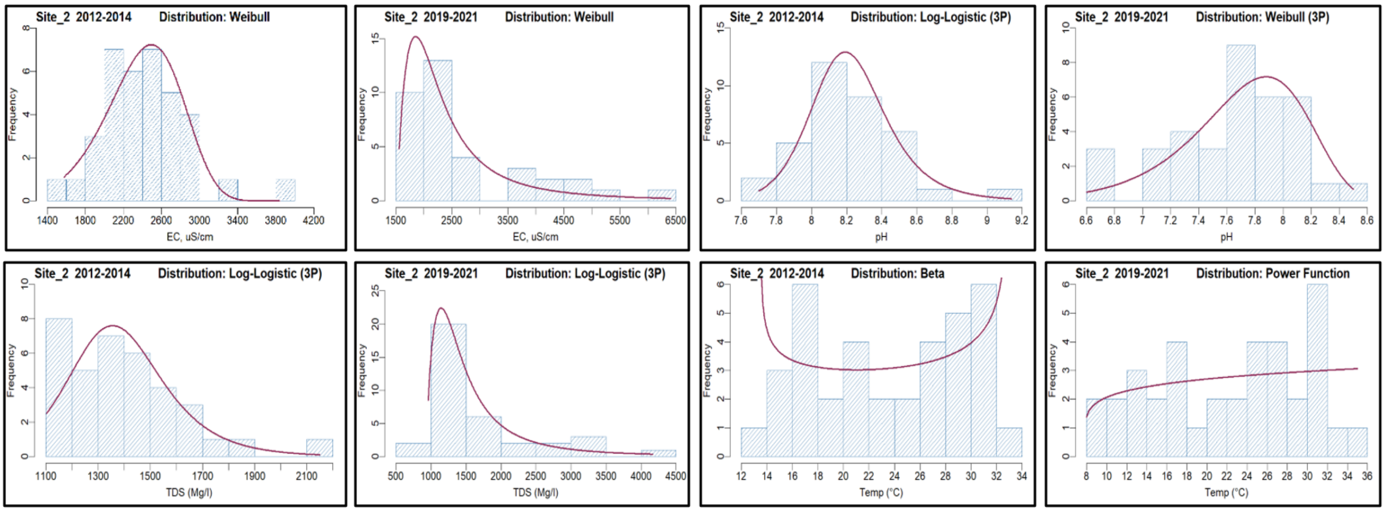


Figure 7. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 2

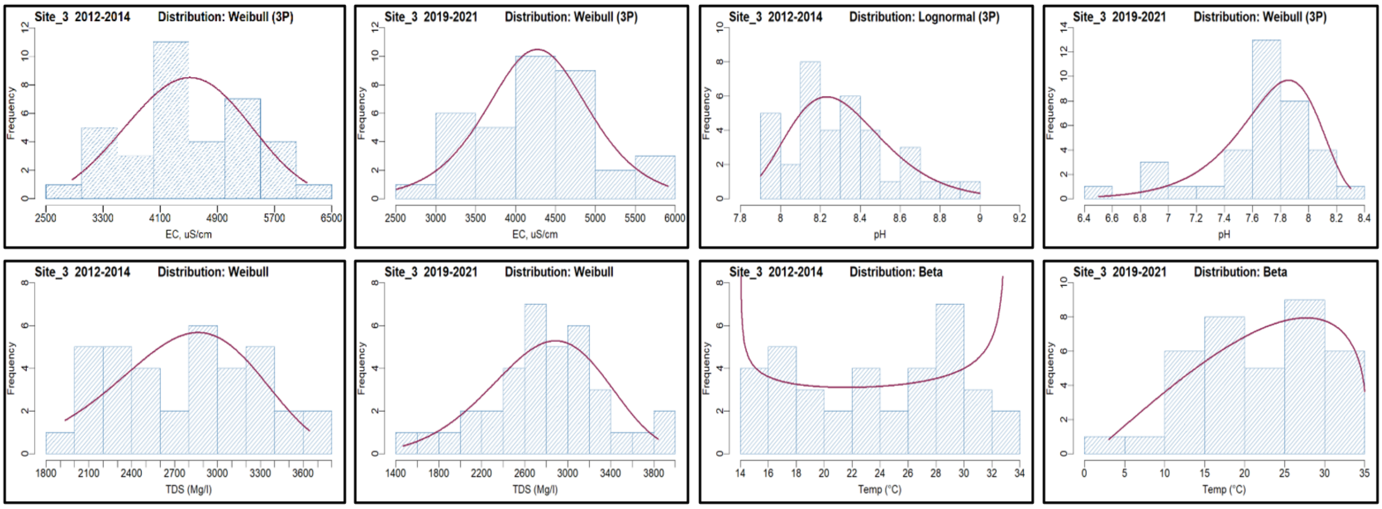


Figure 8. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 3

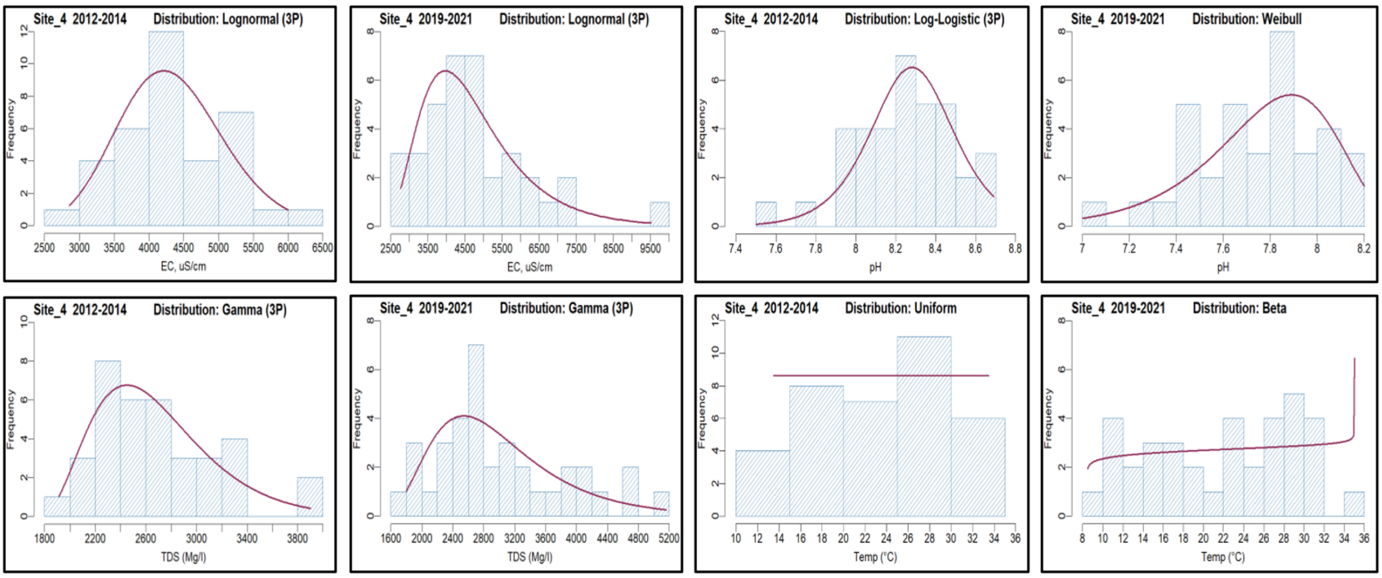


Figure 9. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 4

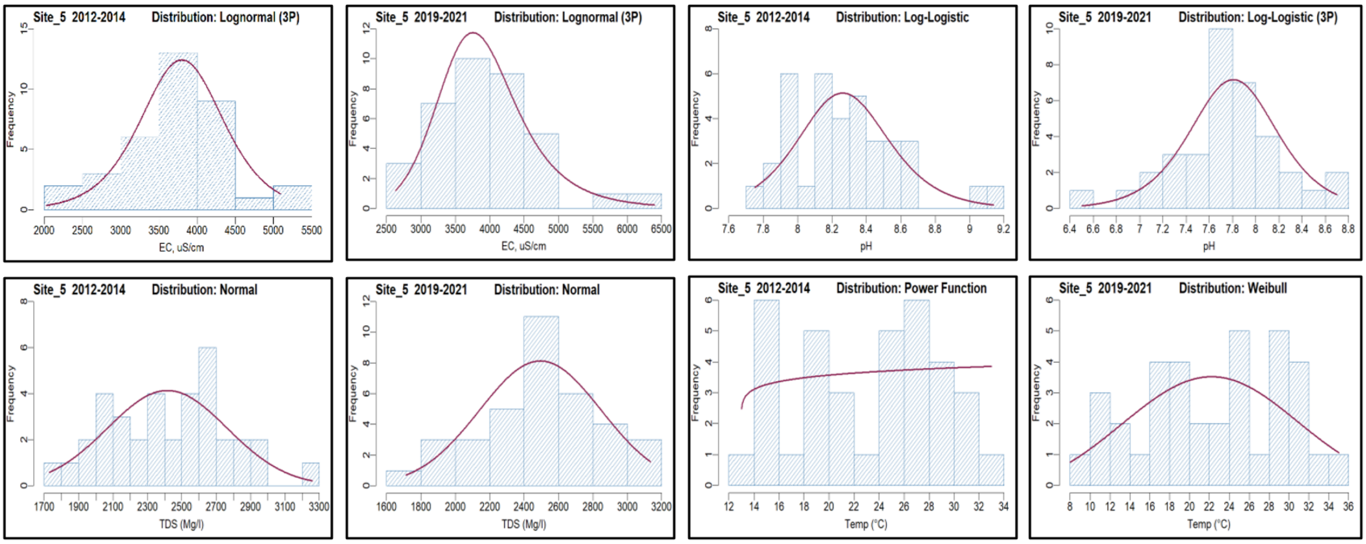


Figure 10. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 5

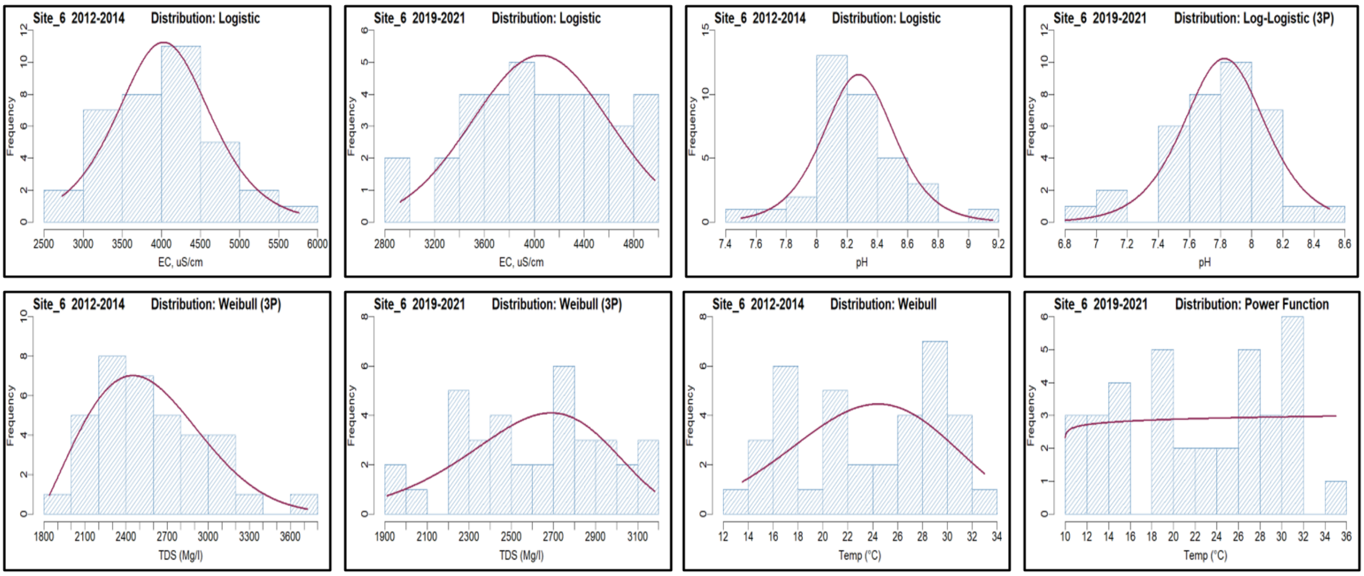


Figure 11. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 6

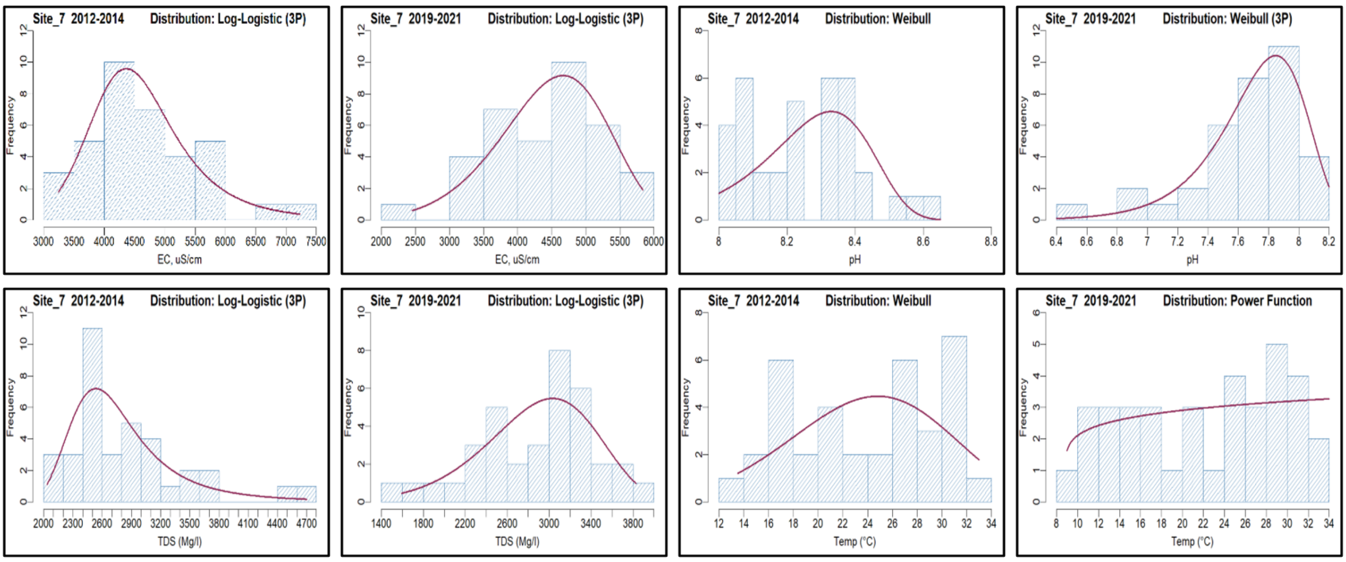


Figure 12. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 7

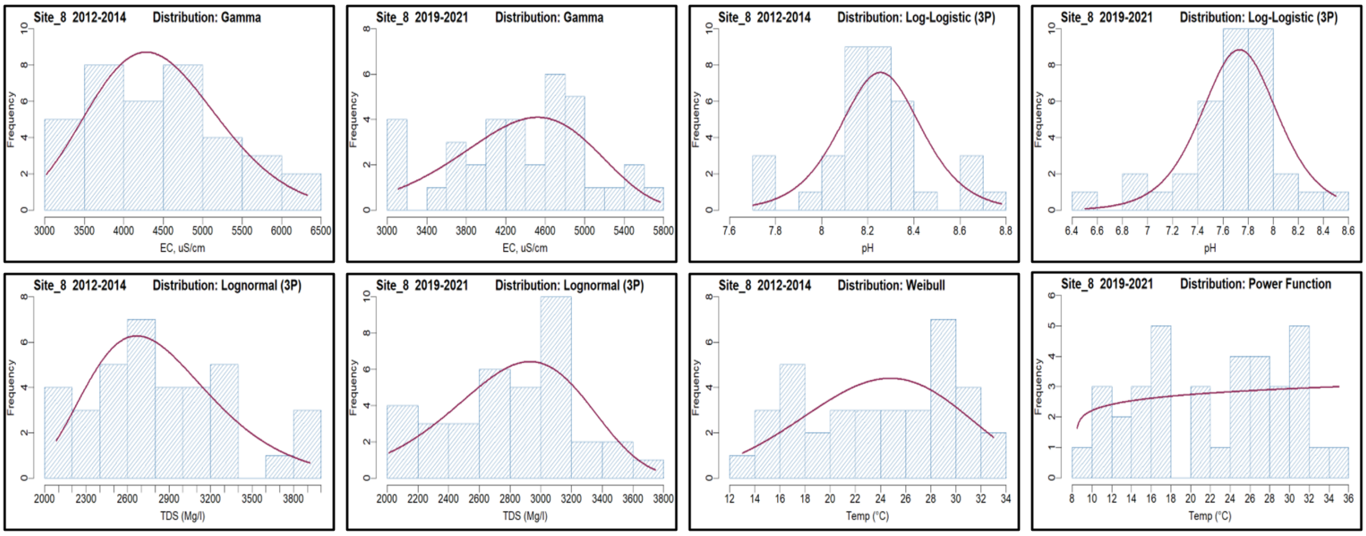


Figure 13. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 8

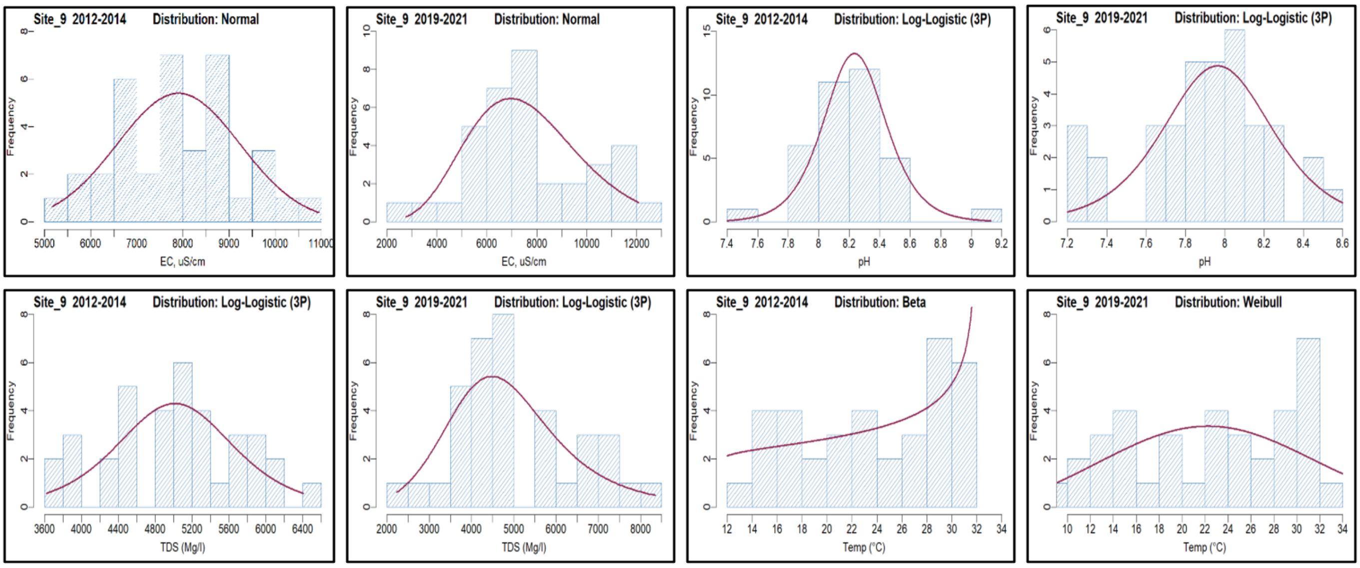


Figure 14. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 9

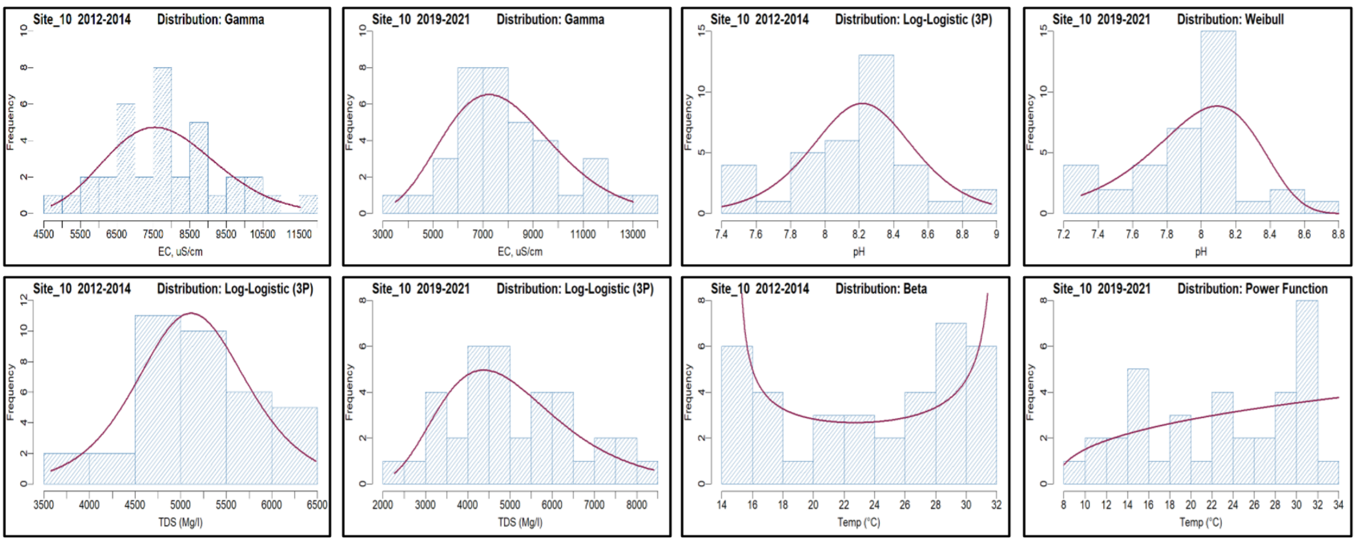


Figure 15. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 10

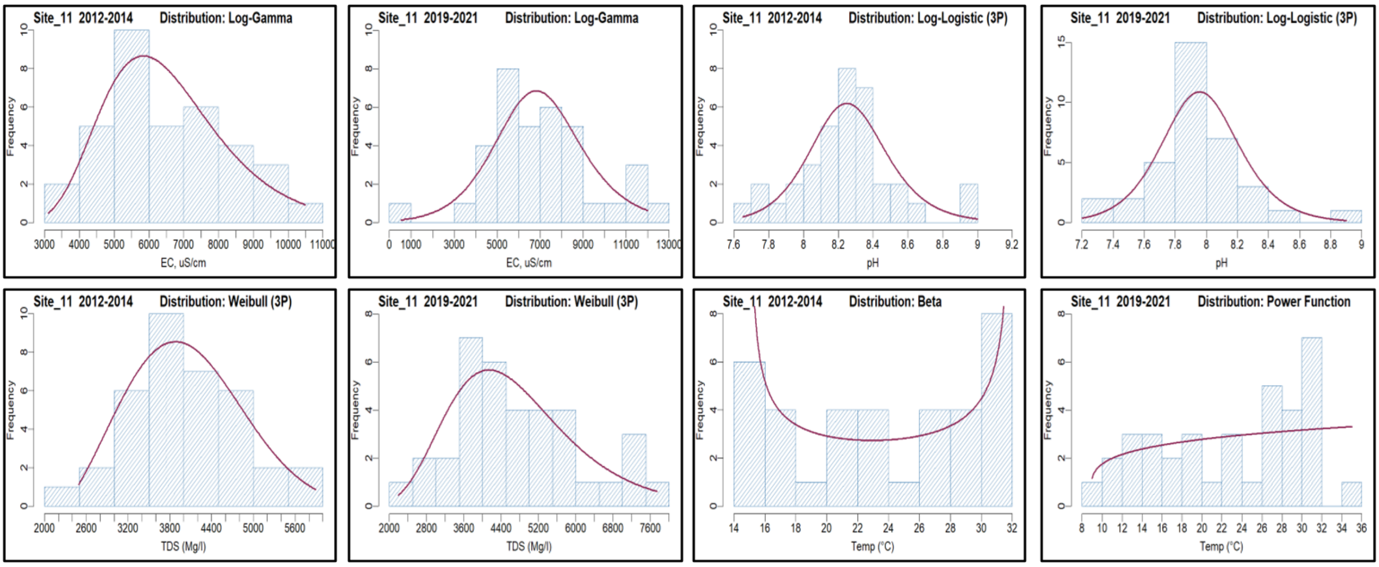


Figure 16. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 11

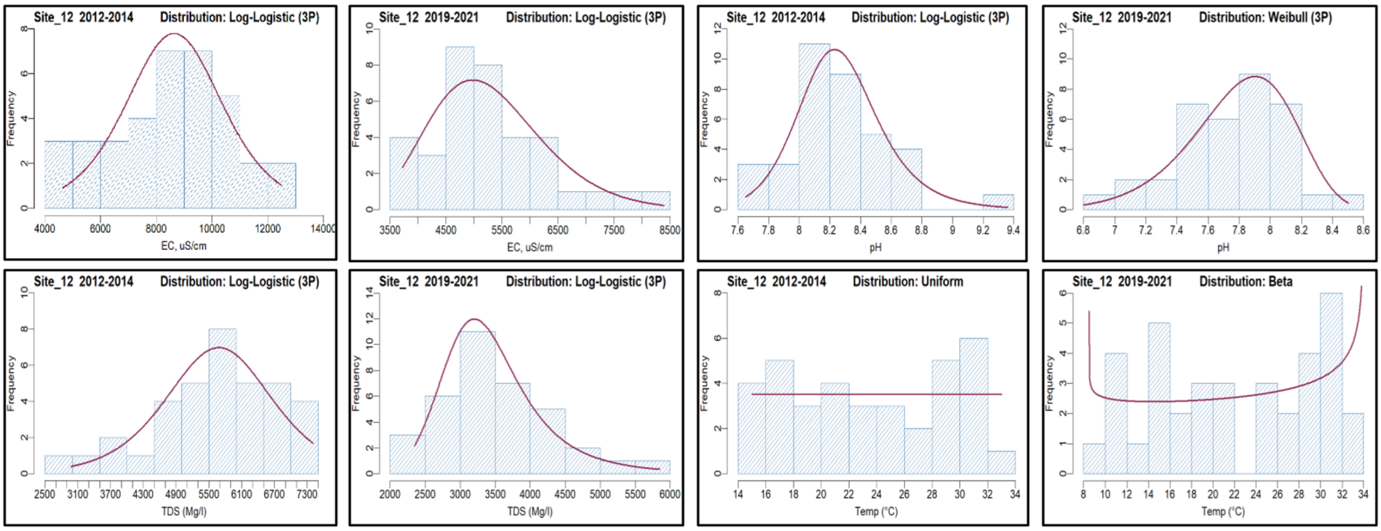


Figure 17. Histogram frequency of observed values for the (EC, pH, TDS, and Temp.) parameters and the best probability distributions for site 12

Regarding plots of the histogram frequency for time series data, with the best probability distributions for it and for the two time periods (2012–2014) and (2019–2021), and for the four parameters (EC, pH, TDS, and Temp.) mentioned previously in the twelve locations, as it appears, in Figures 6-17. Through histogram frequency plots for time series data, the best probability distributions for each parameter and each of the two periods can be observed, as shown in Table 2. From the results, it is clear that the tested parameters did not follow a certain distribution in all sites for both periods. More specifically, the EC parameter and TDS parameter followed the same distribution in both periods in the all 12 sites. While the rest of the parameters did not follow a certain distribution in both spatial and temporal aspects.

An evaluation of trend magnitude was carried out based on Sen's slope of the time series data for the measured parameters (EC, pH, TDS, and Temp.) to obtain the best-fitting trend models, as shown in Figures 18-21, as well as for the two time periods (2012–2014) and (2019–2021). The Sen's slope is a non-parametric method used to estimate the trend or slope of a time series of data. It is expressed as the change in the response variable per unit change in time. Table 3 shows the results of this test, which represent the values of Sen's slope in addition to the trend. Trend detection is necessary to forecast the quality of water for consumption purposes. The results indicated that there is no trend for the EC parameters in all sites and for both periods, except for site 2 during the second period. The pH parameters got the highest number of trends during the first period only. Most of the parameters, except Temp., showed trends in the site 2 during the second period. There was no trend for the TDS parameter in all sites and both periods, except for sites 1 and 2 during the second period. The time series during the two periods showed no trend for all the parameters in all sites during the two periods, and no variable showed a downward trend. For Sen's slope, the results showed that during the first period, the parameter Temp. had zero value for most cases during the first period in all the sites except the site 2. The highest (+ve) value of the Sen's slope was beyond the EC parameter at the site 2 during the second period, while the (-ve) value took place in the site 12 during the first period.

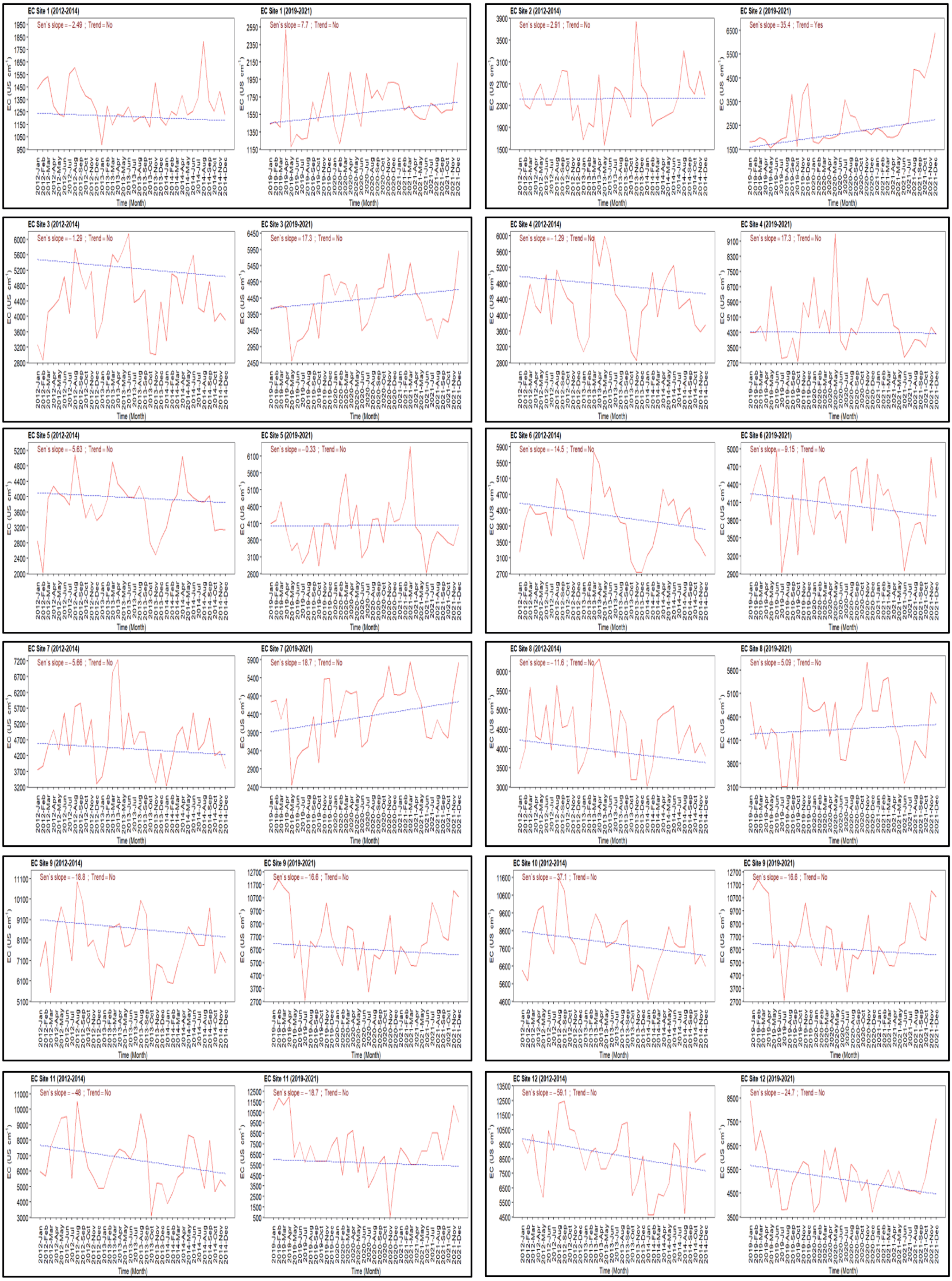


Figure 18. The best-fitted trend models of observed values for the EC parameter in the 12 sites, and for two periods, 2012–2014 and 2019–2021

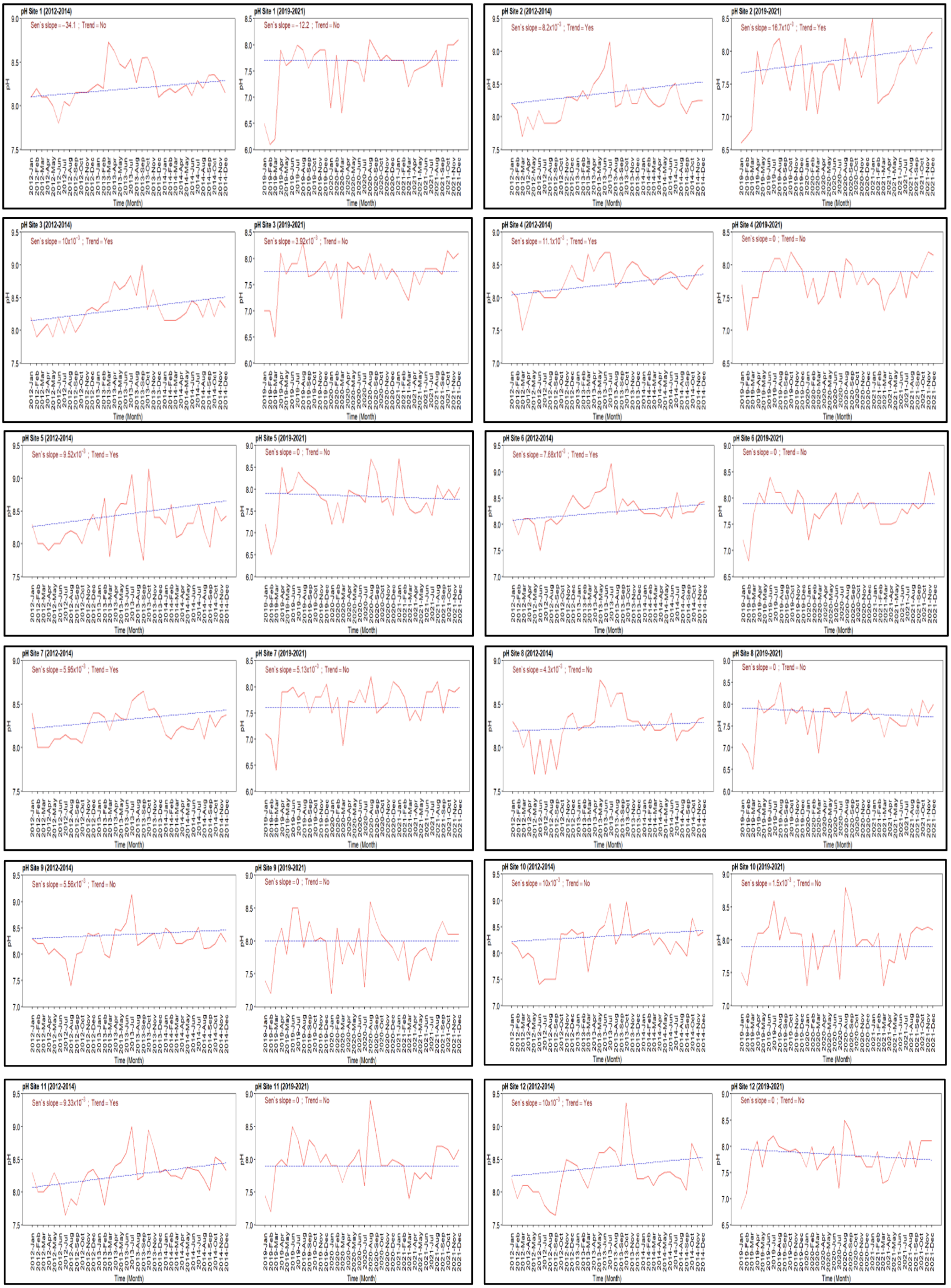


Figure 19. The best-fitted trend models of observed values for the pH parameter in the 12 sites, and for two periods, 2012–2014 and 2019–2021

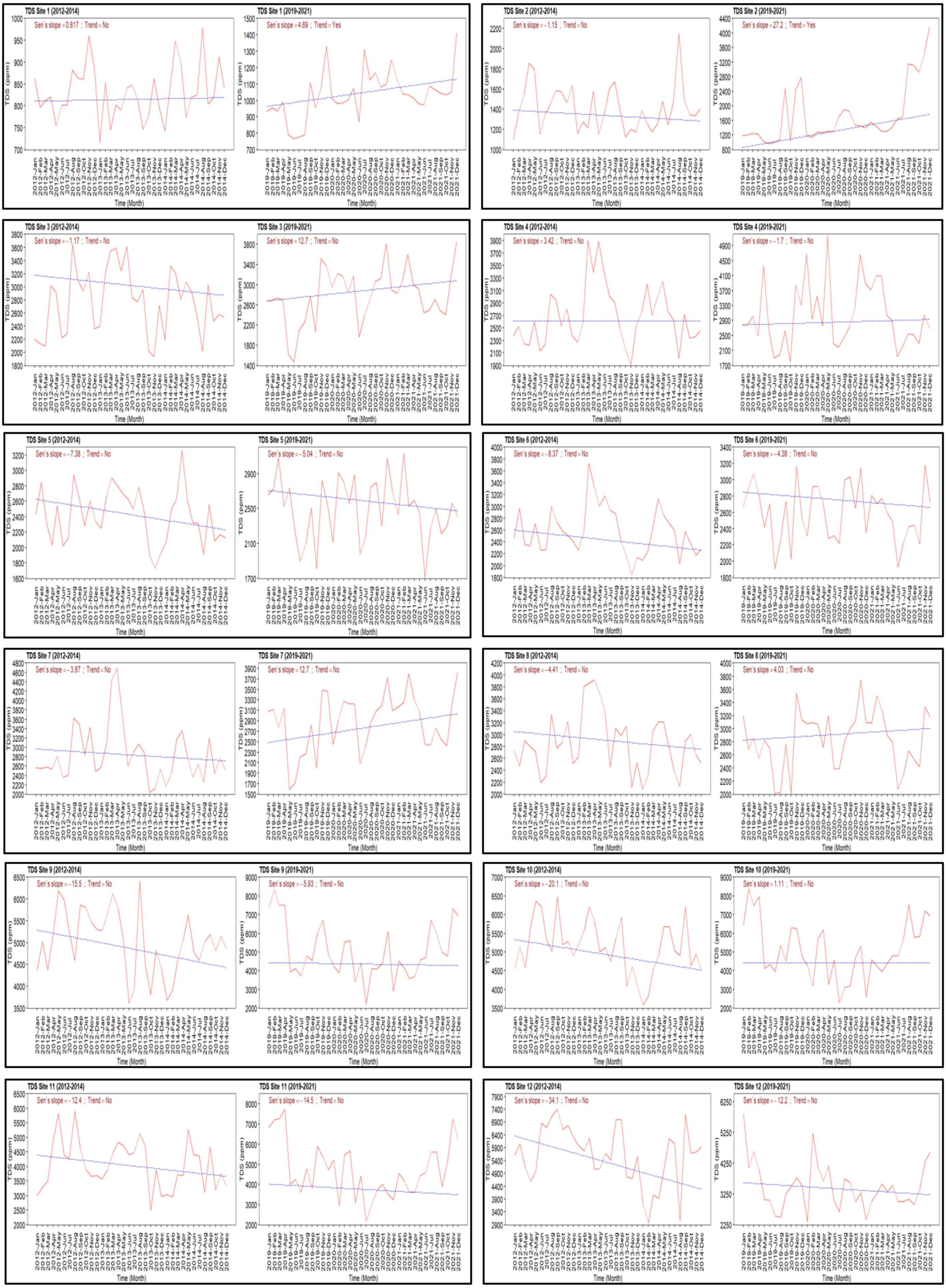


Figure 20. The best-fitted trend models of observed values for the TDS parameter in the 12 sites, and for two periods, 2012–2014 and 2019–2021

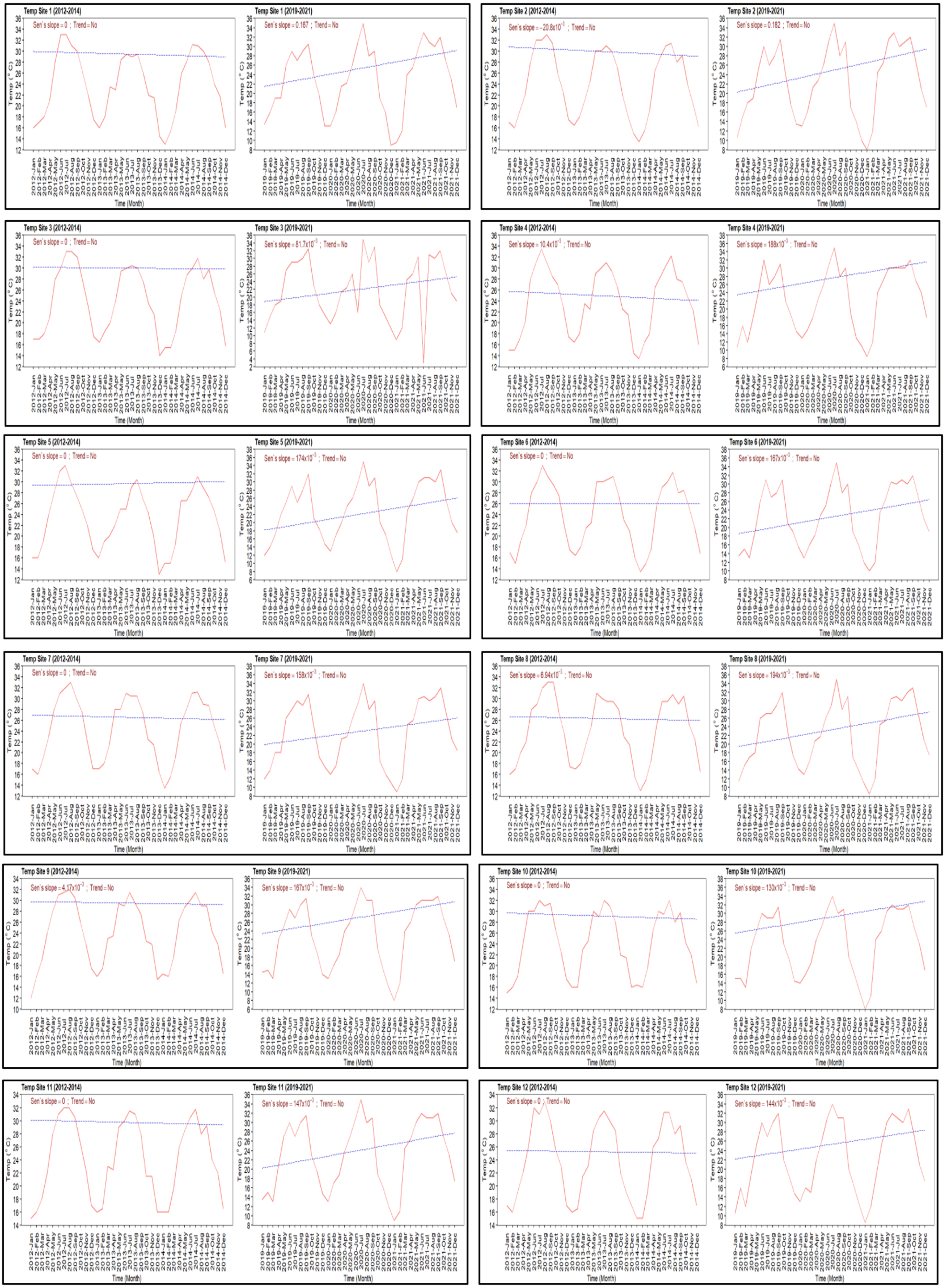


Figure 21. The best-fitted trend models of observed values for the temperature parameter in the 12 sites, and for two periods, 2012–2014 and 2019–2021

Table 3. The values of Sen's slope and the detection of the trend

Site No.	Period (2012–2014)			Period (2019–2021)		
	Parameter	Sen's Slope Value	Trend	Parameter	Sen's Slope Value	Trend
Site 1	EC	-2.49	No	EC	7.7	No
	pH	-34.1	No	pH	-12.2	No
	TDS	0.817	No	TDS	4.69	Yes
	Temp.	0	No	Temp.	0.167	No
Site 2	EC	2.91	No	EC	35.4	Yes
	pH	8.2×10^{-3}	Yes	pH	16.7×10^{-3}	Yes
	TDS	-1.15	No	TDS	27.2	Yes
	Temp.	-20.8×10^{-3}	No	Temp.	0.182	No
Site 3	EC	-1.29	No	EC	17.3	No
	pH	10×10^{-3}	Yes	pH	3.92×10^{-3}	No
	TDS	-1.17	No	TDS	12.7	No
	Temp.	0	No	Temp.	81.7×10^{-3}	No
Site 4	EC	-1.29	No	EC	17.3	No
	pH	11.1×10^{-3}	Yes	pH	0	No
	TDS	3.42	No	TDS	-1.7	No
	Temp.	10.4×10^{-3}	No	Temp.	188×10^{-3}	No
Site 5	EC	-5.63	No	EC	-0.33	No
	pH	9.52×10^{-3}	Yes	pH	0	No
	TDS	-7.38	No	TDS	-5.04	No
	Temp.	0	No	Temp.	174×10^{-3}	No
Site 6	EC	-14.5	No	EC	-9.15	No
	pH	7.68×10^{-3}	Yes	pH	0	No
	TDS	-8.37	No	TDS	-4.38	No
	Temp.	0	No	Temp.	167×10^{-3}	No
Site 7	EC	-5.66	No	EC	18.7	No
	pH	5.95×10^{-3}	Yes	pH	5.13×10^{-3}	No
	TDS	-3.87	No	TDS	12.7	No
	Temp.	0	No	Temp.	158×10^{-3}	No
Site 8	EC	-11.6	No	EC	5.09	No
	pH	4.3×10^{-3}	No	pH	0	No
	TDS	-4.41	No	TDS	4.03	No
	Temp.	6.94×10^{-3}	No	Temp.	194×10^{-3}	No
Site 9	EC	-18.8	No	EC	-16.6	No
	pH	5.56×10^{-3}	No	pH	0	No
	TDS	-15.5	No	TDS	-5.93	No
	Temp.	4.17×10^{-3}	No	Temp.	167×10^{-3}	No
Site 10	EC	-37.1	No	EC	-16.6	No
	pH	10×10^{-3}	No	pH	1.5×10^{-3}	No
	TDS	-20.1	No	TDS	1.11	No
	Temp.	0	No	Temp.	130×10^{-3}	No
Site 11	EC	-48	No	EC	-18.7	No
	pH	9.33×10^{-3}	Yes	pH	0	No
	TDS	-12.4	No	TDS	-14.5	No
	Temp.	0	No	Temp.	147×10^{-3}	No
Site 12	EC	-59.1	No	EC	-24.7	No
	pH	10×10^{-3}	Yes	pH	0	No
	TDS	-34.1	No	TDS	-12.2	No
	Temp.	0	No	Temp.	144×10^{-3}	No

5. CONCLUSIONS

The existence of life in Al-Hammar Marsh, Iraq, depends on the water quality of its effluents from water sources. Water quality in any ecosystem is essential to make the water meet its purposes. Thus, water quality must be examined periodically over time using various parameters to evaluate the change in water characteristics. These parameters involved EC, pH, TDS, and temperature. In this work, monthly values of water quality parameters were analyzed using statistical methods and trend analysis. The time series of monthly measured values of four water quality variables (EC, PH, TDS, and temperature) over 6 years in 12 sites during two periods, 2012–2014 and 2019–2021, were used for this analysis. An evaluation of the best-fitted trend models for each parameter and site was provided. The results showed that there was a slight increase in the temperature of the water and an increase in EC from the first period to the second period. The time series during the two periods showed no trend for all the parameters in all sites during the two periods, and no variable showed a downward trend. The tested parameters did not follow a certain distribution in all sites for both periods. The EC parameter and TDS parameter followed the same distribution in both periods in all 12 sites. While the rest of the parameters did not follow a certain distribution in both spatial and temporal aspects. The time series results of the observed monthly values for the pH parameter in all 12 sites indicated that there was a reduction in pH value over time, i.e., from the first period to the second period. The TDS parameter followed the same change in EC over all sites. Where for site 1, there was an increase in TDS values with time from the first period to the second period, while there was a reduction in TDS values from the first period to the second period in site 12. There was a fluctuation in TDS values for the rest sites in both periods. This means the water quality of the marsh fluctuates with time due to the variation in the parameters. This fluctuation may result from the change in water quantity due to climate change and limit the water sources in the headwaters.

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