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Investigation of the Effect of Climate Change on Energy Produced by Hydroelectric Power Plants (HEPPs) by Trend Analysis Method: A Case Study for Dogancay I–II HEPPs

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Abstract: One of the most important measures taken in reducing the impact of climate change resulting from global warming is the production of energy from clean and renewable resources. Hydroelectric power plants are leading renewable energy sources. In this study, the effects of climate change on hydroelectric power plants, a renewable energy source, have been investigated. Dogancay I and II Hydroelectric Power Plants, which are built on the Sakarya River located in the Sakarya basin of Turkey, was selected as a study area. Moreover, the monthly average energy, runoff, and efficiency parameters of hydroelectric power plants and the monthly average precipitation, temperature, and humidity physical parameters of the Sakarya province, which is a working area, were considered. The length of time-series data is 48 months (2015–2018). Analysis of the data was performed with the innovative polygon trend analysis (IPTA) method, which is one of the newest trend analysis methods. When the studies in the literature are examined, the IPTA method is applied to hydroelectric energy data for the first time thanks to this study. Therefore, it is thought that this study will contribute a great deal to the literature. As a result of this study, a generally decreasing trend was observed in IPTA graphs of energy, flow, and efficiency parameters. In terms of the physical parameters of rainfall, temperature, and humidity, there was a decreasing trend in rainfall and humidity graphs and no trend in temperatures was observed.

Keywords: renewable energy; hydroelectric power plant; climate change; IPTA method; dogancay HEPPs; Sakarya; Turkey

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1. Introduction

The effects of climate change resulting from global warming can be measured according to physical parameters. Severe and unstable weather events can be evaluated as the melting of glaciers or rising sea levels, causing great changes in the frequency or amount of heavy rain events on a global scale. Changes in the physical climate parameters affect clean energy production sources directly and indirectly. For example, imbalances in precipitation frequency and amounts can affect river flows. Moreover, changes in land cover can strongly influence the hydrological regime. The lack of stable and balanced precipitation can cause decreasing river flows, which generate less energy for hydroelectric power plant (HEPP) capacities [1,2].

The effects of climate change are observed all over the world. In particular, risks associated with increases in drought frequency and magnitude in Middle Eastern countries (Southern Europe, North Africa and Near East) and southern Africa are projected to be significantly greater. The investigation of the effects of climate change in Turkey, which is a Middle Eastern country, plays a crucial role for future water management in terms of hydroelectric power plant function.

While investigating the effects of climate change, physical parameters (hydro-meteorological data) can be in a linear or non-linear relationship over time. Methods for trend analysis are generally used a prediction tool. Trend analysis methods can be used to define, systematically determine, and estimate the quantitative properties of data, regardless of whether such data are linear or stochastic (non-linear) over time. Among the most widely used trend analysis tests, the Mann–Kendall test, Mann–Kendall rank correlation test, Spearman Rho test, and innovative trend analysis are used [3–6]. However, current trend analysis methods show weaknesses in this area, as data do not provide information about changes over time and do not form an approach in seasonal transitions. In this context, other methods were elaborated, such as innovative polygon trend analysis (IPTA). This method provides an approximation of the passage of data between days, weeks, or months. Therefore, the IPTA method appears to be suitable for use in engineering fields, such as hydroelectric power generation, agricultural activities, irrigation, and water supply [7].

In general, there are many studies investigated trend analysis [8–20]. However, these studies concern numerical methods. Graphical approaches, such as innovative polygon trend analysis (IPTA), represent an alternative to existing numerical methods. Achite et al. [21] applied the IPTA method to investigate precipitation data for seven stations, located in the Wadi Sly basin of Algeria. Ceribasi et al. [22] evaluated the IPTA method to investigate temperature data for six stations in the Susurluk basin of Turkey. They also applied the trend polygon star concept. Naveed et al. [23] applied the IPTA method to the trend analysis for monthly streamflow data, obtained from 34 measurement stations in the Hindukush-Karakoram-Himalaya (HKH) region of Pakistan. Akçay et al. [24] applied the IPTA method to trend analysis for monthly streamflow data, which included 14 stations in Eastern Black Sea Basin of Turkey. Hırca et al. [25] applied the IPTA and Mann–Kendall methods to trend analysis of precipitation data for eight stations located in Eastern Black Sea Basin of Turkey.

In general, climate change has a direct and indirect impact on the HEPPs efficiency. There are many studies describing potential climate changes all over the world. Li et al. [26] have studied meteorological and hydrological droughts in the Mekong River Basin and surrounding areas under climate change. They have stated that, although the total precipitation is expected to increase in the future, the droughts will not disappear. What's more, such droughts may even increase in some regions, because of the uneven spatial and temporal distribution of precipitation. In the work of Etheram et al. [27], the authors investigated reservoir operation under climate change. They have clearly indicated that climate change is one of the major reasons for several real water scarcity occurrences around the world. In the work Jin et al. [28], the authors have indicated the variance in the runoff variation under climate change and human activities. Based on results, they concluded that, except for climate change, the changes in land use and land cover are significant in runoff variation shaping. Hence, the individual contribution of the specific factors affected for retention may help policy-makers to devise targeted water resource management plans.

Therefore, in this study, the effects of climate change, resulting from global warming, on hydroelectric power plants were investigated. The studies have been conducted for Dogancay I and II Hydroelectric Power Plants, which were built on the Sakarya River, located in the Sakarya Basin of Turkey. Moreover, in the work, the monthly average energy, runoff, and efficiency parameters of hydroelectric power plants and monthly average precipitation, temperature, and humidity physical parameters of Sakarya province were investigated. According to the authors' knowledge, the IPTA method has not been used to detect trends in parameters influencing hydroelectric power plants.

2. Materials and Methods

2.1. Study Area

One of Turkey's most important basins is the Sakarya Basin. The basin contains 7% of water required for the whole country. The total basin area is 58,160 km^2. The main tributaries of the Sakarya River are the Porsuk Stream, Karasu Stream, Ankara Stream, Goksu Stream, Cark Stream, and Mudurnu Stream. The region of Sakarya Basin includes the provinces of Sakarya, Bilecik, Kutahya, Eskisehir, and Ankara. Sakarya Basin receives an annual rainfall of 33,184 million m^3 [29].

Sakarya province is among the main metropolitan cities of Turkey. Its population is approximately 1 million. Therefore, studies on renewable energy sources for this metropolitan city will provide a great benefit in energy planning, especially for Turkey and then for Sakarya province. Hydroelectric power plants are at the forefront of renewable energy sources. Turkey has great water resources due to its location. Obtaining energy by using these water resources will make a great contribution to the country's economy.

On the other hand, climate change has a great impact on existing water resources. In order to reduce this effect, it is extremely important to protect existing water resources. Because of these water resources, energy is produced in hydroelectric power stations. Therefore, forward-looking analysis of these hydroelectric power plants in Sakarya is of great importance in energy planning. Therefore, these HEPPs were selected in the study.

The location of Sakarya province and Dogancay HEPPs selected for this study is given in Figure 1. General characteristics of Dogancay I and II HEPPs are given in Table 1.

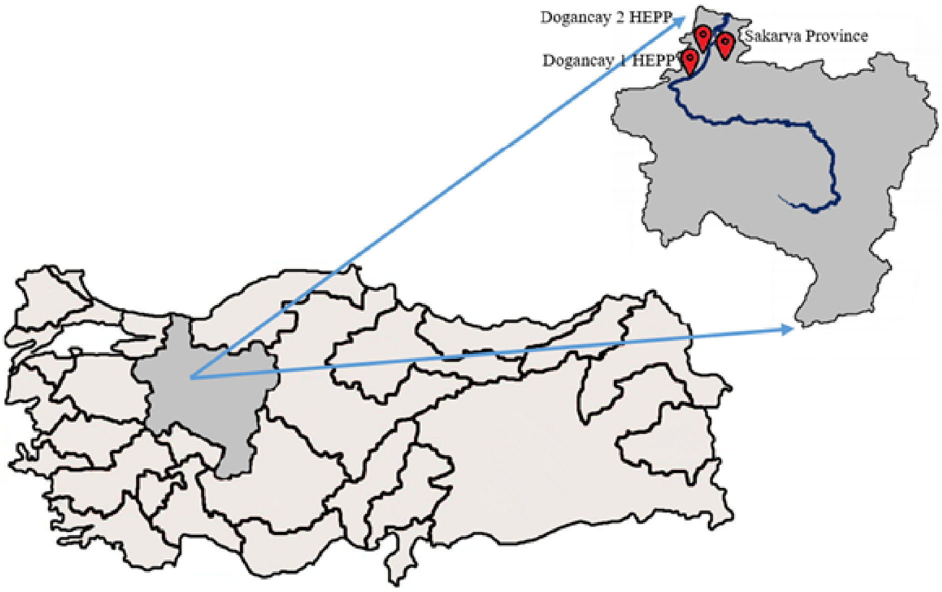

Figure 1. Location of Sakarya Province and Dogancay HEPPs on Turkey Basins Map.

Table 1. General Features of Dogancay HEPPs.

Parameter	Dogancay I HEPP	Dogancay sII HEPP
Installed Power	15.942 Mw	15.663 Mw
Installed Power Ratio	%0.0372	%0.0372
Production Capacity	171.63 GWh/year	171.63 GWh/year
Location	Sakarya, Geyve	Sakarya, Geyve
License Number	EU/1188-4/856	EU/1188-4/856
Operating Company	Akfen Energy	Akfen Energy
Coordinates	40.57982, 30.33603	40.63992, 30.34117

Data course line graphs of energy, flow, and efficiency parameters of Dogancay I and II HEPPs are given in Figure 2. Physical parameters of the precipitation, temperature, and humidity of Sakarya province are given in Figure 3.

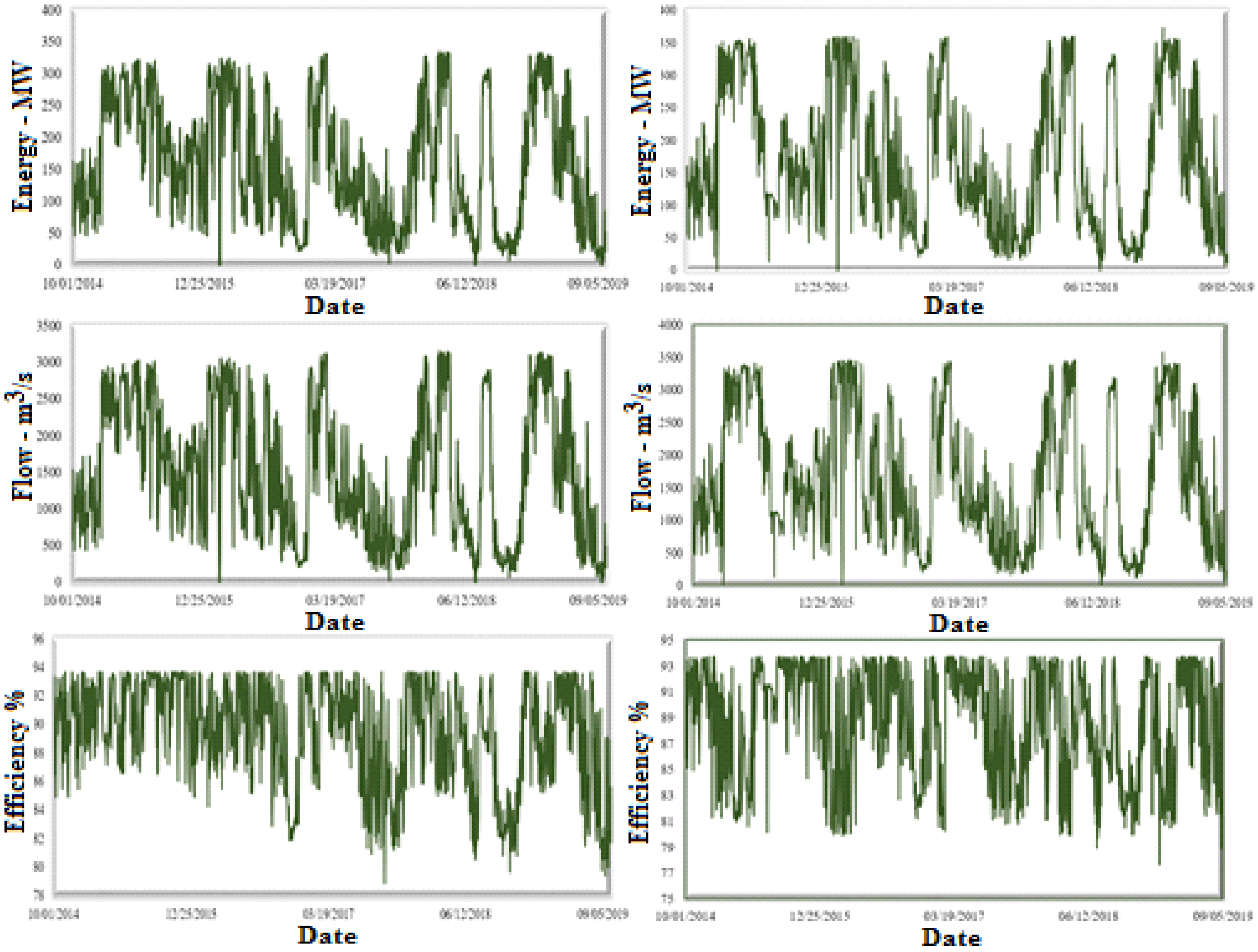

Figure 2. Data Course Line Graphs of Energy, Flow and Efficiency Parameters of Dogancay I and II HEPPs.

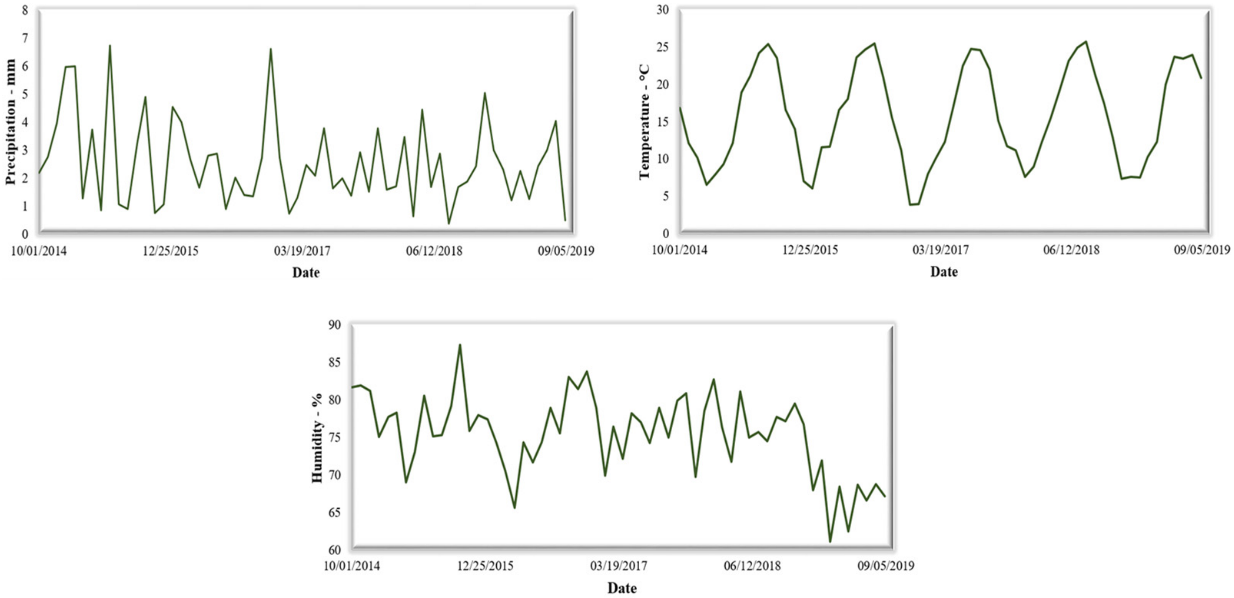

Figure 3. Physical Parameters of precipitation, Temperature and Humidity of Sakarya Province.

2.2. Trend Analysis by IPTA Method

In the presented work, the analysis was carried out for the following factors: monthly average energy, runoff, and efficiency parameters of hydroelectric power plants and monthly average precipitation, temperature, and humidity. The study was conducted using the IPTA method, elaborated by Şen [30,31]. The length of data in the database of the electricity generation joint stock company is 48 months (2015–2018). Energy parameters data used in study were obtained from General Directorate of State Hydraulic Works. Physical parameter data of Sakarya province were obtained from General Directorate of Meteorology. When the data set is analyzed with this method, the steps are as follows.

1. In this method, the time scale of the data can be daily, weekly, monthly, or annual.
2. In this study, since the time scale of the data is selected monthly, the processing steps of the IPTA method are explained according to this time scale.
3. The length of the existing data set in the analysis of the data set is divided into two equal parts with the IPTA method (e.g., if the length of the data set is 30 years, it is divided into two equal parts, the first data set for 15 years and the second data set for 15 years).
4. Since the time scale of the data is monthly, arithmetic means and standard deviations are calculated for each month (for both data sets).
5. These calculated data are placed on the cartesian coordinate axis.
6. The first data set is placed on the x-axis of the coordinate axis and the second data set is placed on the y-axis.
7. The endpoint of the polygon created for each month is created as in Figure 4.

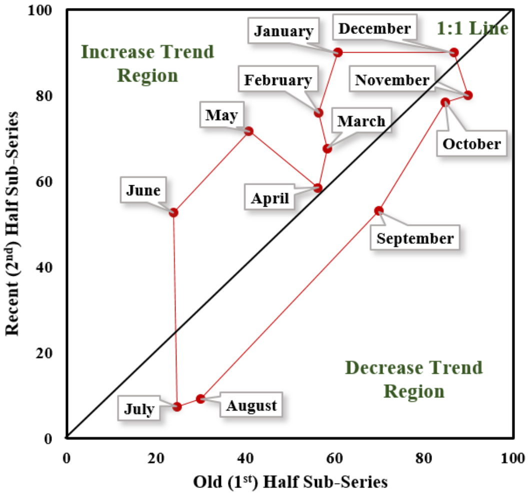

Figure 4. Hypothetical IPTA Graph for Monthly Records.

8. The 45-degree (1:1) line shown in Figure 4 is the non-trend region.
9. The upper region of the 45-degree line is increasing trend region.
10. The lower region of the 45-degree line is decreasing trend region.
11. The origin of the coordinate axis can be different from zero. For arithmetic mean or standard deviation values, the smallest initial value can also be selected.

Evaluating the hypothetical generate IPTA graph in Figure 4, the following results are observed.

1. The polygon finish lines created for each month are combined with each other.
2. This finish line constitutes trend information.
3. The polygon formed by the distribution of these finish lines may vary depending on the effects of hydro-meteorological events.
4. If a single polygon is formed in the IPTA graph, it is concluded that its data changes systematically.
5. The longer the line between the two months, the more significant the trend that exists between these two months.
6. January, February, March, May, and June are in the increasing trend region in Figure 4.
7. July, August, September, October, and November are in the decreasing trend region.

8. April–December is in non-trend region.
9. The longest line showing the transition between the two months is between August and September.
10. Since the data have a homogeneous structure, a single polygon is formed.
11. If the data have a complex structure, multiple polygons will appear on the IPTA graph.

3. Results

In this study, the IPTA method has been applied to trend assessment in mean monthly energy, flow, and efficiency parameter data of Dogancay I and II HEPPs, which are located on the Sakarya River. The results of analysis are presented in Figure 5. Figure 6 presents the results of trend analysis, conducted by the IPTA method for the following meteorological factors: mean monthly precipitation, temperature, and humidity for the analyzed catchment.

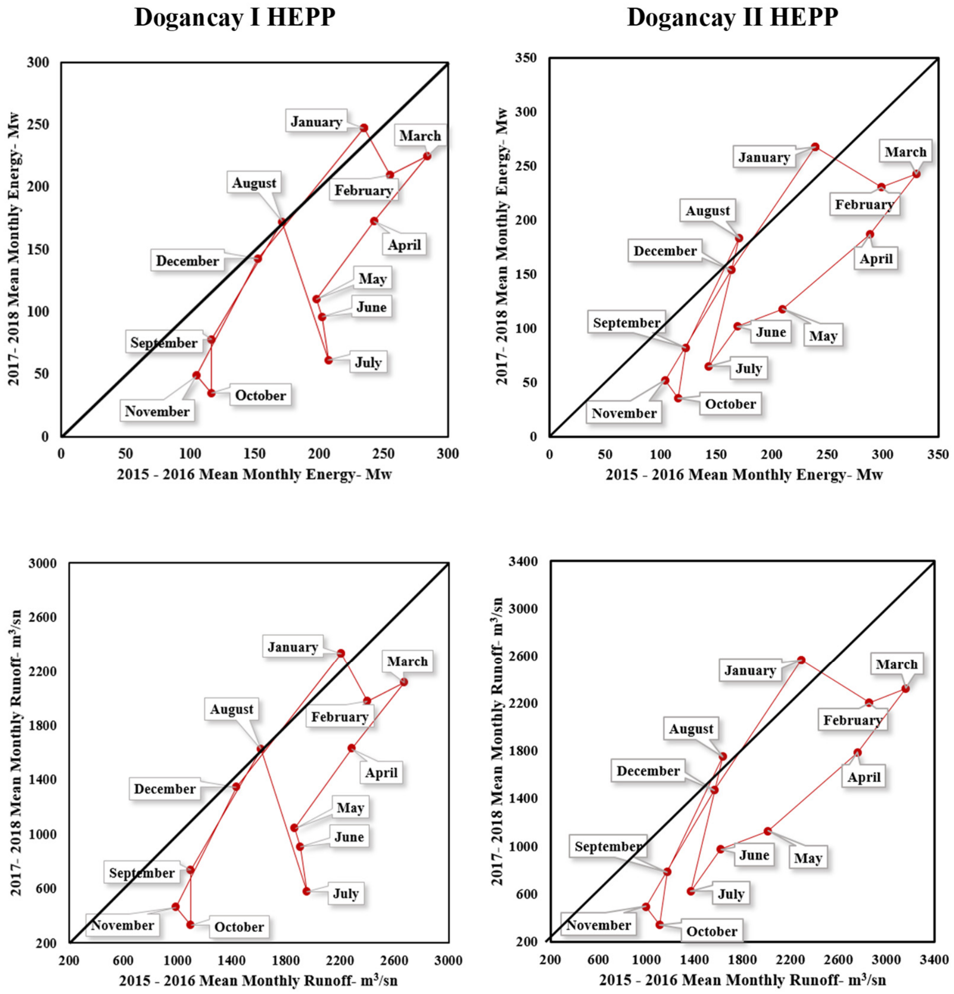

Figure 5. IPTA Method Graphs of Arithmetic Mean Analysis Results of Dogancay I and II HEPPs.

Based on results presented above, it can be concluded that not a single polygon is observed in any graph, as shown in Figures 5 and 6. Since there is not a single polygon in any graph, the data have a complex structure. For IPTA graphs of Dogancay I-II HEPPs, the longest trend line for energy and runoff data is between December and January, and the longest trend line for efficiency data is between November and December. For IPTA graphs of Sakarya Province, the longest trend line for precipitation data is between June and July, and the longest trend line for temperature data is between September and October, and for humidity data it is between April and May. It has been observed that there is a heterogeneous relationship between the data. A general evaluation of mean analysis results in Figures 5 and 6 is given in Table 2.

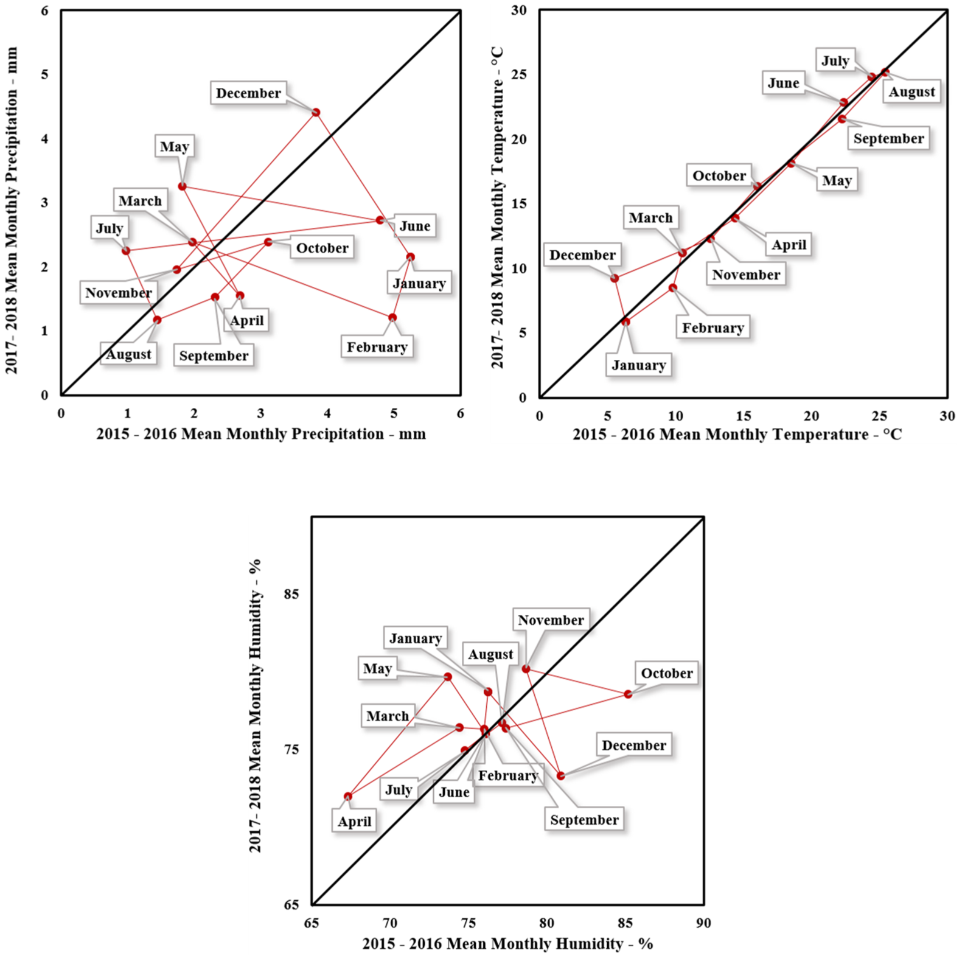

Figure 6. IPTA Method Graphs of Arithmetic Mean Analysis Results of Sakarya Province.

Table 2. General Evaluation of Arithmetic Mean Analysis Results for Each Parameter.

Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Dogancay I (Energy)	🟥	🟦	🟦	🟦	🟦	🟦	🟦	⬜	🟦	🟦	🟦	⬜
Dogancay I (Runoff)	🟥	🟦	🟦	🟦	🟦	🟦	🟦	⬜	🟦	🟦	🟦	⬜
Dogancay I (Efficiency)	🟥	🟥	🟥	🟦	⬜	🟦	🟦	🟦	🟦	🟦	🟦	🟥
Dogancay II (Energy)	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦	🟦	⬜
Dogancay II (Runoff)	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦	🟦	⬜
Dogancay II (Efficiency)	🟥	🟥	🟥	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟥
Sakarya (Precipitation)	🟦	🟦	🟥	🟦	🟥	🟦	🟥	🟦	🟦	🟦	🟥	🟥
Sakarya (Temperature)	⬜	🟦	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	🟥
Sakarya (Humidity)	🟥	⬜	🟥	🟥	🟥	⬜	⬜	⬜	⬜	🟦	🟥	🟦
	🟥	**Increasing Trend**			🟦	**Decreasing Trend**			⬜	**Non-Trend**		

The results presented in Table 2 show that when energy and runoff data of Dogancay I HEPP are analyzed, it can be seen that less energy and runoff is observed in 10 months compared to the first series. While more energy and runoff were observed in January, compared to the first series, equal amounts of energy and runoff were observed in both series in August and December. For efficiency data results of Dogancay I HEPP, it is seen that less efficiency is observed in seven months compared to the first series. While more efficiency was observed in four months compared to the first series, equal amounts of efficiency were observed in both series in May. When energy and runoff data of Dogancay II HEPP are analyzed, it is seen that less energy and runoff is observed in 10 months compared to first series. While more energy and runoff were observed in January and August compared to the first series, equal amounts of energy and runoff were observed in both series in December. In efficiency data results of Dogancay II HEPP, it is seen that less efficiency is observed in six months compared to the first series. More efficiency was observed in six months. As a result of the analysis of precipitation data of Sakarya province, a decreasing trend was observed in seven months and an increasing trend was observed in five months.

As a result of the analysis of temperature data of Sakarya province, a decreasing trend was observed in February and an increasing trend was observed in December and in other months. Hence, there is no trend. As a result of the analysis of humidity data of Sakarya province, a decreasing trend was observed in October and December, while an increasing trend was observed in five months, and in other months there is no trend.

The IPTA method has also been applied to standard deviation evaluation for monthly energy, flow, and efficiency parameter data. The results of analysis are given in Figure 7. The IPTA method was also applied to trend analysis for the standard deviation of monthly precipitation, temperature, and humidity physical parameter data in the analyzed region. The results are presented in Figure 8.

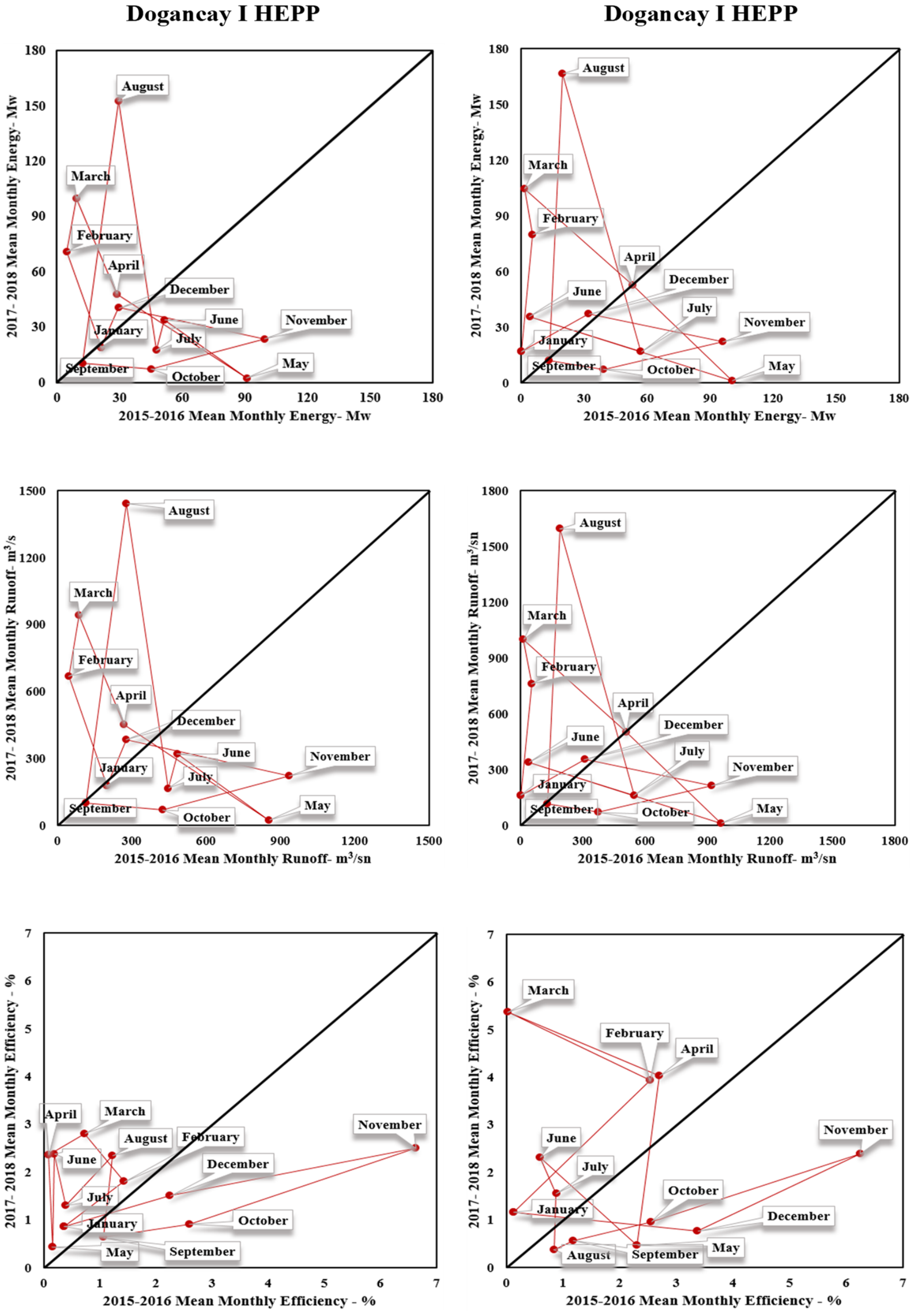

Figure 7. IPTA Method Graphs of Standard Deviation Analysis Results of Dogancay I and II HEPPs.

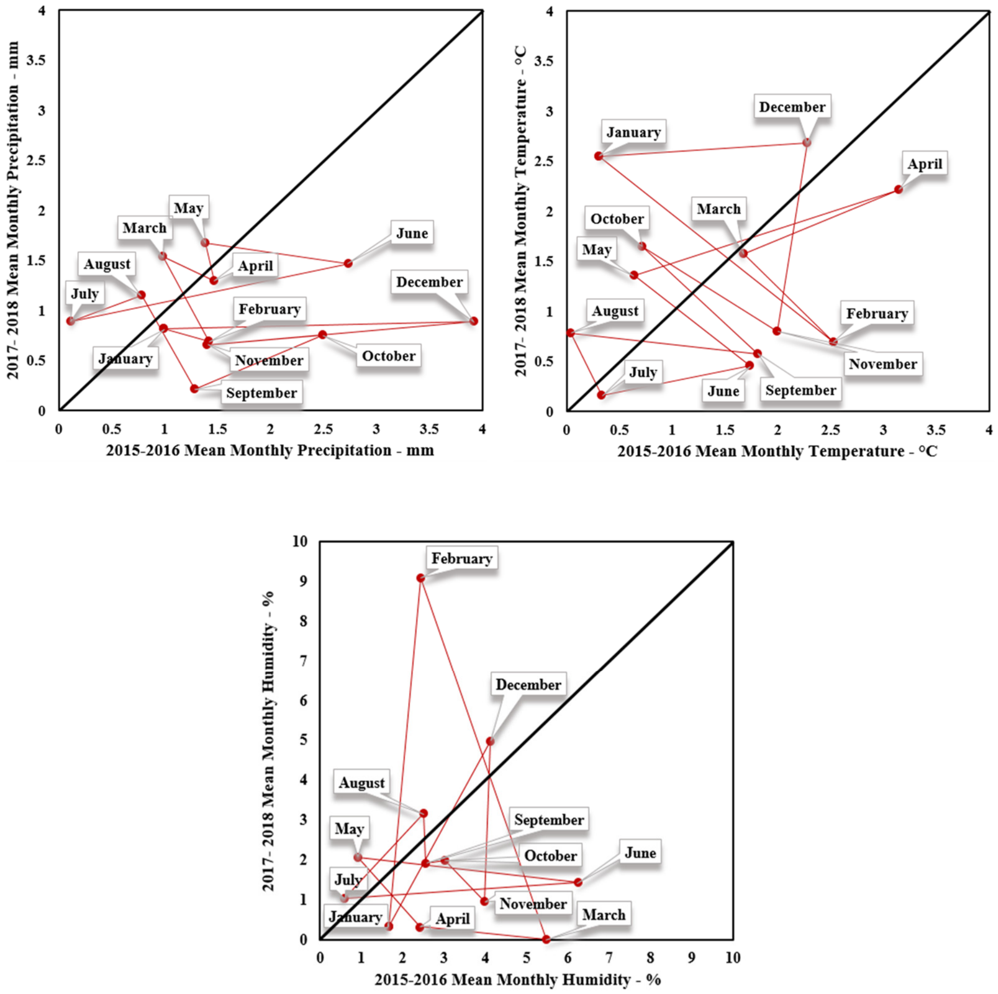

Figure 8. IPTA Method Graphs of Standard Deviation Analysis Results of Sakarya Province.

The results presented in Figures 7 and 8 show that not a single polygon is observed in all graphs of Figures 7 and 8. Since there is not a single polygon in all graphs, the data have a complex structure. In IPTA graphs of Dogancay I-II HEPPs, the longest trend line for energy and runoff data is between August and September and the longest trend line for efficiency data is between October and November. In IPTA graphs of Sakarya Province, the longest trend line for precipitation data is between December and January, and the longest trend line for temperature data is between January and February, and for humidity data it is between February and March. It has been observed that there is a heterogeneous relationship between the data. A general evaluation of standard deviation analysis results in Figures 7 and 8 is given in Table 3.

The results presented in Table 3 have shown that when energy and runoff data of Dogancay I HEPP are analyzed, it is seen that less energy and runoff is observed in five months compared to and first series. While more energy and runoff were observed in five months, compared to and first series, equal amounts of energy and runoff were observed in both series in January and September. In efficiency data results of Dogancay I HEPP, it is seen that less efficiency is observed in four months compared to first series. Meanwhile, more efficiency was observed in eight months compared to and first series. When energy and runoff data of Dogancay II HEPP are analyzed, it is seen that less energy and runoff is observed in four months compared to and first series. Meanwhile, more energy and runoff were observed in five months compared to first series, and equal amounts of energy and runoff were observed in both series in three months. In efficiency data results of Dogancay II HEPP, it is seen that less efficiency is observed in six months compared to the first series. Meanwhile, more efficiency was observed in six months compared to and first series. As a result of the analysis of precipitation data of Sakarya province, a decreasing trend was observed in eight months and an increasing trend was observed in four months. As a result of the analysis of temperature data of Sakarya province, a decreasing trend was observed in six months and an increasing trend was observed in five months. There is no trend in March. As a result of the analysis of humidity data of Sakarya province, a decreasing trend was observed in seven months, and an increasing trend was observed in five months. Tables 4 and 5 presents statistical values of mean and standard deviation for energy, runoff, and efficiency in Dogancay I and Dogancay II HEPPs. Table 6 presents statistical values of mean and standard deviation for precipitation, temperature, and humidity in Sakarya Province.

Table 3. General Evaluation of Standard Deviation Analysis Results for Each Parameter.

Parameter	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Dogancay I (Energy)	▨	🟥	🟥	🟥	🟦	🟦	🟦	🟥	▨	🟦	🟦	🟥
Dogancay I (Runoff)	▨	🟥	🟥	🟥	🟦	🟦	🟦	🟥	▨	🟦	🟦	🟥
Dogancay I (Efficiency)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦	🟦	🟦	🟦
Dogancay II (Energy)	🟥	🟥	🟥	▨	🟦	🟥	🟦	🟥	▨	🟦	🟦	▨
Dogancay II (Runoff)	🟥	🟥	🟥	▨	🟦	🟥	🟦	🟥	▨	🟦	🟦	▨
Dogancay II (Efficiency)	🟥	🟥	🟥	🟥	🟦	🟥	🟥	🟦	🟦	🟦	🟦	🟦
Sakarya (Precipitation)	🟦	🟦	🟥	🟦	🟥	🟦	🟥	🟥	🟦	🟦	🟦	🟦
Sakarya (Temperature)	🟥	🟦	▨	🟦	🟥	🟦	🟦	🟥	🟦	🟥	🟦	🟥
Sakarya (Humidity)	🟦	🟥	🟦	🟦	🟥	🟦	🟥	🟥	🟦	🟦	🟦	🟥

🟥 **Increasing Trend** 🟦 **Decreasing Trend** ▨ **No Trend**

The results presented in Table 4 for Dogancay I HEPP show that the longest trend lines of energy were 132.94 Mw and 143.451 Mw, respectively. The longest trend slopes were −492.186 and 8.275, respectively, and runoff were 1250.88 m^3/s and 1349.74 m^3/s, respectively. In regard to slopes, the longest trends were −492.19 and 8.27, respectively. In the case of efficiency, the longest trend lines were 6.11% and 4.34%, respectively, and slopes were 14,649 and 61,516, respectively. The results presented in Table 5 for Dogancay II HEPP show that the longest trend lines of: energy 136.851 Mw and 154.686 Mw, respectively, and slopes 6.693 and 25.048, respectively. The longest trend lines of runoff were 1310.586 m^3/s and 1481.38 m^3/s, respectively, slopes 6.693 and 25.048, respectively, and efficiency 6.163% and 3.963%, respectively. The longest trend slopes were 11.065 and 28.055, respectively. Based on results presented in Table 6 for Sakarya Province it was concluded that the longest trend lines of precipitation were 3.8 mm and 2.9 mm, respectively. The longest trend slopes were 3.525 and −4.776, respectively. The longest trend lines of temperature were 8.1 °C and 2.9 °C, respectively, slopes −3.996 and 6.670, respectively, and humidity 9.975% and 9.583%, respectively. The longest trend slopes were 10.680 and 29.103, respectively.

Table 4. Statistical Values of Arithmetic Mean and Standard Deviation of Dogancay I HEPP.

Dogancay I HEPP—Energy		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (Mw)	42.390	32.573	66.150	76.840	15.126	35.189	116.742	109.156	43.058	18.375	105.289	**132.94**
	Trend Slope	−1.867	0.504	1.250	1.390	−3.216	−6.927	−3.108	1.715	**−492.186**	−1.179	1.959	1.270
Standard Deviation	Trend Length (Mw)	54.477	29.456	55.498	77.210	50.661	16.900	136.635	**143.451**	33.035	56.587	71.831	23.342
	Trend Slope	−3.197	6.497	−2.676	−0.737	−0.806	4.348	−7.475	**8.275**	−0.101	0.299	−0.246	2.535
Dogancay I HEPP—Runoff		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (m^3/s)	398.85	306.48	622.41	722.99	142.32	331.09	1098.44	1027.06	405.13	172.89	990.68	**1250.88**
	Trend Slope	−1.87	0.50	1.25	1.39	−3.22	−6.93	−3.11	1.71	**−492.19**	−1.18	1.96	1.27
Standard Deviation	Trend Length (m^3/s)	512.58	277.16	522.18	726.47	476.68	159.01	1285.61	**1349.74**	310.83	532.44	675.87	219.63
	Trend Slope	−3.20	6.50	−2.68	−0.74	−0.81	4.35	−7.47	**8.27**	−0.10	0.30	−0.25	2.53
Dogancay I HEPP—Efficiency		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (%)	0.270	0.810	1.462	0.766	1.477	3.113	2.871	2.134	3.767	2.680	**6.106**	1.023
	Trend Slope	−4.925	0.671	−0.344	−1.248	−1.530	2.573	0.752	0.493	**14.649**	−0.626	4.966	0.308
Standard Deviation	Trend Length (%)	1.425	1.222	0.781	1.926	1.934	1.091	1.337	1.717	1.561	**4.338**	4.500	1.994
	Trend Slope	0.881	−1.442	0.698	−27.968	**61.516**	−5.155	1.255	10.070	0.178	0.393	0.227	0.339

Table 5. Statistical Values of Arithmetic Mean and Standard Deviation of Dogancay II HEPP.

Dogancay II HEPP—Energy		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (Mw)	70.321	34.013	69.878	104.394	43.845	44.906	121.479	111.975	47.160	20.079	118.192	**136.851**
	Trend Slope	−0.636	0.394	1.339	0.878	0.393	1.427	4.304	2.102	**6.693**	−1.382	1.714	1.508
Standard Deviation	Trend Length (Mw)	63.074	25.325	73.367	69.942	102.422	56.059	154.284	**154.686**	26.080	58.585	65.370	38.052
	Trend Slope	11.309	−6.199	−1.009	−1.084	−0.358	−0.356	−4.008	**25.048**	−0.181	0.263	−0.234	0.633
Dogancay II HEPP—Runoff		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (m^3/s)	673.441	325.732	669.197	999.751	419.889	430.049	1163.37	1072.35	451.642	192.292	1131.893	**1310.586**
	Trend Slope	−0.636	0.394	1.339	0.878	0.393	1.427	4.304	2.102	**6.693**	−1.382	1.714	1.508
Standard Deviation	Trend Length (m^3/s)	604.045	242.529	702.617	669.817	980.864	536.857	1477.53	**1481.38**	249.760	561.048	626.034	364.414
	Trend Slope	11.309	−6.199	−1.009	−1.084	−0.358	−0.356	−4.008	**25.048**	−0.181	0.263	−0.234	0.633
Dogancay II HEPP—Efficiency		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (%)	2.488	1.743	2.855	3.603	2.639	3.957	2.547	1.491	4.057	3.255	**6.163**	2.110
	Trend Slope	−0.092	0.305	0.065	0.641	−0.555	1.529	0.134	−0.420	**11.065**	−0.619	6.465	2.316
Standard Deviation	Trend Length (%)	3.666	2.889	2.997	3.586	2.524	0.813	1.180	0.392	1.433	**3.963**	3.302	3.269
	Trend Slope	1.154	−0.571	−0.498	9.040	−1.082	−2.707	**28.055**	0.580	0.282	0.390	0.567	−0.121

Table 6. Statistical Values of Arithmetic Mean and Standard Deviation of Sakarya Province.

Sakarya Province—Precipitation		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (mm)	0.982	3.230	1.105	1.911	3.019	**3.847**	1.172	0.928	1.181	1.439	3.217	2.661
	Trend Slope	**3.525**	−0.393	−1.172	−1.973	−0.178	0.124	−2.289	0.406	1.071	0.311	1.168	−1.596
Standard Deviation	Trend Length (mm)	0.441	0.951	0.540	0.386	1.365	2.686	0.717	1.063	1.334	1.097	2.529	**2.930**
	Trend Slope	−0.308	−1.943	−0.499	**−4.776**	−0.151	0.222	0.389	−1.876	0.448	0.089	0.091	0.023
Sakarya Province—Temperature		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (°C)	4.332	2.793	4.695	5.950	6.060	2.880	1.075	4.809	**8.109**	5.310	7.714	3.521
	Trend Slope	0.775	3.789	0.692	1.029	1.215	0.972	0.334	1.122	0.847	1.165	0.429	**−3.996**
Standard Deviation	Trend Length (°C)	**2.894**	1.225	1.601	2.650	1.419	1.435	0.684	1.778	1.531	1.535	1.905	1.975
	Trend Slope	−0.836	−1.038	0.436	0.344	−0.817	0.210	−2.117	−0.115	−0.984	−0.665	**6.670**	0.067
Sakarya Province—Humidity		**January–February**	**February–March**	**March–April**	**April–May**	**May–June**	**June–July**	**July–August**	**August–September**	**September–October**	**October–November**	**November–December**	**December–January**
Arithmetic Mean	Trend Length (%)	2.430	1.594	8.354	**9.975**	4.384	1.697	2.943	0.439	8.122	6.747	7.258	7.153
	Trend Slope	**10.680**	−0.060	0.625	1.211	−1.522	0.781	0.738	−1.463	0.281	−0.251	−3.094	−1.173
Standard Deviation	Trend Length (%)	8.809	**9.583**	3.067	2.314	5.376	5.670	2.878	1.258	0.458	1.415	4.027	5.266
	Trend Slope	11.273	−2.987	−0.101	−1.157	−0.119	0.071	1.111	−27.186	0.151	−1.067	**29.103**	1.883

4. Discussion

The main aim of this study was the trend analysis of selected hydro-meteorological data and energy production for hydroelectric power plants located in the Sakarya Basin. The analysis has been conducted using the IPTA method. In general, different statistical methods are used for the trend detection in the hydro-meteorological time-series. The methods are classified as parametric and nonparametric numerical approaches [32]. The parametric tests are characterized as more powerful but require the independent and normal distribution of random variables. For the nonparametric tests, the data must be independent, but outliers' values are better tolerated [33]. The most common numerical non-parametric approach for trend detection in hydro-meteorological data is the Mann–Kendall test [34–36]. The biggest disadvantage are of the Mann–Kendall test is that it is not suited for time-series with autocorrelation (periodicities). In order for the test to be effective, it is recommended to remove all know autocorrelation effects, which further complicates the calculations [37–39]. The parametric tests have other limitations, linked with the null hypothesis [40], which assumes a serial correlation of data [41,42]. Taking into consideration the limitation of numerical tests, the graphical approaches represent an alternative. In the study conducted Mohorji et al. [43], annual and monthly selected meteorological factors were discussed from an innovate template point of view, which provides meaningful information concerning different classical numerical methodologies. They have stated that graphical tests help not only to identify possible trends in low, medium, and high time series separately, but also support trend identification and determination over a succession of multi-duration. The IPTA method which represents the graphical approaches has some advantages. Firstly, is non-parametric approach and free from the time-series dependency. The method provides not only trends, but also their transformation, from increasing to decreasing and vice-versa in the particular months and seasons. The trend slopes and lengths can be determined between particular periods. The IPTA method provides good linguistic and numerical interpretation trend deduction in the form of the polygons. If more than one polygon is formed, then it indicates the complexity and dynamics in the hydro-meteorological phenomena. In should be emphasized by way of general conclusion that trends in hydro-meteorological time-series are usually comparable. Rathnayake [44] compared the Mann–Kendall test and IPTA methods in rainfall trend analysis. He concluded that, in general, both techniques provide comparable results. Moreover, based on studies, it was concluded that the IPTA method is easy to conduct. On the other hand, Serinalidi et al. [45] detected some limitations of the graphical methods. They concluded with diagrams of methods equivalent to well-known two-sample quantile-quantile plots. They indicated that, when applied to finite-size samples, diagrams do not enable the type of trend analysis that they are supposed to do. Further, they highlighted that the expression of confidence intervals quantifying the uncertainty of diagrams, is mathematically incorrect. Moreover, they concluded that the formulation of the formal tests is also incorrect, and their correct version is equivalent to a standard parametric test for the difference between two means. In general, they stated that the graphical methodology is affected by sample size, distribution shape, and serial correlation as any parametric technique devised for trend analysis.

The results obtained from studies have shown the trends in the hydro-meteorological factors that may affect hydropower generation. This means the analyzed random variables did not come from the same general population. Hence, it was concluded that significant factors affecting one of the analyzed variables appeared in the analyzed period [46]. Sojka [47] concluded that, from the perspective of HEPPs efficiency, the changes in hydrological and meteorological factors may be unfavorable and result in a reduction in the efficiency of run-of-river hydropower plants. What is more important, local factors play a dominant role in the changing of HEPPs' efficiency. The monthly changing parameters in a hydroelectric power plant are mainly the energy produced, flow rate, and efficiency. When other parameters are examined, there are parameters such as net head, turbine type, and penstock included. However, these parameters are fixed; they do no change monthly. Therefore, only energy, flow, and efficiency were selected in the study. Precipitation, temperature, and Humidity data were selected for Sakarya province. These parameters are of great importance to energy production. These parameters also have an influence on sensitivity of the HEPPs work. The studies conducted by Hamududu and Killingtveit [48] have shown that the consequences of climate change in individual countries and regions can be significant, both positive and negative, in terms of hydropower generation view. The research of Dallision et al. [49] has demonstrated a clear impact of future water resources changes for the work of hydropower plants. Their results demonstrate the need for action now, especially in terms of the planning and design of installations. The schemes and turbines must be designated with future streamflow patterns. The research conducted by Gaudard et al. [50] indicated that the hydropower potential is expected to decrease for most European countries. Moreover, all the changes in the work of HEPPs due to changes in hydro-meteorological factors should guarantee adequate environmental flow below investment [51–53]. In general, future HEPP projects contribute to tackling climate changes. However, their negative effects, such as reducing total outflow left to river, changing the seasonal of natural flow regime, and modifying the ground water level, are severely dangerous for water ecosystems [54–56]. The studies conducted by Sahu et al. [57] have shown that the long-term impacts of climate changes for HEPPs work is a serious threat to the river hydrology and biodiversity. Future research should answer the relevant question concerning how the effects of climate change will impact HEPPs efficiency, directly affecting the river regime and quality of biodiversity. The results of a study described by Hasan and Wyseure [58] supported our conclusion, describing that climate change could alter the seasonal flow regime for particular basins and the hydropower potential could change due to the changing climate in the future. According to Qin et al. [59], climate change is expected to alter regional hydrological regimes, affecting the operation and performance of reservoirs and hydropower facilities. They have emphasized that as precipitation in basins is expected to increase, the projected mean annual inflow and hydropower generation will increase. These increases are mostly seasonally concentrated. Savelsberg et al. [60] have investigated the impact of climate change on Swiss hydropower, concluding that the electricity prices and overall system costs increase under dry conditions and decrease under average or wet conditions. The studies conducted by Afram and Kwadwo [61] have indicated that the relationship between hydropower production and climate variability and change affects sustainable development. They indicated that rainfall variability may have accounted for even more than 20% of the inter-annual fluctuations in power generation. Our work confirmed the examples of studies considering how changes of meteorology factors, such as temperature and precipitation, can influence the efficiency of HEPPs. During the ongoing warming of the climate, the use of renewable energy will be increased and thus HEPPs should have more efficiency. Trends of hydroclimatic parameters, mainly in autumn, show that this can be a problem with water resources and in the future HEPPs can help to resolve the situation concerning the energy demand.

5. Conclusions

In this study, the effects of climate change on hydroelectric power plants, a renewable energy source, have been investigated. Dogancay I and II hydroelectric power plants, built on the Sakarya River located in the Sakarya basin of Turkey, was selected as the study area. Moreover, monthly average energy, current, and efficiency parameters of hydroelectric power plants and the monthly average precipitation, temperature, and humidity physical parameters of Sakarya province, which is a working area, were used to perform the analysis in this study. The length of these data is 48 months (2015–2018) and analysis of the data was performed with the innovative polygon trend analysis (IPTA) method, which is one of the newest trend analysis methods. When the studies in the literature are examined, the IPTA method is applied to hydroelectric energy data for the first time thanks to this study. Therefore, it is thought that this study will contribute a great deal to the literature. As a result of the analyses made, there is no homogeneity in all the data used in the study, since a single polygon is not seen in IPTA graphs for Dogancay I–II HEPPs and Sakarya Province. Especially in terms of precipitation, temperature, and humidity parameters analyzed for Sakarya province, this inhomogeneity emerges as an effect of climate change. Therefore, this effect will greatly affect the energy produced in Dogancay I-II HEPPs. Moreover, a change in the hydrological regime of the river below the hydroelectric power plants or a change due to climate variability will also affect habitat conditions. Although it is not possible to completely eliminate the effects of climate change, important steps must be taken to minimize them. A few of them are mentioned below:

1. One of the biggest causes of climate change is the use of fossil fuels. The public should be informed to reduce the use of this fuel.
2. Conservation of existing water resources is of great importance for climate change. Therefore, the public should be informed about water consumption.
3. Controlling the carbon emission values of industrial factories is of great importance for climate change.
4. Increasing the use of renewable energy sources is also extremely important for climate change.

On the other hand, the data of two hydroelectric power plants located in Sakarya province of Turkey were used in the study. These are the limitations to this study. It will be of great importance in terms of energy planning to obtain the data and analyses of other hydroelectric power plants in Sakarya province and to make forward-looking estimates of the rivers in Sakarya province.

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