Research Article

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The Effect of Atmospheric Parameters and Climate Changes on the NDYI Index in the Hyrcanian Forests

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Abstract
The increase in the production and entry of greenhouse gases into the earth's atmosphere has disturbed the balance of the environment. The signs of climate change (caused by global warming) are clearly visible and its effects are tangible. According to the United Nations, if the current trend continues, the global average temperature will increase by 3.2°C by the end of the century, which will have terrible consequences if it happens. This research aimed to investigate the effects of greenhouse gases and climate changes resulting from them on Hyrcanian forests. The Hyrcanian forests, as one of the oldest forest areas (remaining from the Paleogene era), were studied by telemetry from 2013 to 2021. The analysis of the images taken from the Landsat 8 satellite showed that during 9 years, the NDVI index decreased by 0.6 units and the average air temperature increased by 0.5°C. Although the average relative humidity has only increased by 2%, the average annual rainfall has recorded an increase of 25mm. The analysis of the statistics showed that the rains occur irregularly and are often torrential. Therefore, it is predicted that as the average temperature continues to increase, the NDVI index will further decrease, and as a result, the forest cover will become weaker and the soil will lose more water absorption power, and due to the increase in average rainfall. Successive floods will occur. Therefore, soil erosion increases and the extinction and migration of plant and animal species increase significantly.

Key Words: Greenhouse Gases, Climate Changes, Hyrcanian Forests, Global Warming, NDVI, Remote Sensing.

Introduction

With the industrial revolution, the need for energy increased and the extraction and consumption of coal, oil, gas, etc. increased [1]. The increase in the production and emission of greenhouse gases caused the planet to become warmer. The warming of the earth has caused climate change [2]. Climatic changes include the melting of glaciers, rising ocean water, stopping or collapsing of ocean currents, the occurrence of violent storms (oceanic or desert), expansion of deserts, destruction of forests, drying up of rivers and lakes, loss of underground water tables, drought Continuous and long-term, torrential rains and so on [3-20].

According to the United Nations, global warming will reach 3.2°C by the end of this century. This number has been calculated as an average for the entire planet, and some areas will definitely experience more global warming than this amount. It should be added that even global warming of less than 2°C does not mean definitively passing the crisis and preventing the occurrence of climate change [21]. Because this amount of climate change that has happened so far has caused the weather factors to change completely in many regions of the planet.

The Hyrcanian forests were studied as one of the oldest broad-leaved forests in the world (remaining from the Paleogene era) [22]. The Hyrcanian forests are 25 to 50 million years old and 55,000 km2 (21,000 mi2) wide, considered one of the most valuable and oldest treasures of the natural history of the planet. These forests are located on the southern edge of the Caspian Lake (the rest of the Tethys Sea) and the northern slopes of the Alborz Mountains [23, 24]. On July 5, 2019, at the forty-third meeting of the United Nations Educational, Scientific and Cultural Organization (UNESCO), Hyrcanian forests were registered in the World Heritage List in 1584.

It is obvious how global warming has caused climate change. But it should be known how deep the impact of climate change phenomenon is and to what extent it can affect the atmospheric parameters. The Normalized Difference Index of Vegetation (NDVI) is a good tool to investigate and monitor the changes in land covered by vegetation in the long term [25]. In this way, we will have a better understanding of the impact of weather conditions on the NDVI index.

This study aims to measure the impact of atmospheric parameters on the NDVI index in Hyrcanian forests to have a correct understanding of the long-term effects of global warming on the climate changes caused by it.

The absence of significant change in meteorological parameters (temperature, humidity, and precipitation) (independent variables) as well as the NDVI index (dependent-continuous variable) means confirming hypothesis H0, while the significance of the changes means confirming hypothesis H1. The criteria for evaluating the hypotheses were the relationship H0: $\mu 1=\mu 2$ (p-value ≥ 0.05) versus the relationship H1: $\mu 1\neq\mu 2$ (p-value < 0.05). Also, the significance level was considered to be 0.05 (p-value $= 0.05$).

Materials and methods

Materials

NDVI index (Normalized Difference Vegetation Index) was studied in the depths of Hyrcanian forests (Mazandaran plains) and its relationship with 3 components of average temperature (°C), average relative humidity (%), and average precipitation (mm) was measured.

Recorded meteorological data was one of the required materials. By referring to the tutiempo website, the meteorological data of the synoptic station located in the Kaselian region, the Zir-Ab part of Sawadkoh functions in Mazandaran province, were extracted from 2013 to 2021 [26]. Average temperature, average relative humidity, and average precipitation indices were used from the total information extracted.

Landsat 8 satellite images from 2013 to 2021 were downloaded from the LandViewer/EOS website [27]. The NDVI index of the mentioned region with an area of 200 km2 (approximately) was calculated for a period of 9 years (36 seasons) using ENVI 5.3 software (Figure 1).

Finally, average temperature, average relative humidity, average precipitation, and NDVI were collected as primary data (Table 1).

Table 1: Meteorological data and information extracted from satellite images

36.32066°N 53.02691°E - Altitude: 655m - R: 6092 G: 6481 B: 7260				
	NDVI*	T**	H***	PP****
2013	0.6175	17.2	80.2	49.8
2014	0.667445	17.2	78.7	28.7
2015	0.634275	17.0	79.0	29.6
2016	0.68735	17.0	80.9	55.1
2017	0.648614	17.5	77.9	41.8
2018	0.633143	17.9	79.9	46.7
2019	0.561757	17.4	80.3	77.1
2020	0.652817	17.1	80.1	66.9
2021	0.551647	17.6	81.4	50.8

*. Normalized Difference Vegetation. **. Average Temperature (°C). ***. Average relative humidity (%). ****. Total rainfall and/or snowmelt (mm).

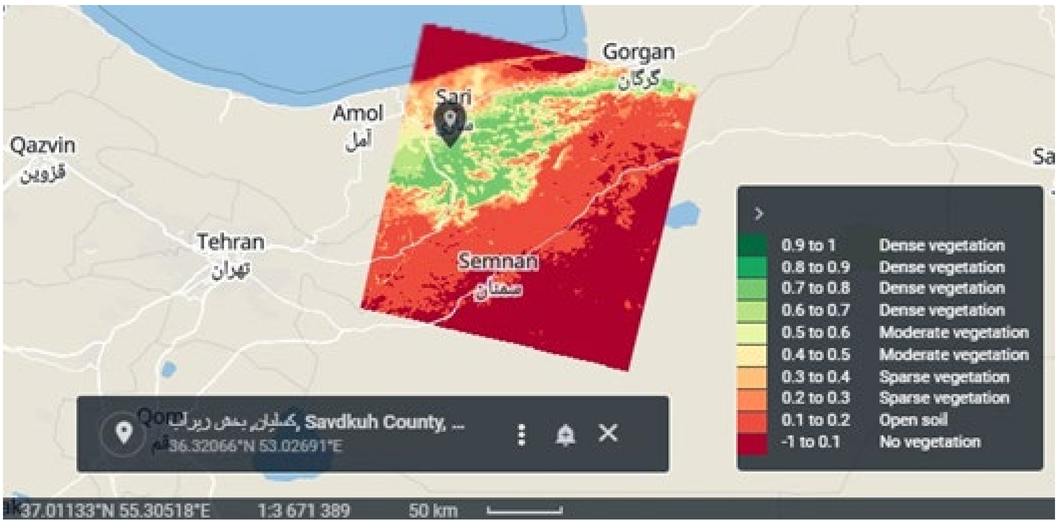

Figure 1: UTM coordinates of the studied station and NDVI filter on the Lansat 8 Aug./30/2021 satellite image (L8/LC08_L1TP_163035_20210830_02_T1)(LANDVIEWER/EOS, 2022a)

Methods

Descriptive Statistics test, One Sample T-test, and 2 Excel software - Microsoft Office Professional Plus 2019 and IBM SPSS Statistics 26 were used to store, process, categorize, analyze data, draw tables, and draw graphs.

Results

The normal distribution of the samples was evaluated in three periods, annual, seasonal and monthly, using the analysis of histogram charts and examining the skewness and skewness tables. The normality of the data was confirmed based on the histogram chart. Also, the limit of elongation and skewness in all 3 time periods (annual, seasonal, and monthly) was observed between +2 and -2. In this way, the normality of the data was confirmed by both methods (Tables 2-a, 2-b, and 2-c). Of course, according to the number of studied samples, it is possible to prove the normality of the data by using the central limit theorem.

Table 2: Elongation and skewness index

		N	Mean	Std. Deviation	Skewness**		Kurtosis***	
		Statistic*	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Yearly[a]	NDVI	9	.628283197	.0454317833	-.782	.717	-.224	1.400
	Average Temperatured	9	17.3222	.30322	.800	.717	-.044	1.400
	Average relative humiditye	9	79.8222	1.10315	-.444	.717	-.354	1.400
	Total rainfall and/or snowmeltf	9	49.6111	15.78500	.345	.717	-.185	1.400
Seasonl[b]	NDVI	32	.631306858	.1390853301	-.793	.414	-.109	.809
	Average Temperatured	36	17.3250	6.63830	.125	.393	-1.534	.768
	Average relative humiditye	36	79.8222	3.27921	-.503	.393	-.805	.768
	Total rainfall and/or snowmeltf	36	49.6194	30.26884	.684	.393	-.328	.768
Monthly[c]	NDVI	75	.620165556	.1631629747	-1.091	.277	.962	.548
	Average Temperatured	108	17.3278	7.28337	.073	.233	-1.537	.461
	Average relative humiditye	108	79.8259	4.31120	-.606	.233	-.391	.461
	Total rainfall and/or snowmeltf	108	49.6065	42.38222	1.403	.233	3.422	.461

a-The data is based on the annual novel section. b- Data based on seasonal periods. c- Data is based on a monthly period. d- Average temperature based on degrees Celsius (°C). e- Average relative humidity based on the percentage (%). f- Average precipitation based on (mm). *- The number of tested samples. **- Skewness. ***- Kurtosis

Yearly

According to the normal distribution of the samples (Table 2), a one-factor t-test was performed and the collected data related to the last 9 years were evaluated (Table 3). Considering that the changes in all 4 parameters were significant (p-value < 0.05), it was concluded that all 4 parameters are related at the annual time point. The results show that the NDVI index decreased by 0.1 on average during this period. Meanwhile, the average air temperature has increased by 0.32°C over 9 years. In the same period, the average relative humidity shows an increase of 4.82%. The average load has not remained constant and has recorded an increase of 24.61 mm compared to 9 years.

Table 3: One-Sample T-Test analysis – annual

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Year	.628283197	0.7	-4.736	8	.001	-.0717168027	-.106638763	-.036794843
Average Temperature*	17.3222	17	3.188	8	.013	.32222	.0891	.5553
Average relative humidity**	79.8222	75	13.114	8	.000	4.82222	3.9743	5.6702
Total rainfall and/or snowmelt***	49.6111	25	4.677	8	.002	24.61111	12.4777	36.7445

Seasonal

The normal distribution of the samples was confirmed according to Table 2. Then, a One-Sample T-Test was performed and the collected data related to 32 seasons for NDVI index and 36 seasons related to atmospheric parameters (average temperature, average relative humidity, and average precipitation) were evaluated (Table 4). Unlike the results obtained in the annual section, the average air temperature parameter was not significant (p-value ≥ 0.05). But the results showed that the two parameters of average relative humidity and average precipitation as well as the parameter of NDVI index were significant (p-value < 0.05). Therefore, it can be concluded that in the seasonal period (3 months), the parameters of relative humidity, average precipitation, and NDVI are related to each other and have interacted with each other. According to the results listed in Table 4, the NDVI index shows a decrease of 0.07 in the seasonal survey. Also, the parameters of average relative humidity of 4.82% and average precipitation of 24.61mm show an increase during 36 seasons. While the changes in the studies conducted on the average temperature factor for the seasonal section proved to be meaningless.

Table 4: One-Sample T-Test analysis – seasonal

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Season	.631306858	0.7	-2.794	31	.009	-.0686931423	-.118838751	-.018547533
Average Temperature	17.3250	17	.294	35	.771	.32500	-1.9211	2.5711
Average relative humidity	79.8222	75	8.823	35	.000	4.82222	3.7127	5.9317
Total rainfall and/or snowmelt	49.6194	25	4.880	35	.000	24.61944	14.3779	34.8609

Winter

After a point-to-point comparison of the winter seasons over 9 years, it was found that all four parameters had significant changes during the winter seasons. In this way, it can be said that the observed changes in the NDVI index were related to the changes in atmospheric parameters. Atmospheric parameters are also related (Table 5). The results show that the NDVI index decreased by 0.23 during 9 winter seasons. In the same period, the average relative humidity has increased by 7.65% and the average rainfall has increased by 33.72mm.

Table 5: One-Sample T-Test analysis - winter seasons

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Season	.464337302	0.7	-5.020	6	.002	-.2356626984	-.350523955	-.120801442
Average Temperature	9.3000	17	-33.170	8	.000	-7.70000	-8.2353	-7.1647
Average relative humidity	82.6444	75	15.514	8	.000	7.64444	6.5081	8.7807
Total rainfall and/or snowmelt	58.7222	25	3.983	8	.004	33.72222	14.1975	53.2469

Spring

The desired parameters were compared point by point in 9 spring seasons (Table 6). The results showed that the average precipitation changes were not significant (p = 0.715). But other atmospheric parameters and NDVI index have had significant changes. Hence, it can be concluded that the changes in NDVI index and average temperature and average relative humidity in spring seasons are related. On the other hand, it can be said that the average rainfall in the spring seasons did not affect the observed changes in the NDVI index, average temperature, and average relative humidity. NDVI index has had a significant change in the spring seasons and its decreased value was 0.06. Also, the average increase in air temperature in these 9 years for spring seasons was 3.64°C, and the average relative humidity shows an increase of 2.14%. Of course, as mentioned, the changes in the average precipitation parameter were not significant. Because only 2mm increase in rainfall was recorded in the comparison of the data of 9 spring seasons.

Table 6: T-factor analysis - spring seasons

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Season	.764110803	0.7	11.600	8	.000	.0641108026	.051365898	.076855707
Average Temperature	20.6444	17	21.228	8	.000	3.64444	3.2485	4.0403
Average relative humidity	77.1444	75	4.155	8	.003	2.14444	.9542	3.3347
Total rainfall and/or snowmelt	27.0000	25	.378	8	.715	2.00000	-10.1923	14.1923

Summer

The analysis of the data collected for the summer seasons showed that the significant changes in the NDVI index and average temperature were not related to the parameters of average relative humidity and average precipitation. Because average relative humidity and average precipitation were not significant. Therefore, in the summer seasons, the observed changes in the NDVI index were only influenced by the average temperature and were not affected by the other 2 factors (Table 7). The results show that the amount of significant changes in the NDVI index has decreased by 0.03. The amount of significant changes in the average temperature for the summer seasons shows 9.12°C.

Table 7: One-Sample T-Test analysis - summer seasons

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Season	.729007143	0.7	4.275	6	.005	.0290071429	.012405776	.045608509
Average Temperature	26.1222	17	32.664	8	.000	9.12222	8.4782	9.7662
Average relative humidity	77.0000	75	2.151	8	.064	2.00000	-.1437	4.1437
Total rainfall and/or snowmelt	30.9444	25	1.026	8	.335	5.94444	-7.4130	19.3019

Fall

The results show that all the factors under study had significant changes in the autumn seasons as well as the winter seasons (p-value = 0.000). Therefore, it can be said that the observed changes in the NDVI index were related to the changes in all 3 atmospheric parameters (Table 8). In the analysis of data related to the 9 autumn seasons, it was observed that the changes in the NDVI index were equal to 0.14 decrease. Also, the average temperature has increased by 3.76°C during this period. During this period, 7.5% has been added to the average value of relative humidity, and average precipitation has also increased by 56.81mm.

Table 8: One-Sample T-Test analysis - autumn seasons

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Season	.552379012	0.7	-7.733	8	.000	-.1476209877	-.191643474	-.103598501
Average Temperature	13.2333	17	-14.649	8	.000	-3.76667	-4.3596	-3.1737
Average relative humidity	82.5000	75	28.347	8	.000	7.50000	6.8899	8.1101
Total rainfall and/or snowmelt	81.8111	25	7.061	8	.000	56.81111	38.2573	75.3649

Monthly

Based on the obtained results listed in Table 2, the normality of the distribution of the samples was checked. Data related to 75 months were evaluated using a One-Sample T-Test for the NDVI index and 108 months related to atmospheric parameters (average temperature, average relative humidity, and average precipitation) (Table 9). The results indicate that the average air temperature parameter is not significant (p-value = 0.641). But other parameters (average relative humidity, average precipitation, and NDVI index) were significant (p-value = 0.000). So, it can be concluded that the parameters of relative humidity, average precipitation, and NDVI are related to each other at the monthly time point. The results listed in Table 9, which are derived from the data analysis, show that the NDVI index decreased by .07%, the average relative humidity increased by 4.82%, and the average precipitation was 24.6mm.

Table 9: One-Sample T-Test analysis – monthly

One-Sample Test								
	Mean	Test Value	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
NDVI Month	.620165556	0.7	-4.237	74	.000	-.0798344444	-.117374836	-.042294053
Average Temperature	17.3278	17	.468	107	.641	.32778	-1.0616	1.7171
Average relative humidity	79.8259	75	11.633	107	.000	4.82593	4.0035	5.6483
Total rainfall and/or snowmelt	49.6065	25	6.034	107	.000	24.60648	16.5219	32.6911

Discussion and conclusion

Examining the results shows that the NDVI index is influenced by weather parameters, and other studies confirm this result(Fu & Burgher, 2015). In such a way, with the increase of the average temperature in a certain period, the average NDVI index has decreased. The result of a study conducted in China in 2020 showed that strengthening the vegetation cover (strengthening the NDVI index) in a plateau from 1982 to 2015 has caused a decrease in air temperature by 0.02°C, and in this study, it is mentioned that During a decade, the strengthening of the NDVI index caused the average air temperature of the region to decrease by 0.05°C [29]. The graphs show that the NDVI index has decreased by 0.1 in a point-to-point comparison for the years 2013 to 2021 in a certain geographical area. Also, in the research conducted by Cristiano et al. in 2014 on the tropical forests of Argentina, it was found that the decrease and increase (fluctuation) in air temperature will have a destructive effect on the NDVI index [30]. In addition, it should be added that the statistical tests showed that the average humidity and average precipitation have increased. This is while the average air temperature has increased by 0.5°C at the same time and place. In such a way that the average humidity is about 5% and the average precipitation is about 25mm increase (Figure 1). Lakshmi Kumar and colleagues also believe that NDVI is related to annual rainfall [31]. In another research conducted in the northeast of Iran (a region near the Hyrcanian forests), it was proved that the annual rainfall and air temperature are closely correlated with the fluctuations of the NDVI index [32].

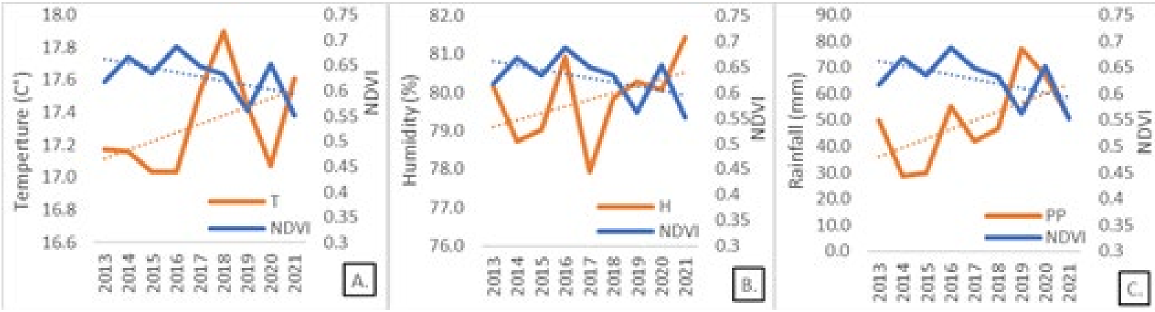

Figure 1: Investigating the influence of atmospheric parameters on the NDVI index

A point-by-point comparison of the influence of atmospheric parameters on the NDVI index for winter seasons shows that all four components of temperature, relative humidity, precipitation, and NDVI have had significant changes. The NDVI index showed an average decrease of 0.23 (3%). The highest observed decrease in the NDVI index among winter seasons was recorded in 2019 (37.30%) and 2018 (26.65%), respectively. The average air temperature for the winter seasons shows a decrease of 0.43% (0.32°C). The average humidity for winter seasons has increased by 0.36% (7.64mm). Also, the average precipitation calculation shows an increase of 8.71% (Figure 2).

Spring season is considered a very important time for plants due to waking up from winter sleep and it can be called as the golden time for measuring the NDVI index. Studies show a positive correlation between the NDVI index and air temperature in spring and autumn [33]. The measurement of the temperature parameter for the spring seasons shows that the slope of the NDVI index has decreased along with the intensification of the slope of the average temperature increase. In such a way that the average temperature has increased by 0.98% (0.9°C) during 9 years in a point-to-point comparison of spring seasons. But the average NDVI index has recorded a decrease of 0.11% (0.06). The biggest decrease in the NDVI index was recorded in 2015 and 2021 (about 5% each). The highest temperature increase was recorded in 2019 at 5.44% and in 2021 at 5.19%. In general, 9 spring seasons were monitored, and the average humidity increased by a total of 0.56%. The average rainfall has fluctuated. The average rainfall in the spring season fluctuated a lot. The average amount of precipitation increased only for 2016 (633.32%) and 2019 (121.19%), and the rest of the spring seasons were all recorded with a negative average compared to the previous year. But despite the extreme fluctuations, 65.15% (about 5mm) of average seasonal precipitation had increased in the target area (Figure 2).

It is expected that the NDVI index will be at the maximum possible value in the summer season. By calculating the average NDVI index for 9 summer seasons (point by point), 0.92% increase was observed. The average temperature component had increased by 0.80% (equivalent to an increase of 0.4°C). Also, the average relative humidity increased by 0.19%. The recorded results for the average precipitation show an increase of 67.10% (about 29mm) (Figure 2).

Tan et al. stated that there is a positive correlation between average temperature and NDVI index(Tan et al., 2015). The average NDVI index for the autumn seasons has decreased by 2.44%. The biggest decrease was for 2021, which was 52.12%. The average air temperature parameter was also compared. 0.5°C increase in average air temperature was calculated by comparing autumn seasons with each other. The average humidity had decreased by 0.07%. While the average precipitation was associated with an increase of 2.89% (44mm) (Figure 2).

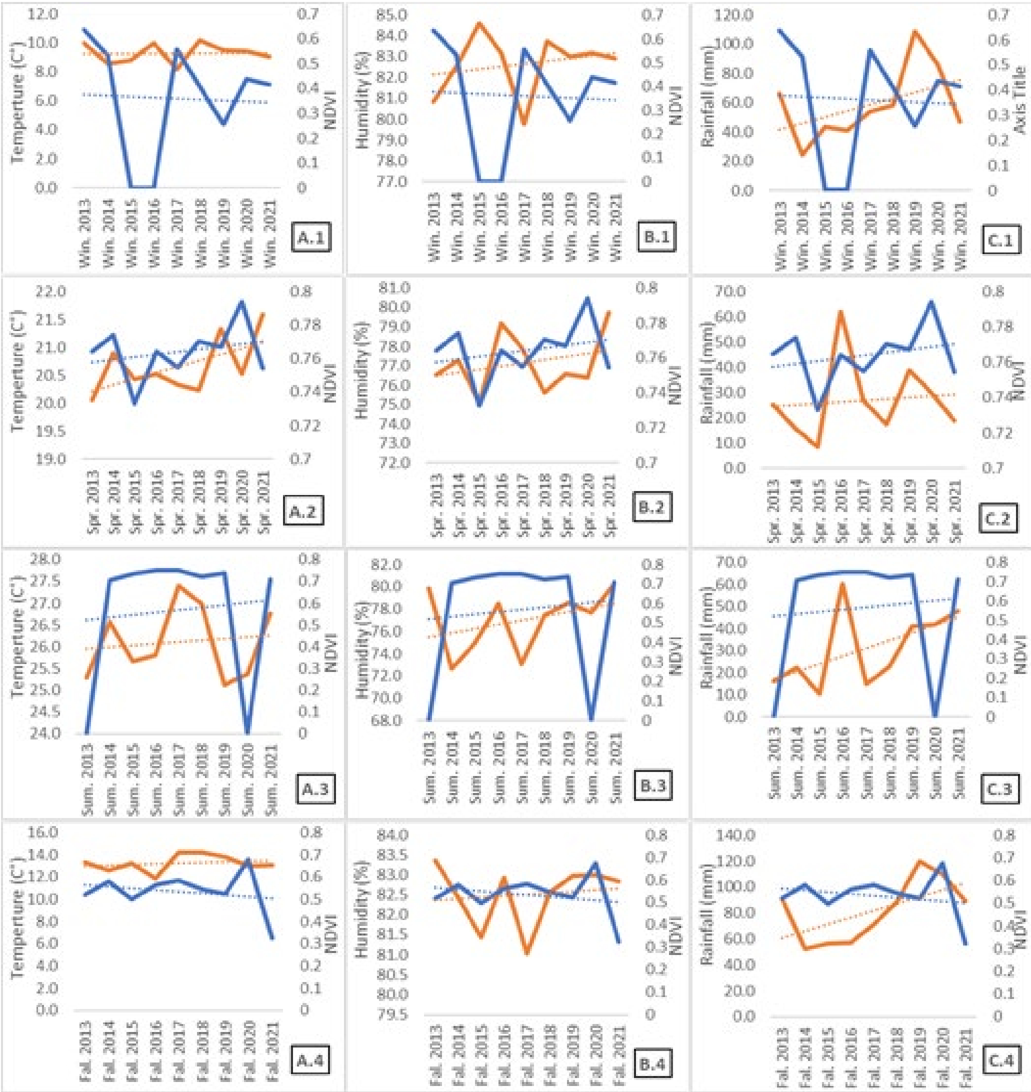

Figure 2: point by point examination of the influence of atmospheric parameters on the NDVI index

During 1 decade (9 years), the NDVI index has decreased by 0.6 units and the average air temperature (independent and effective parameter) has also increased by 0.5°C during the same period. Although the humidity component has only increased by 2%, it has recorded a 25mm increase in the average precipitation in this period. In the future, if the same trend continues, it is expected that the NDVI index will be more affected by the increase in average temperature and its downward trend will intensify (according to the research results). In this way, due to the increase in average rainfall, the occurrence of natural disasters such as floods, soil erosion, consecutive droughts, damage, extinction, and migration of species. plant/animal have a significant increase [34-37].

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