Spatio-temporal trends of forest fires in Greece (2000 - 2021)

3rd International Conference on Environmental Design (ICED2022)
22-23 October 2022, Athens, Greece

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Introduction

Forest are among the decisive contributors in order for the ecosystems to function like a well-oiled machine. Unfortunately, in the past years, where the meaning of the phrase “climate change” has been imprinted in society, forest fires have taken a toll on the peninsula of the Greek region. In a Mediterranean climate, forest fires are a common phenomenon. Strong winds and scorching summers can easily benefit the emergence of a wildfire. Sadly, the rise of the temperatures, the constant polluting and commonly spotted arson incidents are multiplying the sights of fires throughout a calendar year to an alarming rate, even on the winter and spring. The main objective of the present study was to investigate the spatio-temporal trends concerning the number of forest fires and the recorded burned areas in the Greek territory through the period 2000-2021. The Mann-Kendall non-parametric test was utilized along with the Sen Slope Index for the purpose of revealing potential trends. Hierarchy Clustering and the K-means algorithm were utilized for spotting similarities among Prefectures. Usage of the number of forest fires(FF), the Population (POP), surfaced extend (SE), the average Gross Domestic product (GPP) and the land use cover (LUC) for each Prefecture were exploited as materials during Cluster Analysis.

Materials & Methods

The analysis that took place concerns the amount of forest fires along with the burnt area of all Prefectures of Greece during the period 2000-2021. The methodology followed during the study could be separated into a three stages process. During stage one, explanatory analysis was performed in order to analyze the number of forest fires and also the burned area monthly per Prefecture and for a period of 22 years (2000-2021), in Greece. During this stage, boxplots and heatmaps were created. The second stage involved utilizing the Mann-Kendall non-parametric test to evaluate the potential increasing or decreasing trends regarding the number of forest fires and burnt area. Furthermore, the Sen'Slope index was used to detect the monotonic trends and to evaluate their tendency. During the final stage Hierarchy Clustering and K-means algorithm were utilized for spotting similarities among Prefectures in regards to the number of forest fires and burnt areas.

Results & Discussion

The analysis revealed that the year 2001 had the highest number of forest fires (3159), whereas concerning the temporal distribution August was the month with the highest fire occurrence (8379) (Table 1, figure 1). From the boxplot analysis one can observed that March, April, July and August had the highest variation concerning the number of forest fires, while May showed the lowest variation (Figure 2). The results of a Mann Kendall analysis revealed a statistical significant decrease in the number of fires (Q value = -7.55) on July, whereas an increase in the number of fires have been observed during April (Q value = + 9.40) (Table 2). In more details, the highest statistical significant trend increase was observed in Messinia prefecture (+1.87), while the highest statistical significant trend decrease was observed in Attica (-1.95) (Table 5). However, the highest statistical significant

trend increase in the burned areas was observed in Attica Prefecture (+480.00), while the highest statistical significant trend decrease observed in Arcadia (-95.00) (Table 5). Through careful study, some years have some wild statistics that far exceed the average rate of not only forest fires but also the burned acres per year. For instance, in 2020, we can clearly extract from (figure 1) that in January, in the middle of winter, 201 fires occurred respectively. Something even more eye-catching is the number of fires that were reported in March of the year 2012, with a staggering 518 been reported. Lastly, for the month of April, we are experiencing 9.4 additional fires per year, a statistic that overwhelms by far the other presented rates. In respect of the number of burned areas, two years stand out the most; 2007 and 2021. The trends also reveal some dazzling facts. Attica has a very disturbing and frightening stat. Almost 480 additional hectares are burnt out each year and the statistic of burned areas in July is even worse. More than 1109 additional hectares are sizzling each passing year, a number frightening for the future of forests and the Greek wildlife. But despite the shade of these years we also can see some where a low amount of land area was landed onto flames. A prime example is that of 2017 were, despite an amount of 10.356 fires occurring, only 231.323 acres were burned.

Table 5. Trend Analysis concerning Prefectures of Greece

Perfecture	number of events Test Z	Signific.	Q	burned area Test Z	Signific.	Q
ACHAIAS	-2,11793	*	-1,67	-0,56396		-24,14
AITOLOAKARNANIAS	-0,42314		-0,50	-0,56396		-20,29
ARGADIAS	-2,63044	**	-1,00	-2,25583	*	-94,99
ARGOLIDOS	-1,63983		-0,56	0		-4,40
ARTAS	-0,73431		-0,19	-1,74827	+	-3,90
ATTIKIS	-2,31838	*	1,95	1,804668	+	480,01
CHALKIDIKIS	1,438666		0,88	1,127917		21,99
CHANION	-2,08831	*	-1,78	-0,84594		-21,73
CHIOU	-0,48083		-0,10	-0,56396		-9,20
DODEKANISON	0,934378		0,29	1,015125		13,66
DRAMAS	-2,26003	*	-1,33	-0,95873		-14,51
EVIAS	-1,55274		-0,77	0,789542		126,98
EVRITANIAS	-1,38445		-0,33	-0,22558		-0,40
EVROU	-0,36672		-0,33	0,394771		10,77
FLORINAS	-0,02828		0,00	0,338375		2,63
FOKIDOS	-1,84044	+	-0,36	-1,86106	+	-23,12
FTHIOTIDAS	-2,00445	*	-1,42	0		-0,69
GREVENON	0,651582		0,57	-0,22558		-1,27
ILIAS	-0,64933		-0,75	0,733146		15,48
IMATHIAS	-2,17677	*	-0,44	-0,67675		-0,87
IOANNINON	-1,69322	+	-1,92	-0,62035		-22,36
IRAKLIOU	1,537428		0,40	1,184313		5,34
KARDITSAS	-0,3108		-0,10	-0,67675		-4,29
KASTORIAS	-0,67855		-0,42	-0,78954		-8,94
KAVALAS	-1,58582		-0,83	-0,84594		-8,71
KEFALLONIAS	-0,2825		-0,30	0,507563		16,10
KERKIRAS	-1,52512		-0,43	-1,97386	*	-16,71
KIKLADON	3,234341	**	0,88	1,297105		54,37
KILKIS	1,780011	+	1,23	1,466292		21,00
KORINTHIAS	-1,66611	+	-1,00	2,368626	*	243,01
KOZANIS	1,043738		0,67	0		0,62
LAKONIAS	2,060908	*	1,53	0,563959		153,07
LARISAS	0		0,00	-0,11279		-5,12
LASITHIOU	2,210599	*	0,77	1,297105		21,89
LEFKADOS	-1,33687		-0,31	-1,74827	+	-6,29
LESVOU	1,52837		0,50	1,409896		8,01
MAGNISIAS	-0,25436		-0,11	-1,12792		-30,78
MESSINIAS	1,833595	+	1,87	0,225583		8,32
PELLAS	0,707107		0,28	1,240709		7,84
PIERIAS	2,234457	*	1,13	1,973855	*	6,83
PREVEZAS	-1,1575		-0,80	-0,33838		-7,44
RETHIMNOU	-0,39551		-0,27	-1,24071		-7,32
RODOPIS	1,217198		0,27	1,184313		4,05
SAMOU	0,876812		0,25	0,169188		1,48
SERRON	1,130919		0,36	0,112792		1,01
THESPROTIAS	0		0,00	-0,22558		-1,86
THESSALONIKIS	-1,5573		-0,33	-0,0564		-0,09
TRIKALON	-1,07437		-0,67	-0,50756		-5,65
VIOTIAS	0,423474		0,25	-0,56396		-57,81
XANTHIS	-0,11196		-0,06	0,225583		1,47
ZAKINTHOU	-0,02823		0,00	-0,16919		-16,66

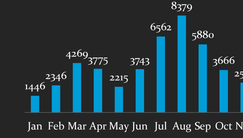

Figure 1 Monthly distribution of wildfire events

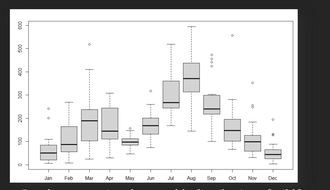

Figure 2 Boxplot concerning the monthly distribution of wildfire events

Table 1 Forest fires of all districts of Greece during the period of 2000-2021 per month

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	6	7	24	29	128	317	518	551	456	153	184	83
2001	57	92	321	75	97	260	397	525	473	567	256	49
2002	82	269	292	61	107	195	281	246	100	75	31	4
2003	15	46	123	105	141	185	343	419	236	195	58	17
2004	20	137	148	147	90	74	292	366	424	184	126	47
2005	73	61	186	283	137	126	267	313	218	142	86	25
2006	39	38	78	136	84	134	256	376	303	77	77	64
2007	241	108	193	142	112	201	512	426	239	158	51	18
2008	87	164	226	119	81	189	362	476	251	196	112	41
2009	20	45	100	116	99	198	269	359	169	101	46	25
2010	53	63	100	163	107	173	251	332	241	66	98	63
2011	18	75	115	111	49	133	360	547	441	281	353	127
2012	107	81	518	243	106	210	394	594	299	202	110	39
2013	47	49	147	285	157	204	244	410	299	192	86	89
2014	44	62	194	85	73	163	254	334	153	145	43	23
2015	109	106	56	235	87	119	249	327	227	76	137	132
2016	85	207	103	268	95	203	242	438	178	133	116	194
2017	40	127	237	308	110	129	270	411	282	236	99	65
2018	54	56	203	244	69	132	213	144	235	147	123	41
2019	13	184	410	132	46	123	168	256	240	148	41	52
2020	201	198	237	213	93	135	186	236	235	116	248	28
2021	35	171	258	275	147	140	234	293	181	86	96	25

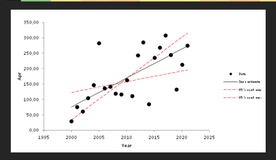

Table 2 Trend Analysis number of wildfire events

Month	Test Z	Signific.	Q
Jan	0,65		1,091
Feb	1,8	+	4,222
Mar	1,35		4,944
Apr	2,88	**	9,4
May	-1,27		-1,4
Jun	-1,64		-3,8
Jul	-3,89	***	-7,545
Aug	-1,92	+	-7,333
Sep	-1,52		-4,462
Oct	-0,79		-1,857
Nov	0,14		0,588
Dec	0,85		0,647

Figures Trend Analysis – April Wildfire events

Following the boxplot of 2007 (figure 7), it seems that it was a relatively busy year for the fire department with 11.895 fires overall, the country witnessed the darkest summer of an entire generation. More than 2.623.933 acres of land were scorched, historical sights such as the ancient Olympia were endangered and most importantly 63 people were killed. To put into perspective what a disaster took place that year, in 2021, a year when it was considered that a huge amount of land was burned, the numbers reveal that the acres lost in the fire were 1.332.141, almost half of 2007. The weather conditions, in some scale, can explain the wildfires in this year. For example, in Spring, in spite of the constant rainfalls and thunderstorms, the temperature was relatively high, even reaching 30 o C. In June though, the temperature skyrocketed at approximately 45-46 o C for 2 whole weeks. This drought remained stable in July, where it was also enhanced by strong winds and extreme dry conditions. Under this state, forest fires can easily pop at any place and spread in lighting speeds.

The Cluster Analysis separated the entire territory of Greece into seven (7) clusters. Attica prefecture consisted the only input of 1 st cluster, while the 3 rd cluster consisted with prefectures which most of them had the highest number of fire occurrence (Evia, Ilia, Korinthia, Messinia, Lakonia). (Figure 8).

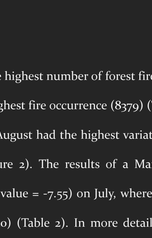

Figure 7. Boxplot concerning the amount of forest fires in 2007

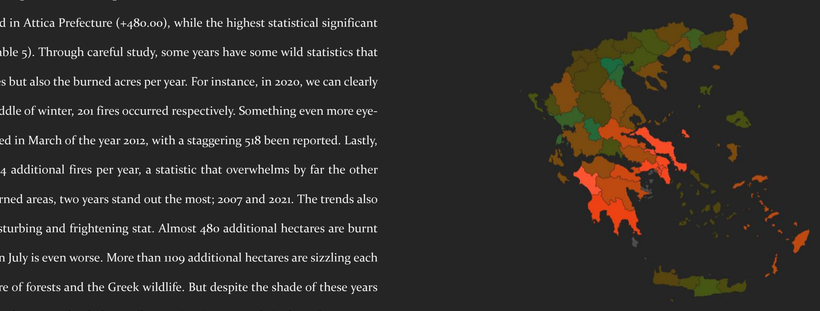

Figure 6. Choropleth map of the burnt area of Greece in acres x 10^3 during the last 22 years

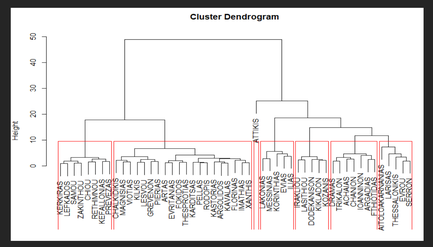

Figure 8. Hierarchy Clustering (7 clusters)

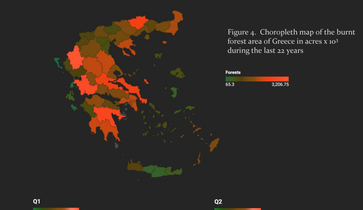

Figure 9. The trend of the frequency of wildfires

Figure 10. The trend of burnt areas

Table 3 Burned area of all districts of Greece during the period of 2000-2021 per month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	27,5	44,5	277,1	6545,1	1407,5	3424,1	515899,6	203342,3	105708,5	1314,1	9076,1	68,4
2001	145,1	493,1	14065,3	586	666,4	1229,3	9113,3	27488,9	15294	23744,2	4534,6	255,9
2002	595,3	1830,4	3590,2	126,3	272,5	2596,5	3395	6393,2	554,8	208,2	207,6	3,4
2003	17,9	167,5	1033,6	522,3	962,8	2748,7	6136,1	9071,2	2775,5	3283,3	415,2	47
2004	110,1	647	744,3	1556,4	1478,3	3691,6	12649,7	5068,2	1488,4	1718,2	1646,9	277
2005	322,1	143,7	1497	5687,77	400,42	545,89	19315,24	6950,02	1892,73	1247,81	1255,39	53,9
2006	97	91,56	483,32	1160,43	217,53	5758,46	9886,24	32829,89	5728,42	279	145,67	286,44
2007	1520,23	324,51	1417,8	654,38	1268,59	58574,64	2657644,4	1144933	8010,58	2824,43	216,97	25,66
2008	641,46	1041,35	4363,54	7765,37	391,48	3921	130474	4757863	17582,39	1312,69	1174,49	8216,79
2009	118	105,8	211,2	597,8	577	14852,6	18194,8	154040,2	16923,7	5030,4	243,2	97
2010	247,1	215,5	654,4	723,5	1225	2339,1	18851,5	27621	6764,6	591,4	1680,2	375,4
2011	49,4	387,3	484,6	453,4	113,3	1595,7	28474,8	936398	20285,3	4999,2	8308,2	991,2
2012	495,9	415,9	5222,9	1721,8	796,7	20926,2	35221,5	177561,1	10610,1	2547,8	945,2	417
2013	1572,2	158,4	1442,2	2041,3	4608,1	10239,6	44646	44179,9	6297,8	1659,9	518,3	773,1
2014	139,21	912,45	1168,76	639,56	258,04	22798,67	14137,68	22997,38	1196,51	2467,22	124,64	324,13
2015	819,79	687,18	118,8	1343,87	459,69	2745,82	28339,71	14627,11	15312,42	223,11	5882,11	1412,97
2016	450,62	2689,58	915,04	3837,42	821,16	27839,55	75949,84	20596,36	61533,92	1500,86	9278,86	1799,63
2017	143,77	604,44	2166,9	2492,8	679,92	5758,9	13796,32	81722,07	18480,82	5307,74	920,4	312,92
2018	313,19	571	2580,12	2249,81	705,01	5960,32	68698,74	5243,88	3574,4	8295,59	802,01	287,3
2019	317,21	680,23	4984,33	1252,81	86,88	536,89	11036,72	35123,46	14895,96	8284,36	341,31	318,2
2020	1326,41	368,86	1857,41	2121,61	3400	3494,54	42865,84	21858,57	21564,19	7942,12	2494,18	240,1
2021	204,89	646,25	1742,59	7617,39	58094,26	4341,97	36048,63	748213	10963,63	2136,15	1314,07	72,62

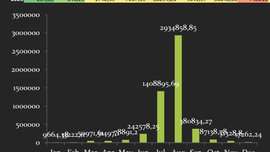

Figure 5. Monthly distribution of burned areas

Table 4 Trend Analysis of burned areas

Month	Test Z	Signific.	Q
Jan	1,52		10,119
Feb	1,58		23,010
Mar	0,68		42,446
Apr	1,69	+	68,464
May	0,34		10,317
Jun	-0,62		-94,433
Jul	1,30		1109,020
Aug	0,34		462,993
Sep	0,96		326,913
Oct	1,35		111,997
Nov	0,00		2,474
Dec	1,02		5,248

Conclusion

Exploring the spatio-temporal trends, regarding the number of forest fires and the recorded burned areas in the Greek territory during the period 2000-2021, the following conclusions emerge. It is obvious that in Central Greece and Peloponnesus there have been more fires than the rest of the mainland as well as more burned area. This follows as the drought is more intense in the south due to climate. A remarkable year is 2007 where more than 2,623,933 acres of land was burned as shown by the processing of data. To correctly draw conclusions, the Mann-Kendall parametric test, the Sen Slope index, the hierarchical clustering and the K-means algorithm were used. Concluding the outcomes of the study could provide useful information to the local and government authorities and agencies concerning.

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