



Meteorological patterns and the evolution of West Nile virus in an environmentally stressed Mediterranean area

Anastasios Mavrakis · Christina Papavasileiou ·
Dimitrios Alexakis · Evangelos C. Papakitsos ·
Luca Salvati

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Abstract The present work investigates the increase of confirmed cases of West Nile virus and the relationship between weather-related patterns and the geographical expansion of West Nile virus in Greece, with a special focus on West Attica, Central Greece, a semi-arid, ecologically fragile Mediterranean area. Using data from the European Environment Agency, European Drought Observatory of Joint Research Centre, the pairwise relationship between surface air temperature anomalies, precipitation anomalies, soil moisture index anomalies, and the fraction of absorbed photosynthetically active radiation anomalies (fAPAR) was evaluated during summer time of 2018, a particularly intense virus outbreak. The empirical results of this study indicate that total

precipitation during 2018 was extremely high, nearly 500% above the average. These conditions contributed to the increase of soil moisture index anomaly and fAPAR, creating an ideal microenvironment (wet soils and green pastures) for mosquito breeding. This phenomenon was directly associated with a drastic outbreak of West Nile virus cases in the area, compared with earlier years. Our results indicate how unusually high values of summer precipitation may have contributed (both through direct and indirect ecological channels) to the rapid spread of the West Nile virus in West Attica, causing a significant number of confirmed cases and fatalities. Climate change may bring forth other issues aside from natural disasters, including—but not limited to—virus expansion.

A. Mavrakis
West Attica Secondary Education Directorate, Greek
Ministry of Education, I. Dragoumi 24 Str., GR-
19200 Elefsis – Attica, Greece
e-mail: mavrakisan@yahoo.gr

A. Mavrakis · D. Alexakis · E. C. Papakitsos
Laboratory of Geoenvironmental Science
and Environmental Quality Assurance, Department
of Civil Engineering, University of West Attica, 250
Thivon & P. Ralli Str., GR-12244 Athens, Greece
e-mail: d.alexakis@uniwa.gr

C. Papavasileiou
Environmental Disaster and Crisis Management
Strategies – Post Graduate Programme, National
and Kapodistrian University of Athens, University
Campus, Ilisia, Athens GR-15784, Greece
e-mail: xripapav@gmail.com

C. Papavasileiou
Athens 2nd Directorate of Secondary Education, Greek
Ministry of Education, Pappa E & Filellinon Str.,
GR-14234 Nea Ionia – Attica, Greece

E. C. Papakitsos (✉)
Department of Industrial Design and Production
Engineering, University of West Attica, 250 Thivon Av.,
GR-12244 Egaleo, Greece
e-mail: papakitsev@uniwa.gr

L. Salvati
Department of Economics and Law, University
of Macerata, Via Armaroli 43, I-62100 Macerata, Italy
e-mail: luca.salvati@unimc.it

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Introduction

Since the end of 2019 and the beginning of 2020, humanity has been facing the outbreak of the SARS-CoV-2, also known as COVID-19, which became a global pandemic. The enforcement of lockdowns, as a measure of protection and limitation of the pandemic spread, has come under sharp criticism and concern (Ioannidis et al., 2020). COVID-19 is a ring in a chain of biological hazards (or biohazards), which include infectious diseases as an effect of natural disasters (Papavasileiou et al., 2021). These biohazards have appeared during the last decades in many countries, threatening humanity. Zoonotic diseases, like Zika virus, dengue virus disease, and West Nile virus (hereafter, WNV), are usually spreading through a vector, i.e., a population of infected (and infecting) mosquitoes (Allen et al., 2017). WNV, which causes the West Nile fever (hereafter, WNF), is a zoonotic, infectious, weather-related disease (Chaskopoulou et al., 2016; Paz, 2015; Poh et al., 2019). Being a seasonal

(summer) disease, the spread of WNV depends on the population of mosquitoes, typically developing in the warm season. Assuming the population of mosquitoes as depending on local weather conditions (Hahn et al., 2015; Paz, 2015; Poh et al., 2019), Schwarzbach (2006) has described the mosquitoes life cycle and the WNV transmission cycle. Besides the virus’ transmission, other associated risks may include environmental conditions, the vectors, the animal reservoirs, and human behaviour, thus making the overall concern about WNV a complex and multifactorial problem.

Even though it is called WNV, as its symptoms were first categorized and isolated in Uganda, the virus reportedly afflicted people and livestock in the Middle East, Europe, Asia, Africa, and North America. Although it is generally a mild disease (approximately 8 out of 10 infected persons have mild or no symptoms at all), it may cause encephalitis (brain inflammation), especially among the elderly. WNV has been spreading widely in recent years, while it has been established in Greece (Figs. 1 and 2), following an increase in the species of mosquitoes.

In this context, West Attica prefecture is located in Central Greece, West of the Greater Athens area, representing an emblematic example of urban-rural relationships. This area includes the Megara plain, which

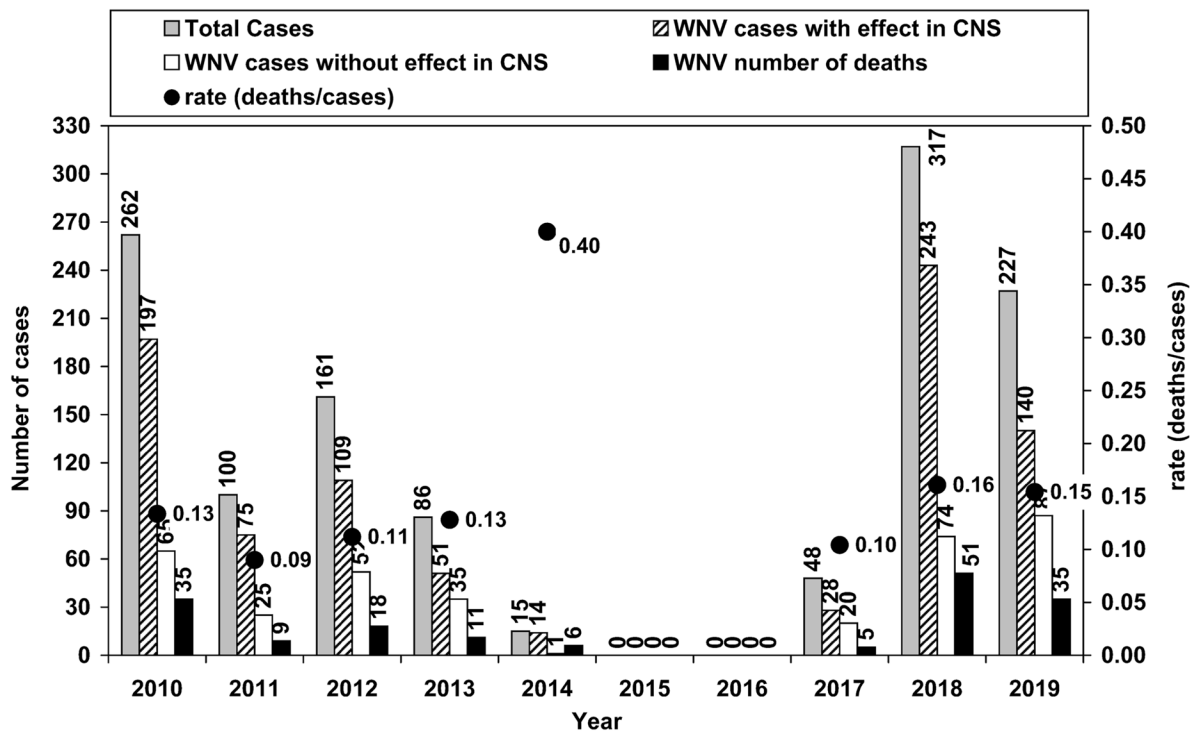


Fig. 1 Number of WNV cases per category

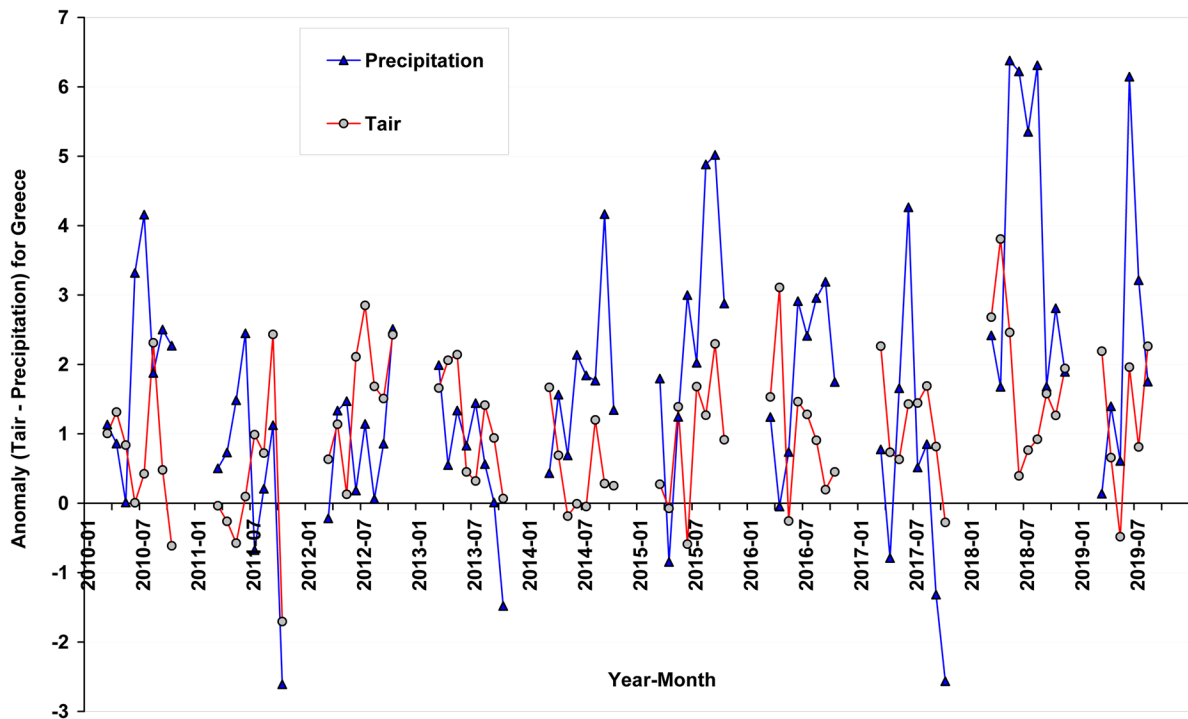


Fig. 2 Surface air temperature (T_{air}) anomaly and precipitation anomaly in Greece, March–October, 2010–2019

is an agriculture plain with olive cultivation, and the industrial Thriasio Plain, with four municipalities, namely, Elefsis, Aspropyrgos, Mandra, and the community of Magoula. Western Attica is a well-known region of Greece for its social, economic, and environmental problems and challenges (e.g., see Di Felicianonio & Salvati, 2015; Pili et al., 2017; Rontos et al., 2016). These issues become even more complicated because of the presence of motley social groups of diverse origins (e.g., religious, national, social, and ethnic) and values-background (Clapp & Norfolk, 2017; Cuadrado-Ciuraneta et al., 2017; Di Felicianonio et al., 2018; Panori et al., 2019), causing a negative impact on natural resources (Duvernoy et al., 2018), loss of social cohesion (Salvati & Serra, 2016), uncertain economic growth (Salvati, 2016), and indirect effects in the local climatic regime, which became warmer and drier (Mavrakis et al., 2015a, b, 2016). Although Thriasio Plain extends nearly 500 km², the industrial activities are concentrated over 120 km². The terrain of the latter area is smooth, having a slight inclination (3%) toward the sea, surrounded by hilly and mountainous reliefs. Therefore, this semi-enclosed area produces weak local atmospheric circulation patterns,

affecting the capability of atmospheric environment for self-cleaning through natural mechanisms. Moreover in this respect, during late autumn and winter, the altitudes of temperature inversion are especially low, while they frequently become lower than the surrounding hills and “comparable to the elevation of the highest chimneys of the large industrial compounds” (Mavrakis et al., 2015a, b). These conditions favour the maintaining of high temperatures close to the ground. The same conditions during summertime are favorable for the increase in the population of mosquitoes. Industrialization of this area and its transformation from rural to industrial settlements, without a master plan and supporting facilities, gave rise to intense land use change. Additionally, two protected wetlands are located in West Attica (the shallow Koumoundourou Lake and the Vourkari shallow aquatic area in Megara Plain). These two wetlands have an inestimable value for the prefecture, because they accommodate large populations of birds. Yet, these particular wetlands are abandoned and “undervalued” by the local communities and the state and can be a particularly suitable area for mosquitoes’ development.

Based on these premises, the present study assumes the outbreak of WNF as reflective of significant alterations in the average environmental and climatic conditions in an already ecologically fragile and socially sensitive area, like West Attica. Adopting a descriptive framework, the relationship between meteorological and environmental variables and the evolution of WNF epidemics was investigated, by identifying the ideal context for the appearance and development of mosquitoes, the virus' vector. More specifically, this research investigated the relationship between WNV cases and standardized precipitation index (SPI), soil moisture anomaly, and a fraction of the absorbed photosynthetically active radiation anomaly (fAPAR), reflecting growth of new grass as an ideal microenvironment for mosquitoes.

The purpose of this study was to evaluate the impact of critical meteorological and environmental conditions on intensity of the abovementioned biohazard, and especially how the weather conditions may subsequently create an ideal microenvironment for the appearance of mosquitoes. More specifically, any relation between the recorded WNV cases and various environmental indexes was explored, including the standardized precipitation index (SPI), the soil moisture anomaly, and fAPAR, indicating grass natural increase and soil moisture.

Materials and methods

The data used for this study refer to the 2010–2019 decade and include a meteorological dataset and derived products, in order to correlate WNV cases, officially registered each year, with meteorological variables and environmental conditions.

Data of surface air temperature (T_{air}) anomaly and precipitation anomaly for Greece, referring to standard 1981–2010 climatology, were derived from the website of NOAA Physical Sciences Laboratory (PSL) (2020)—Climate Analysis and Plotting Tools, using the ERA–Interim database, from March to October, i.e., the transmission months for Greece. Data for confirmed WNV cases were gathered from the Greece's Centre for Disease Prevention and Control (KEELPNO, 2020) and the European Centre for Disease Prevention and Control (ECDC, 2020).

Meteorological data and products were also gathered from the Copernicus Climate Data Centre (CCDC, 2020) and the European Environmental Agency–European Drought Observatory of Joint Research Centre (EDOJRC,

2020). Selected data include month precipitation, the 1-month standardize precipitation index (SPI-1), the soil moisture anomaly, and a fAPAR. Those variables are assumed as providing a comprehensive evaluation of a microenvironment suitable to development of mosquitoes.

Moreover, for the West Attica Prefecture, precipitation data were gathered from the relevant database of the meteorological stations network of the National Observatory of Athens (NOA) (Elefsis station: <http://penteli.meteo.gr/stations/elefsina/>; Aspropyrgos station: <http://penteli.meteo.gr/stations/aspropyrgos/>).

A hierarchical clustering (Euclidean distances; Ward's agglomeration rule) was used to explore empirical results, grouping variables into homogeneous clusters by year, with the aim at identifying years with specific environmental patterns. The Spearman's rank test was applied to identify significant ($p < 0.01$, after Bonferroni's correction for multiple comparisons) pairwise correlations respectively between the recorded number of WNV cases and the related value of the following indexes: (i) surface air temperature (T_{air}) anomaly and precipitation anomaly, (ii) 1-month standardize precipitation index (SPI-1), (iii) soil moisture anomaly and fAPAR.

Results and discussion

In Fig. 2, the surface air temperature anomaly and precipitation anomaly are illustrated for the months between March and October of years 2010–2019. The anomaly in both variables was particularly high, especially in 2018. The WNV's first cases have been systematically monitored by the Hellenic Centre for Disease Control & Prevention (KEELPNO, 2020) since summer 2010. Since the country's first documented outbreak in 2010, WNV cases were identified in several administrative regions of Greece. The WNV transmission persisted in Greece until 2014; no new cases were reported in 2015 or 2016. In those years, climate was particularly dry (Fig. 3, red, green, and blue lines), as a result of low precipitation. Despite the absence of infections on people, the serological testing revealed that the virus was still circulating in birds (Mavrouli et al., 2015, 2017).

Mavrouli et al. (2015, 2017) suggest that the decline in human infections may have been the result of mosquito management strategies and preventive measures that were implemented with the aim at reducing exposure. Additionally, the development of immune response against

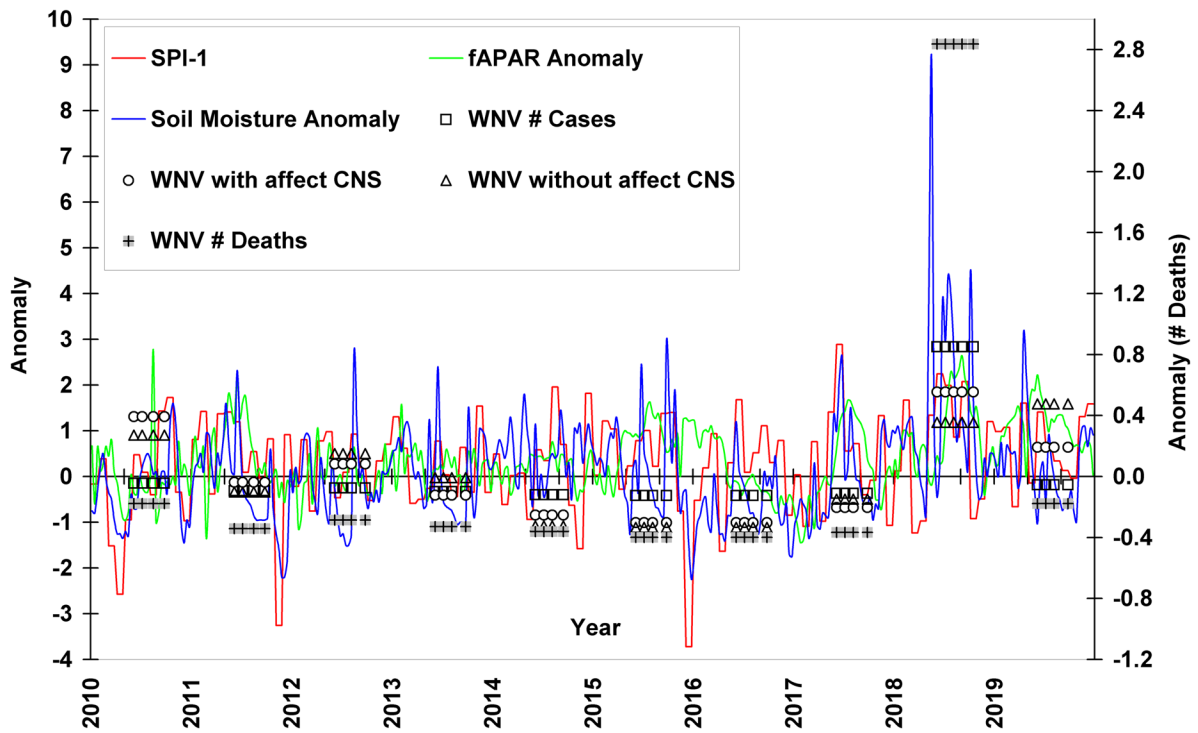


Fig. 3 Comparative meteorological and epidemiological data

WNV may have reduced the cases of human infection, by depleting the susceptible human population. It is also possible that WNV caused infections that were asymptomatic, as occurs approximately in 80% of cases, or that remained mostly undetected. In 2017, WNV has re-emerged in Greece, spreading to new territories (Mavrouli et al., 2015, 2017). Forty-five cases of WNV infection were reported in Greece, between July and September 2017. Most of them were found in areas with no documented history of transmission. According to Mavrouli et al. (2017), the re-emergence of WNV and its expansion into new regions suggest that Greece’s ecological and climatic conditions were (and still are) suitable for WNV circulation.

The recorded cases for summer 2018 were particularly high in comparison with earlier years (ECDC, 2020). Persistence of cases and fatalities during October 2018 had not been recorded before. West Attica was among the prefectures with cases that had not been recorded in earlier years. This particular region is a semi-arid part of Greece (Mavrakis et al., 2015a, b). In this region, 44 deaths had been documented from the WNV infection, for the year 2018.

Figure 3 illustrates the number of total cases, in cases with and without effects in the central nervous system (CNS), as well as in the number of deaths, for the year 2018. This seasonal outburst (Figs. 3 and 4, 2018) had the characteristics of a biological disaster for Greece, including West Attica Prefecture, according to the EM-DAT classification of disasters types (EM-DAT, 2020), added to a series of other recorded natural disasters, such as:

- a) Two strong earthquakes, dated September 7, 1999, and July 19, 2019, with epicenters located in Thriasio Plain (EM-DAT, 2020; Papanikolaou et al., 1999; Kapetanidis et al., 2020);
- b) The catastrophic flash flood of Mandra (West Attica) on November 15, 2017 (Diakakis et al., 2020; EM-DAT, 2020; Speis et al., 2019);
- c) The flash flood of June 2018 in the West Attica municipality of Mandra and the local community of Magoula (EM-DAT, 2020);
- d) The Kineta’s wildfire (West Attica), which burned residential and wild-land areas, and the big fire (July 23, 2018) in Mati (East Attica), with more

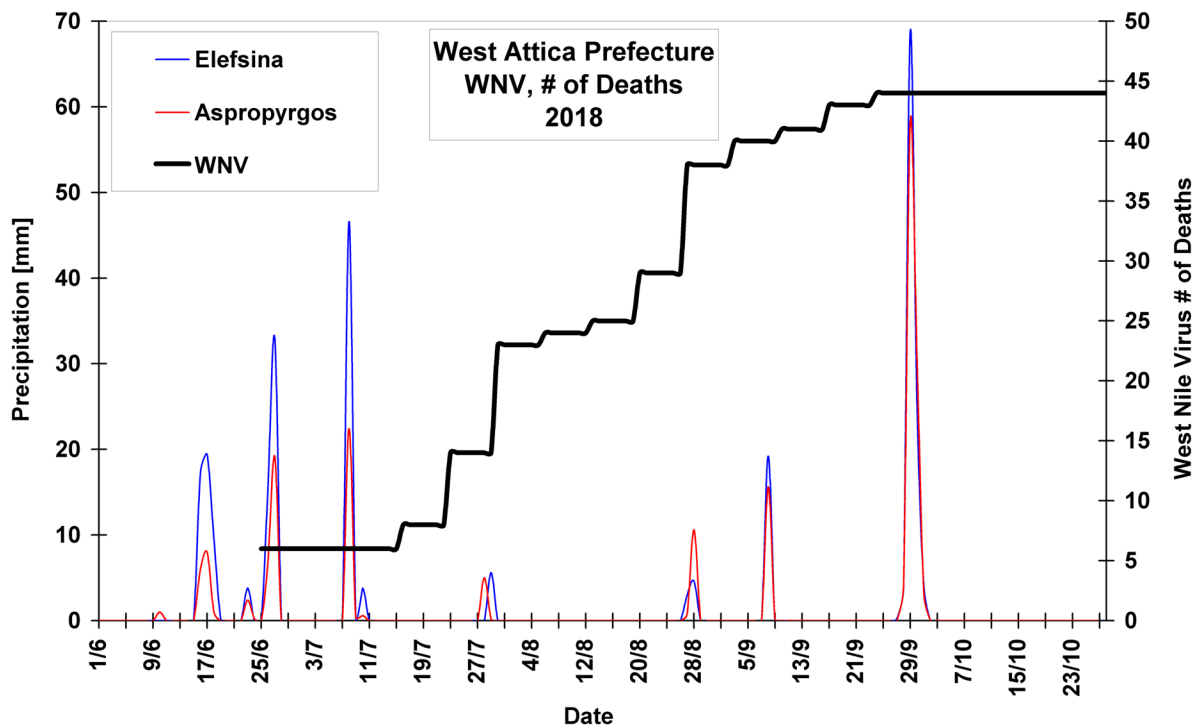


Fig. 4 Daily precipitation values and WNV confirmed deaths for West Attica, Greece, per week (June 1 (W23) to October 26 (W43), 2018)

than 100 casualties on the same day (Alexakis, 2020; Alexakis et al., 2020; EM-DAT, 2020; Vlamaki et al., 2018);

- e) The “Zorbas” medicane (Mediterranean tropical-like cyclones) on September 29th, 2018 (Dafis et al., 2020);
- f) The Kineta’s flood of 2019—West Attica (Lekkas et al., 2019).

All the above disasters revealed problems and weaknesses, regarding emergency planning at both local and regional level (Lekkas et al., 2014).

The summer and early autumn months are ideal as the transmission season for WNV. During those months, the precipitation of 2018 was extremely high, reaching 500% above the climatological values in some cases, as observed in West Attica, according to the Copernicus database (CCDC, 2020). Those enormous precipitation values for this time of the year impacted the SPI-1 drought index, showing positive anomaly values (Fig. 3, red line), and contributed to a massive increase of the Soil Moisture Anomaly (Fig. 3, blue line) and the fAPAR index (Fig. 3, green line), for June–October

2018 (Mavrakis et al., 2015a). Especially for West Attica, those weather conditions were favorable for growing mosquitoes’ population. Those unusually high values of precipitation for this time of the year, contributed (via a lag process; Fig. 4) to the rapid expansion and spread of the WNV, with confirmed cases and fatalities, causing a considerable economic loss, as well.

The downgrading environment of the two legislated wetlands may have also contributed to the outburst of this disease, being a condition in agreement with Schwarzbach’s (2006) that determines a WNV amplification among birds and mosquitoes. The annual rate of deaths per cases remained relatively stable, with the exception of the year 2014, which seems highly increased (Fig. 1).

Eventually, a cluster analysis was performed, applying the annual dataset of anomalies and outbreak variables (SPI-1, fAPAR, soil moisture anomaly, WNV total cases, WNV cases effect in CNS, WNV cases without effect in CNS, WNV number of deaths). The time period covered includes the warm months (June–September) of the years 2010–2019, for which human cases of infection were recorded (for 2018, October was added). The results

Fig. 5 Cluster analysis per year in Greece, for meteorological and epidemiological data

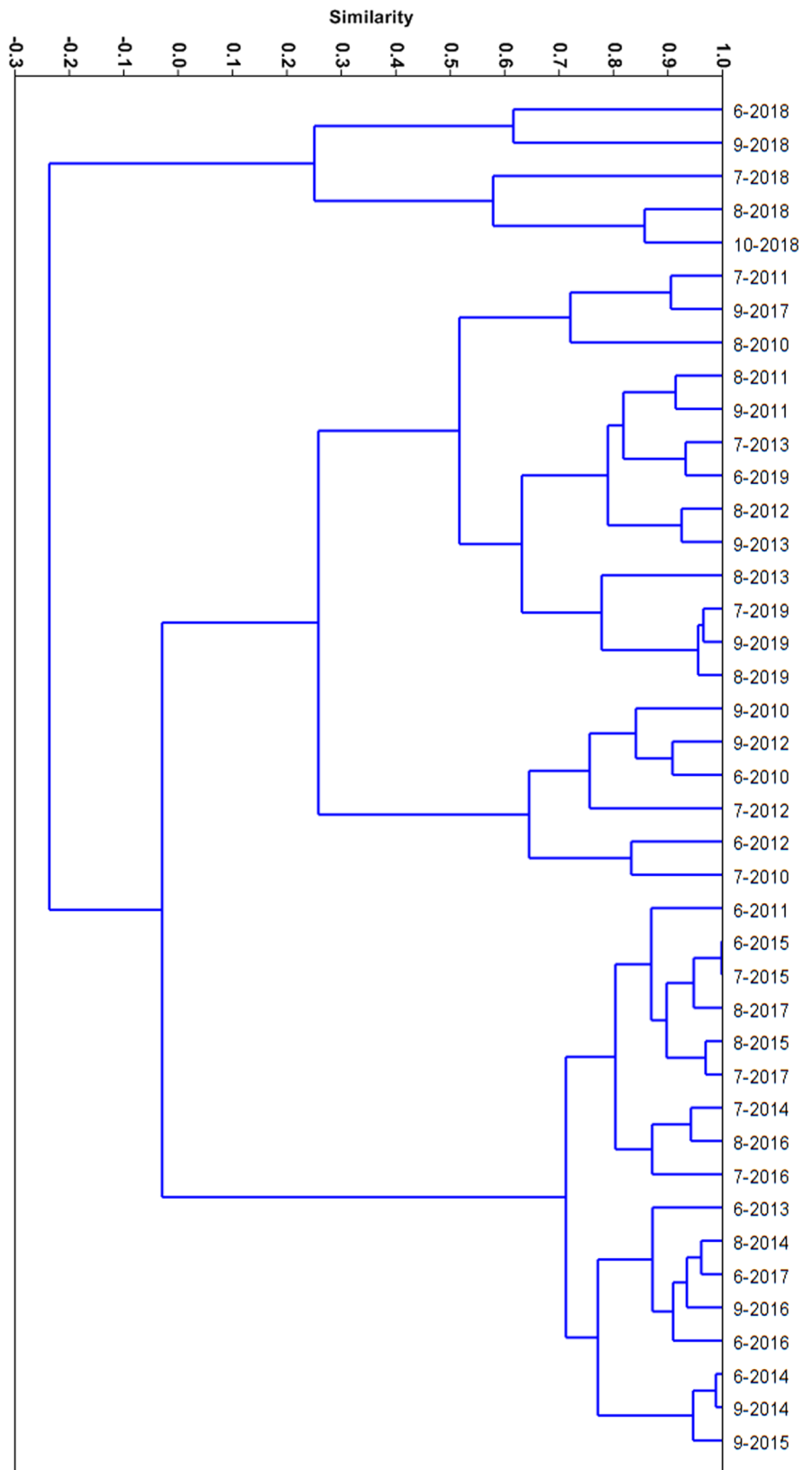


Table 1 Spearman's rank correlation test (bold indicates significant coefficients at $p < 0.01$)

Spearman	SPI-1	fAPAR anomaly	Soil moisture anomaly	WNV no. of cases	WNV with CNS	WNV without CNS	WNV no. of deaths	Precip	T _{air}
SPI-1	1	0.19	0.01	0.78	0.78	0.76	0.81	0.00	0.36
fAPAR anomaly		1	0.03	0.23	0.23	0.23	0.34	0.41	0.16
Soil moisture anomaly			1	0.82	0.82	0.44	0.81	0.01	0.66
WNV no. of cases				1	0.00	0.00	0.00	0.68	0.56
WNV with CNS					1	0.00	0.00	0.68	0.56
WNV without CNS						1	0.00	0.66	0.27
WNV no. of deaths							1	0.58	0.78
Precip								1	0.11
T _{air}									1

are shown in Fig. 5. Hierarchical clustering indicated how variables' pattern was extreme for the year 2018. These results were coupled with other challenges in the area, occurred at the same period: precipitation patterns above normal; fatalities and environmental degradation by wildfires, caused by abnormal horizontal and vertical winds (Vlamaki et al., 2018). This set of disasters—occurred more or less together—caused an intense crisis, stressing the authorities' preparedness plans. Consequences on quality of life, infrastructures, and financial losses were also significant (Karagiannopoulou, 2020; Semenza et al., 2016).

Finally, the Spearman's rank correlation tests were applied, to detect the possible relation of meteorological/environmental variables and the WNV cases per year (Table 1). Significantly positive correlations were found for all categories of WNV cases and SPI-1 meteorological index, with positive coefficients ranging between 0.76 and 0.81. In addition, the strongest positive correlation was found between the WNV cases and the index of Soil Moisture Anomaly, with coefficients ranging between 0.81 and 0.82. The surface air temperature anomaly and the precipitation anomaly indexes also showed positive correlation with all categories of WNV cases, with coefficients between 0.58 and 0.68 for the precipitation anomaly index, and between 0.56 and 0.78 for the T_{air}, reflecting an important role of weather conditions in the WNV outbreak.

The aforementioned bio-hazardous events and consequences have not been recorded in the database of EM-DAT (2020). The Greek General Secretariat for Civil Protection (GSCP) is responsible for

the recording of natural or technological disasters to EM-DAT database. For the recording of an event, norms, classifications, and thresholds of EM-DAT are implemented. Yet, no such records exist in the relevant database. As it is demonstrated, WNV has caused a lot of casualties, especially in 2018, suggesting the need for a broader understanding and recording of related incidents, based on centralized, official approaches. Data regarding such events still remain unpublished; however, they need to be recorded and released in order to improve response of the state and mitigation actions, meeting the increased environmental and safety awareness of the resident population.

Conclusions

There is an increasing trend in frequency and severity of any kind of disasters (natural/technological/biological), while their effects occur on progressively wider scales (EM-DAT, 2020). In this study, the relationship between the precipitation patterns of summer 2018 and the increase in confirmed cases and casualties of the WNV have been investigated in West Attica. Results indicate that the occurrence of unusually high values of soil moisture anomaly for this time of the year (because of positive precipitation and temperature anomaly) may have contributed to the rapid spread of the WNV in West Attica, causing an increase in confirmed cases and fatalities. The WNV constitutes an indirect signal of climatic changes in Europe, affecting the spread of diseases, transmitted

by various vectors (usually insects). The outdoors high temperature anomalies during spring months (i.e., the irregular temperature fluctuation for this season), the prolonged rains (precipitation anomaly) at the beginning of summer and the following heat waves, determined ideal conditions for new outbreaks of mosquitoes' proliferation and WNV infection.

Obviously, climatic change increases the probability of favorable conditions to mosquitoes. The occurrence of these changes is expected to consolidate in the near future, both in Greece and in the rest of Mediterranean Europe. The expansion of this zoonotic (seasonal) disease in Greece supports the need for a civil protection climate service and an Early Warning System (EWS) for the WNV, which is not operating in the country. The collaboration of regional medical and meteorological agencies is essential for the efficiency of such a EWS, as well as the prompt reaction of national monitoring agencies, like the Greek GSCP. The relevant data should be uploaded to EM-DAT, as soon as possible, with the aim at facilitating analysis and forecast, while both precautionary and response measures should be taken immediately by the local public-health authorities (Palmos et al., 2021). While spreading of the WNV is a severe public-health problem, it is considered also an early symptom of an infinitely more severe disease, because of global warming.

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Data availability All data presented in this paper are available from the respective agencies that are mentioned in the text.

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