Article
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THE INFLUENCE OF CLIMATIC FACTORS IN THE TRANSMISSION OF VECTOR BORNE DISEASES

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Abstract

The prevalence of mosquito-borne diseases differs geographically, and transmission times may change in response to the interaction between pathogens, vectors, hosts and the environment. In the context of global warming there is a need to monitor the risk of emergence and re-emergence of vector-borne diseases in Romania. The forecast made in this study shows an increase in temperature until 2050 by 0.78°C, which demonstrated the possibility of extending the transmission period of Plasmodium protozoa until November, of West Nile virus until October and of Dengue fever from June to the first half of September. The results underline the need to introduce vectors and vector-borne disease monitoring and control programmes in Romania in the context of global warming.

Key words: *West Nile, Dengue* fever, *Plasmodium*

External factors, as well as anthropogenic actions, can have a very large impact on global climate (Torres-Vélez and Brown, 2011). Vector-borne diseases are the most sensitive to climate change, as their distribution and evolution is directly controlled by the distribution of vectors, which are influenced by climate change. The effects of global warming and its influence on vector-borne diseases, such as malaria and dengue fever, are a topic of interest to scientists. There is a direct link between climate and the incidence of vector-borne diseases and many studies report a number of patterns explaining the spread and transmission of vector-borne diseases under the influence of temperature (Sutherst, 2004). Mosquito-borne pathogens can affect both animals and humans and are even more difficult to manage once established in a given territory, especially if the reservoir in the wild is represented by wild animals (Tolle, 2009).

The prevalence of mosquito-borne diseases differs geographically, and transmission times can change in response to the interaction between pathogens, vectors, hosts and the environment (Gangosoa *et al*., 2020). The emergence or re-emergence and spread of mosquito-borne diseases are associated with a number of changes in the distribution of their main vectors, either as a result of their accidental introduction or changes in environmental conditions (Ebi, 2013). In Europe, outbreaks of West Nile in humans have occurred mostly in years when temperature anomalies, namely temperature extremes, have occurred (Tran *et al*., 2014; Tabachnick, 2016). Climatic factors, associated with other factors such as human population growth, livestock numbers, intercontinental travel, global trade, urbanisation and land use change, greatly increase the risk of introducing new vector-borne diseases into Europe (Watts *et al*., 2021).

In recent decades, Europe has seen increasing health risks, especially with the intensification of vector-borne diseases such as chikungunya, West Nile virus, Crimean-Congo haemorrhagic fever and Dengue fever (Hotez, 2016; Olesen, 2017). Thus, out of approximately 593 viral diseases that have been identified in animals, on average 29% are vector-borne (Johnson *et al*., 2015). The epidemiology of these vector-borne diseases is influenced by climate and climate change, which play an important role in altering the disease cycle (Randolph, 2009). Temperature increases between different climatic components have direct effects on human and animal health, primarily due to changes in the frequency and intensity of heat waves (Gaughan *et al*., 2010). The presence of competent vectors in the territory, of favourable climatic factors and evidence of climate change can lead to the re-emergence of diseases, such as malaria, in

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countries where it was previously eradicated. Thus, indigenous cases of malaria have been reported in Germany (Kruger *et al*., 2001), Spain (Santa-Olalla Peralta *et al*., 2010), the Netherlands (Sankatsing *et al*., 2013), Italy (Baldari *et al*., 1998), the UK (ECDC, 2019), France (Armengaud *et al*., 2006) and Greece (Danis *et al*., 2011). The IPCC has stated that human activities have already led to a warming of about 1.0 °C since pre-industrial times, which is likely to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate. The 2018 IPCC report highlights that global warming is having a major impact on organisms and ecosystems, as well as it further increases the risk for transmission of vector-borne diseases such as malaria. Global warming determines the increase of the vector capacity of mosquitoes to transmit malaria by shortening the extrinsic incubation period of the parasite, as well as prolongs the mosquito breeding period and increases mosquito density (Kuhn *et al*., 2002; Jetten *et al*., 1996).

The most prevalent mosquito-borne virus is estimated to be dengue virus, which infects 390 million people per year (Bhatt *et al*., 2013) and malaria, despite intensified intervention efforts, causes over 400,000 deaths per year (WHO, 2016).

MATERIAL AND METHOD

In order to follow the evolution of temperatures in Romania and their effects on vector-borne diseases, meteorological data from the National Meteorological Administration from 1961 to the present were processed. Data for each meteorological station were provided, obtaining an average monthly temperature in five geographical regions: Iași, Arad, Bucharest, Sibiu and Tulcea.

This calculated average was used to provide a forecast of temperatures in Romania until 2050. This statistical procedure was obtained through a function within the Excel package called Forcast. This tool predicts a value based on historical data along a linear trend over a time horizon. The Forcast function calculates predictions of future values using linear regression. Choosing this analysis model results in a graphical representation of the forecasted data and a table with the historical and forecasted data used. Thus, in this study we aimed to calculate the climate warming in Romania until 2050, as well as the risk of transmission of some vector-borne diseases: malaria, Dengue fever and West Nile virus.

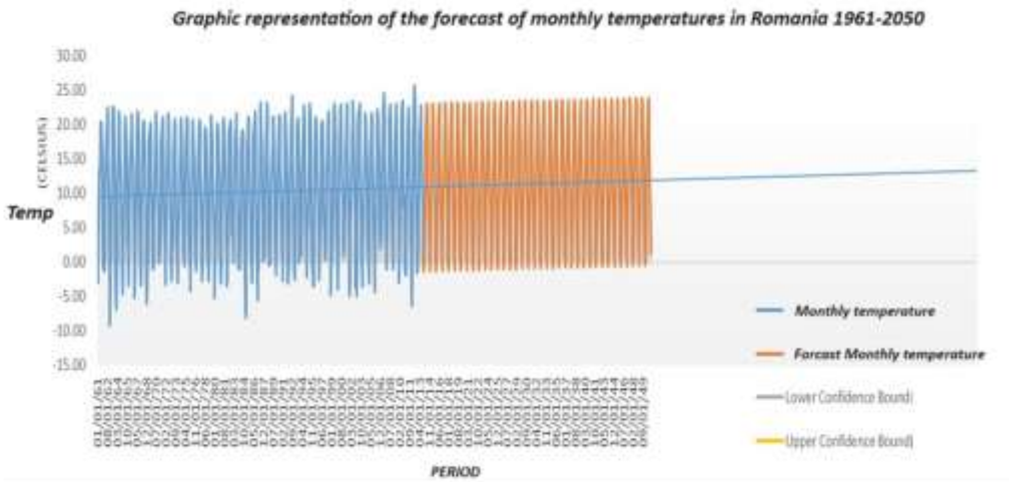

Figure 1 **Graphical representation of monthly temperature forecast in Romania from 1961-2050**

RESULTS AND DISCUSSIONS

The mean temperature obtained was used to indicate the evolution of temperatures over a 28-year horizon compared to the present.

The graph in *Figure 1* shows the evolution of mean annual temperatures recorded in Romania from 1961 to 2013 and is indicated by the blue colour. Temperatures projected up to 2050 are shown in red. The appearance of the graph is specific to seasonality, given by the repetition of the four seasons throughout the year. This shows an increasing trend in temperatures, with a rising trend represented by the line crossing the middle of the graph. In order to better highlight the temperature evolution during the years under study, an indicator called moving average (MA) has been introduced. The role of this indicator is to reduce short-term fluctuations and to highlight long-term trends or cycles in order to eliminate seasonality. With the help of this indicator, we have established the value of the moving average every three years in order to graphically show the evolution of temperatures. This graph gives a result with an estimation accuracy of 95%, with the remaining 5% representing the range in which unexpected events are taken into account, and this can be seen on the graph in *Figure 2*, by means of the Upper Confidence Bond.

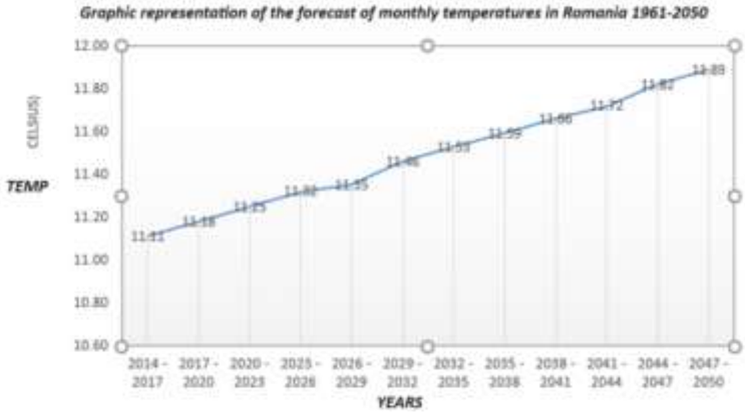

Figure 2 **Average temperatures every three years in Romania from 2014 to 2050**

As can be seen in Figure 2, applying the moving average method, a graph with which the removal of seasonality can be seen was obtained, in order to clearly illustrate the dynamics of temperatures.

The graph suggests that from 2014 to 2050, the temperature increase was estimated to be of almost 1 ºC, i.e., 0.78 ºC.

Malaria forecast 2013-2025 in Romania

Numerous studies have shown that climate change can affect the introduction and spread of vector-borne diseases, affecting the reproduction and development of vector mosquito populations, as well as their vector capacity. Temperature influences the development of the pathogen within the vector, playing a crucial role in the transmission of some vector-borne diseases. In zoonoses, climatic variables cause variations in the distribution and abundance of vertebrate hosts acting as reservoirs of infection.

To forecast the dynamics of malaria cases, a table including three sets of data was developed. The first series is the monthly mean temperature forecast until 2025. The second series is the upper confidence limit. And the third series includes the maximum (mean) temperature, being the average of the warmest days of the month for each station (Iași, Bucharest, Arad, Sibiu and Tulcea).

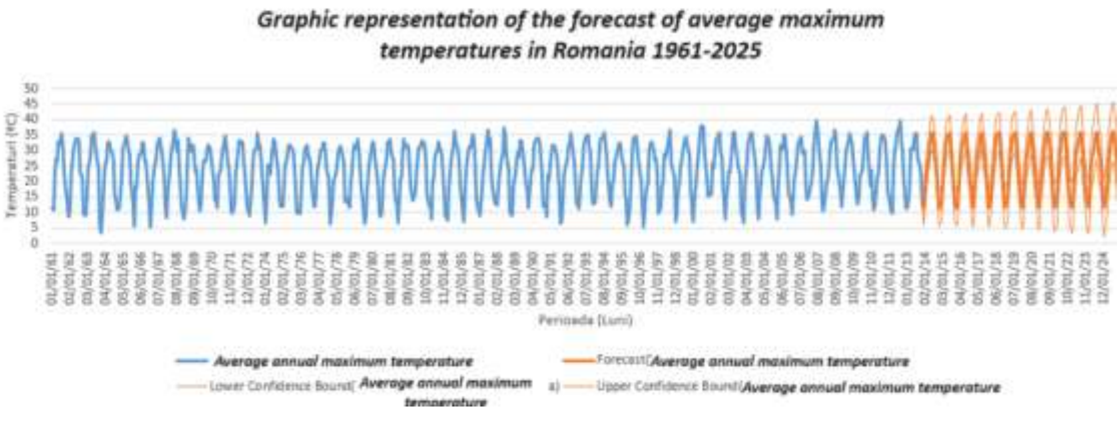

Figure 3 **Graphical representation of the forecast of average maximum temperatures from 1961 to 2025**

Figure 3 shows the average maximum temperature analysis. The meteorological data obtained were recorded for each region. Thus, it was necessary to calculate the average of the warmest days of the month for each station in order to obtain a national analysis. Maximum temperatures for the years 1961-2013 are shown in blue. The projected period to 2025 shows an increasing trend in temperature. The extensions of the forecast period, called Upper Confidence Bounds, illustrate the maximum limit which the mean temperatures can reach, taking into account the forecast error coefficient value of 5%.

Data on the number of days required for parasite development inside the mosquito at 20°C, 25°C and 28°C were also included for this analysis.

TEMP	The length of the development cycle		
	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum
-10.00	-	-	-
20.00	30 - 35 days	16 days	22 days
25.00	15 - 20 days	9 days	10 days
28.00	14 days	10 days	9 - 10 days
35.00	14 days	8 - 10 days	9 - 10 days

Figure 4 **Developmental cycle time for *Plasmodium* species**

For a more efficient representation of the influence of temperatures on the development of *Plasmodium* species, a colour specific to the temperature required for the development cycle has been included. The yellow colour indicates a longer range of days required for Plasmodium protozoa development at 20°C. The orange colour is attributed to a medium range at 25°C and the red colour indicates the shortest range of *Plasmodium* species development at 28°C (*figure 4*). The interpretation comes down to the inverse proportionality between the temperature evolution and the duration of the development cycle. Therefore, as the temperature increases, a decrease in the development time of the protozoan can be observed, which means a prolongation of the transmission period throughout the year. The result of the analysis is illustrated in tabular form marking the most favourable period for the development of the parasite inside the *Anopheles* female in the year 2023 and the forecast made for the year 2025 shows a shortening of the development period of the protozoan inside the vector.

Table 1

Range of development period of *Plasmodium* species inside the vector for the year 2023

Forecast data				The upper limit of the average monthly temperature			Maximum monthly temperature (average)			Average monthly temperature		
YEAR	Average monthly temperature	The upper limit of the average monthly temperature	Maximum temperature of the month (average)	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum
01/01/23	-1.12	4.84	11.68	-	-	-	-	-	-	-	-	-
02/01/23	-0.18	5.80	13.62	-	-	-	-	-	-	-	-	-
03/01/23	5.19	11.18	21.14	-	-	-	30 - 35days	16 days	22 days	-	-	-
04/01/23	12.08	18.10	26.84	-	-	-	15 - 20days	9 days	10 days	-	-	-
05/01/23	17.38	23.41	30.37	30 - 35days	16 days	22 days	14 days	8 - 10 days	10 days	-	-	-
06/01/23	21.09	27.14	33.99	15 - 20 days	9 days	10 days	14 days	8 - 10 days	10 days	30 - 35 days	16 days	22 days
07/01/23	23.19	29.25	35.74	14 days	8 days	9 - 10 days	14 days	8 - 10 days	10 days	30 - 35 days	16 days	22 days
08/01/23	22.65	28.73	36.00	14 days	8 - 10 days	9 - 10 days	14 days	8 - 10 days	10 days	30 - 35 days	16 days	22 days
09/01/23	17.05	23.15	30.33	30 - 35 days	16 days	22 days	14 days	8 - 10 days	10 days	-	-	-
10/01/23	11.06	17.18	26.15	-	-	-	15 - 20days	9 days	10 days	-	-	-
11/01/23	6.66	12.79	20.39	-	-	-	30 - 35days	16 days	22 days	-	-	-
12/01/23	0.51	6.66	13.57	-	-	-	-	-	-	-	-	-

Table 2

Range of development period of Plasmodium species within the vector for the year 2025

Forecast data				The upper limit of the average monthly temperature			Maximum monthly temperature (average)			Average monthly temperature		
YEAR	Average monthly temperature	The upper limit of the average monthly temperature	Maximum temperature of the month (average)	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum	Plasmodium malariae	Plasmodium vivax	Plasmodium falciparum
01/01/25	-1.08	5.64	11.76	-	-	-	-	-	-	-	-	-
02/01/25	-0.14	6.60	13.69	-	-	-	-	-	-	-	-	-
03/01/25	5.23	11.99	21.21	-	-	-	30 - 35 days	16 days	22 days	-	-	-
04/01/25	12.13	18.91	26.92	-	-	-	15 - 20 days	9 days	10 days	-	-	-
05/01/25	17.42	24.22	30.44	30 - 35 days	16 days	22 days	14 days	8 - 10 days	9 - 10 days	-	-	-
06/01/25	21.14	27.96	34.06	15 - 20 days	9 days	10 days	14 days	8 - 10 days	9 - 10 days	30 - 35 days	16 days	22 days
07/01/25	23.24	30.08	35.81	14 days	8 - 10 days	9 - 10 days	14 days	8 - 10 days	9 - 10 days	30 - 35 days	16 days	22 days
08/01/25	22.70	29.57	36.08	14 days	8 - 10 days	9 - 10 days	14 days	8 - 10 days	9 - 10 days	30 - 35 days	16 days	22 days
09/01/25	17.10	23.99	30.40	30 - 35 days	16 days	22 days	14 days	8 - 10 days	9 - 10 days	-	-	-
10/01/25	11.11	18.02	26.22	-	-	-	15 - 20 days	9 days	10 days	-	-	-
11/01/25	6.70	13.64	20.47	-	-	-	30 - 35 days	16 days	22 days	-	-	-
12/01/25	0.55	7.51	13.64	-	-	-	-	-	-	-	-	-

In the range 2021-2025, the upper temperature limit marks the reaching of a new threshold marked by the red colour, of the frequency of periods favourable to the etiological agent of malaria, in July and August. While at the beginning of 2014-2019, the suitable period for Plasmodium was during the summer months, as time goes on, an increase in this period is observed.

For each species, the most suitable period for transmission was identified according to the temperature and the length of the parasite's development cycle inside the mosquito. Thus, it can be observed that the summer months with the extension of the last month of spring and the first month of autumn are the most suitable for malaria transmission (*table 1 and table 2*).

Forecast of West Nile cases in Romania between 2023 and 2025

The West Nile virus has been present in Romania since 1950. The clinical picture and the spread of the virus have led to the need to monitor and control the disease. The importance of West Nile virus infection lies in its impact, sometimes fatal among equines and through transmission to humans.

In the table below, we have illustrated the range of temperature values, organised according to their growth. For reference, the literature says that West Nile virus is transmitted conditionally at the temperature threshold of 23.7 °C, represented by the orange colour. This is the temperature range at which the virus develops, attaching the upper and lower limits of the optimal temperature. As can be seen, a temperature in the lower limit is below the optimum value of 23.7°C, being represented by the absence of a development cycle. But the upper limit is marked by the red colour, exceeding the optimal threshold (*figure 5*).

Tables 3 and *4* show an extension of the West Nile virus transmission period from April to October inclusively, underlining the need to monitor mosquito populations throughout the year, as well as the bird and horse populations that represent the natural reservoir of the virus.

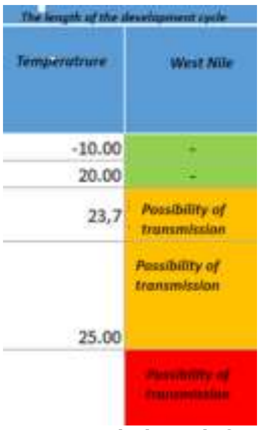

Figure 5 **Development cycle length for West Nile virus**

Table 3

West Nile virus development period range for the year 2023

Year	Forecast data: Average monthly temperature	The upper limit of the average monthly temperature	Maximum temperature of the month (average)	West Nile: The upper limit of the temperature	West Nile: Maximum monthly temperature	West Nile: Average monthly temperature
01/01/23	-1.12	4.84	11.88	-	-	-
02/01/23	-0.18	5.80	13.62	-	-	-
03/01/23	5.19	11.16	21.14	-	-	-
04/01/23	12.08	18.10	26.84	-	Transmission [illegible]	-
05/01/23	17.38	23.41	30.37	-	Transmission [illegible]	-
06/01/23	21.09	27.14	33.99	Transmission [illegible]	Transmission [illegible]	-
07/01/23	23.19	29.25	35.74	Transmission [illegible]	Transmission [illegible]	-
08/01/23	22.65	28.73	36.00	Transmission [illegible]	Transmission [illegible]	-
09/01/23	17.05	23.15	30.33	-	Transmission [illegible]	-
10/01/23	11.06	17.16	26.15	-	Transmission [illegible]	-
11/01/23	6.68	12.79	20.39	-	-	-
12/01/23	0.51	6.66	13.57	-	-	-

Table 4

West Nile virus development period range for the year 2025

Year	Forecast data: Average monthly temperature	Upper limit of monthly average temp	Maximum monthly temperature (average)	West Nile: The upper limit temperature	West Nile: Maximum monthly temperature	West Nile: Maximum monthly temperature
01/01/25	-1.08	5.64	11.76	-	-	-
02/01/25	-0.14	6.60	13.69	-	-	-
03/01/25	5.23	11.39	21.21	-	-	-
04/01/25	12.13	18.91	26.92	-	Possibility of transmission	-
05/01/25	17.42	24.22	30.44	-	Possibility of transmission	-
06/01/25	21.14	27.96	34.06	Possibility of transmission	Possibility of transmission	-
07/01/25	23.24	30.08	35.81	Possibility of transmission	Possibility of transmission	-
08/01/25	22.70	29.57	36.08	Possibility of transmission	Possibility of transmission	-
09/01/25	17.10	23.39	30.40	-	Possibility of transmission	-
10/01/25	11.11	18.02	26.22	-	Possibility of transmission	-
11/01/25	6.70	13.64	20.47	-	-	-
12/01/25	0.55	7.51	13.64	-	-	-

Dengue cases forecast in Romania between 2023 and 2025

A comparison with West Nile virus shows that the optimal threshold of 23.7°C required for West Nile virus is increased by another 3°C required for Dengue virus. This explains why Dengue fever is specific to tropical areas, but also raises the alarm about its presence in an area characterised by a temperate continental climate such as Romania. In the case of this virus, only temperatures above 27°C are conducive to its development. This is marked only by the red colour, signalling the strict conditions of a high temperature (*figure 6*).

The length of the development cycle	
Temperature	Dengue fever
-10.00	-
20.00	-
25.00	-
27.00	possibility of transmission
37.00	possibility of transmission

Figure 6 **Duration of the Dengue virus development cycle**

After the 2018-2022 interval, a further period of increase in the maximum limit is expected, visible in the years 2023, 2024 and 2025 with the addition of September (*table 5*).

Comparing with 2014, over an 11-year time horizon there has been an increase in the upper limit series, which means that there is an increase in temperature and thus more favourable conditions for the spread of Dengue virus in the summer months, extending into September (*table 6*).

Table 5

Dengue virus development period range for the year 2023

An	Forecast data: Average monthly temp	Forecast data: The upper limit of the average monthly temperature	Forecast data: Maximum temperature of the month (average)	Dengue: The upper limit of the average temperature	Dengue: Maximum monthly temperature	Dengue: Average monthly temp
01/01/23	-1.12	4.84	11.68	-	-	-
02/01/23	-0.18	5.80	13.62	-	-	-
03/01/23	5.19	11.18	21.14	-	-	-
04/01/23	12.08	18.10	26.84	-	-	-
05/01/23	17.38	23.41	30.37	-	possibility of transmission	-
06/01/23	21.09	27.14	33.99	possibility of transmission	possibility of transmission	-
07/01/23	23.18	29.25	35.74	possibility of transmission	possibility of transmission	-
08/01/23	22.65	28.73	36.00	possibility of transmission	possibility of transmission	-
09/01/23	17.05	23.15	30.33	-	possibility of transmission	-
10/01/23	11.06	17.18	28.15	-	-	-
11/01/23	6.86	12.79	20.39	-	-	-
12/01/23	0.51	6.66	13.57	-	-	-

Table 6

Dengue virus development period range for the year 2025

Year	Forecast data: Average monthly temp	Forecast data: Upper limit of monthly average temp	Forecast data: Maximum temperature of the month (average)	Dengue: The upper limit of the average temperature	Dengue: Maximum monthly temperature	Dengue: Average monthly temp
01/01/25	-1.08	5.64	11.76	-	-	-
02/01/25	-0.14	6.60	13.69	-	-	-
03/01/25	5.23	11.99	21.21	-	-	-
04/01/25	12.13	18.91	26.92	-	-	-
05/01/25	17.42	24.22	30.44	-	Possibility of transmission	-
06/01/25	21.14	27.96	34.06	Possibility of transmission	Possibility of transmission	-
07/01/25	23.24	30.08	35.81	Possibility of transmission	Possibility of transmission	-
08/01/25	22.70	29.57	36.08	Possibility of transmission	Possibility of transmission	-
09/01/25	17.10	23.98	30.40	-	Possibility of transmission	-
10/01/25	11.11	18.02	26.22	-	-	-
11/01/25	6.70	13.64	20.47	-	-	-
12/01/25	0.65	7.51	13.64	-	-	-

CONCLUSIONS

Projections made up to 2050 show a temperature increase by 0.78 ºC, which can influence up to 100% the increase in mosquito populations and also prolong vector-borne disease transmission periods. The forecast for 2025 shows an extension of the transmission period of *Plasmodium vivax* and *Plasmodium falciparum* species until November when a single complete cycle of the protozoan may develop during the lifetime of the *Anopheles* vector.

For West Nile virus the forecast shows an extension of the transmission period up to and including October, with the risk of the virus surviving inside the mosquito over winter, with the transmission cycle continuing into spring from March.

As regards the risk of emergence of Dengue fever in Romania, the data show that in the summer months of June-August, extending into the first part of September, the extrinsic development of the virus is possible, with the risk of epidemics in the context of imported cases. Thus, we conclude the need to introduce monitoring and control programmes for vectors and vector-borne diseases in Romania, in the context of global warming.

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