

## **A GEOSPATIAL ANALYSIS OF THE RELATIONSHIP BETWEEN ENVIRONMENTAL DRIVERS AND VECTOR-BORNE DISEASES**

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**ABSTRACT.** – **A Geospatial Analysis of the Relationship between Environmental Drivers and Vector-Borne Diseases.** Human health is profoundly affected by weather and climate. Environmental health is becoming a major preoccupation on a world-wide scale; there is a close correlation between a population's state of health and the quality of its environment, considering many infectious diseases are at least partly dependent on environmental factors. When we talk about the environment, we realize that it includes and affects fields of action from our daily life.

Earth observation from space, with validation from in situ observations, provide a greater understanding of the environment and enable us to monitor and predict key environmental phenomena and events that can affect our livelihoods and health. Even though, the use of Earth observation is growing in usefulness for a wide variety of uses, it is extremely unlikely that Earth Observation will be able to detect infectious diseases directly. Instead, Earth observation can be used to detect high NDVI index (and possibly attribute the high surface chlorophyll concentration to a particular disease), and help predict the movement of the agents carrying vector-borne disease. Many diseases need certain temperature and moisture conditions to breed.

The primary objective of analyzing environmental health risk and vulnerabilities is to support the Development Regions to strengthen their capacity to assess, visualize and analyze health risks and incorporate the results of this analysis in a health risk map for disaster risk reduction, emergency preparedness and response plans. At the same time, such an analysis applied in health, allows starting the collection and homogenization of baseline data, information and maps to help health authorities and decision makers to take informed decisions in times of crises.

Informational Health Platform would be used for the integration of data coming from different sources in order to assess, analyze and map vulnerabilities and risks, contributing to the continuity of the decision process during the different phases of the emergency cycle. Decision support tools are based on creating health vulnerability platforms, which can be used first of all to evaluate the environmental conditions and to predict the possible risk of a disease infection in a given location, including variables as population densities, socio-economic issues, health indicators, accessibility to health care, land cover type, soil moisture and surface temperature.

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The fundamental purpose of this work is to reveal the necessity of establishing a quality framework for arguing on the connection between the environment and vector-borne disease transmission, supposing that on any kind of forecasting it is established the extent to which the past is likely to be an accurate guide for the future.

**Keywords:** *NDVI, vegetation, soil moisture, temperature, LANDSAT TM, vector*

## 1. INTRODUCTION

It must be agreed that health monitoring is a promising activity and research when thinking about the population wellbeing.

The focus of public health assessment and monitoring is to improve health and quality of life through the prevention and treatment of disease and other physical and mental health conditions, through surveillance of cases and the promotion of healthy behaviors. Health is an important investment and driver for development, with decreased risk of disease, illness, and injury; better immune functioning; speedier recovery; and increased longevity.

Since the time of Hippocrates (470 – 360 BC), physicians have noticed that some diseases occur at some places while not in others, and disseminate from one geographical region to another. A major milestone towards the use of spatial data in epidemiology was created in 1854 by John Snow, who mapped the occurrence of cholera and public water sources, and established a relationship between them (Dhama, K. *et al.*, 2013).

The World Health Organization (WHO) is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries, monitoring and assessing health trends. The World Health Organization defines environment as it relates to health, as “all the physical, chemical, and biological factors external to a person, and all the related behaviours” (WHO, 2011).

The present study is designed for mapping the spatial distribution of West Nile fever, Tick-Borne Encephalitis and Lyme disease in Romania together with their environmental development conditions. The information appropriate for the vector-borne disease and vector abundance associated with geo-climate determinant variables contribute to mapping the line of disease transmission risk (Palaniyandi *et al.*, 2014).

A vector-borne disease (VBD) is one in which the microorganism which causes the disease is transmitted from an infected individual to another individual by a mosquito, tick or some other agent. Other animals, wild and domesticated, sometimes serve as go-between hosts. The whole issue is transposed into the figure 1 epidemiology triangle, considering that any epidemiology event is caused by interaction of the host, meaning who get the disease, an infectious agent, meaning what causes the disease, and the environment factor, meaning where the disease occurs. The vector is the “tool” for communicating the disease.

Land use/land cover dynamics, urban sprawl, irregular growth of urban development, deforestation, vegetation green up and permanent water are proper for developing a suitable environment of vector borne disease in Romania.

WHO reported that, since 1975, over thirty “new” or “emergent” human infections have appeared (WHO, 2004). Most new infections seem to be caused by pathogens already present in the environment, which have been brought out of obscurity, by changing ecological and social conditions. Infectious diseases have always been an important part of human life. They have significantly influenced human biology and society, even determining the course of major historical events.

Remote sensing is a valuable tool in disease surveillance, especially in vector-borne disease. Earth observation data can help epidemiologists to derive risk areas, vector distributions and relationships between diseases and environmental variables.

Many studies suggest that remote sensing imagery is a viable predictor of vector-borne diseases transmission. For example, some studies indicated that higher malaria incidence rates were associated with broadleaf hill forests, agricultural land, wetland and vegetation types and the lower rates were related to coastal swamps, tall herbs, wetland communities, urban development and water bodies (Hakre, 2004). Considering the nowadays striking situation of Ebola virus, satellite data help identify areas prone to the emergence and spreading of such epidemic by monitoring potential areas where initial contact with the virus might take place. Such areas are isolated rural settlements surrounded by dense tropical forests and oil palm cultivations. These are likely to attract fruit bats, one of the main vectors of the virus.

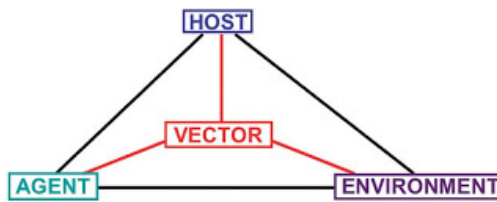
Living in the Copernicus era, from malaria to ebola, infectious diseases might not be able to play tricks for long. Copernicus satellites are increasingly used to provide accurate and timely information in the form of land cover reference maps that can be combined with census data.

Bringing into play the parameters extracted from satellite data, many researchers (Nelson, 2000; Wilson, 2001; Cowell, 1998; Sutherst) considered vegetation indices as the most consistent predictor of mosquito – borne disease transmission, being widely used in epidemiological studies. Among the various remote sensing based values, vegetation measures is utilized also in many epidemiological studies, applying the normalized difference vegetation index (NDVI) imagery, which is the most widely used for vegetation cover and production.

Some emerging and vectorborne disease are present in Europe and of importance to the EU, several thousand cases of tickborne encephalitis being reported here each year. The burden of Lyme disease in Europe is unknown, while cases of West Nile fever in humans were detected in the last decade in Italy, Romania and Hungary between 2008 and 2009.

European Centre for Disease Prevention and Control' mission is to strengthen Europe's defence against infectious diseases. The emerging and vectorborne disease (EVD) programme being part of ECDC Strategies for Disease Specific Programmes 2010 – 2013 is working towards the development of a wide range of timely and topical assessments of the risks that emerging and vectorborne diseases pose to EU citizens, contributing to strengthening EU-wide preparedness and response by providing Member

States with access to expertise, the latest scientific knowledge (ECDC, 2010). EVD programme impose a multidisciplinary approach involving environmental, entomological, behavioural studies, creating a connection between veterinarians, physicians and a wide range of laboratory expertise and academic research. According to this, the present paper research will focus on the usefulness and importance of using earth observation data in epidemiological research, considering imagery an essential source of rich information for enabling people to understand the world.



**Figure 1.** Infectious disease transmission chain

## **2. RESEARCH OBJECTIVES WITHIN THE STUDY AREA**

The study aims at identifying the mutuality between vector-borne disease transmission and the environment using satellite data, fulfilling the following objectives:

- to mapping the spatial distribution of vector borne disease in Romania;
- to assess the climate, landscape and the environmental aspects of vector borne disease transmission;
- to establish a susceptibility index scale of the localities, where the population is prone to vector-borne disease outbreak considering that every small-proportion event in the past, without significant health impact on population, is likely to be an accurate guide for the future.

It is intended to explore the influence of a changing world, focusing on the impact of the environment on vector-borne diseases, considering climate a major environmental driver influencing vector-borne disease epidemiology.

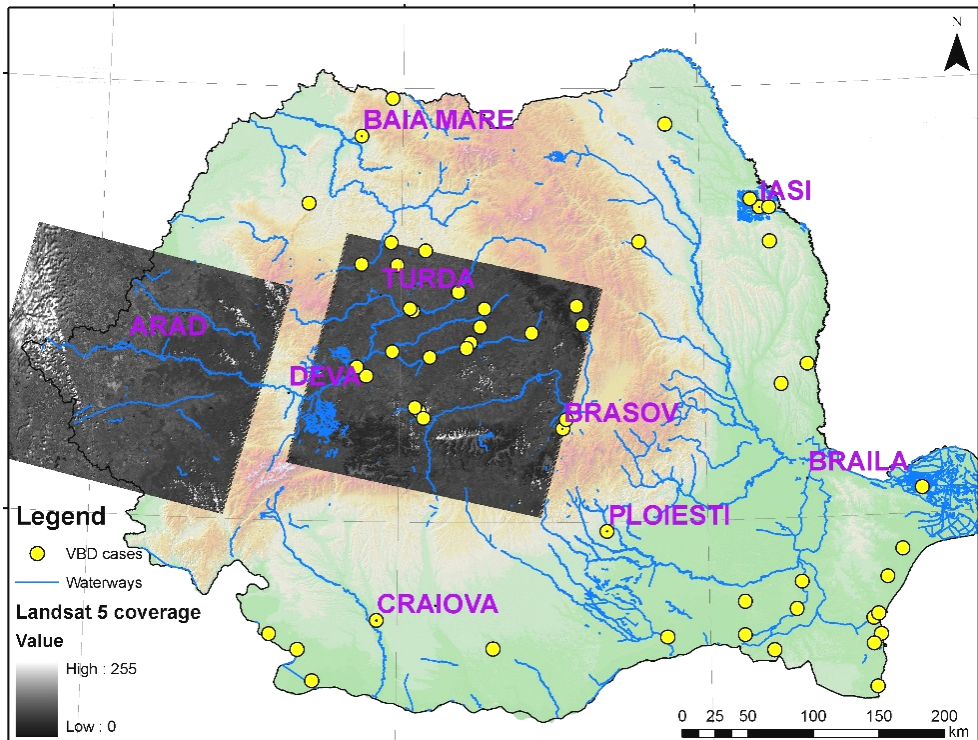
Climate, temperature, precipitation, humidity, wind can influence various aspects of an arthropod vector's life cycle, including survival, arthropod population numbers, vector pathogens interactions and vector distributions (Tabachnick, 2009).

There have been chosen two large areas in Romania, represented by the region of the Carpathian arch, geographically situated on 46<sup>o</sup> latitude North and 24<sup>o</sup> longitude East, and Western part of Romania, lying on 46<sup>o</sup> latitude North and 22<sup>o</sup> longitude East (fig. 2).

Romania has a climate which ranges from temperate to continental, the climatic conditions being modified by the country's varied topography, which inside the Carpathian arch proves milder winters and heavier rainfalls as a result of the Carpathian Mountains, which serve as a barrier to Atlantic air masses.

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The second region of the study corresponding to the Western Plain of Romania, also known as the Banato-Crisana Plain has a warm temperate continental climate with moderate humidity during the year, without excessive dry season and relatively moderate summers.



**Figure 2.** The study area represented by Landsat 5 scenes, July 2009

### 3. DATA ACQUISITION AND PROCESSING

Two Landsat - 5 TM images were acquired for July 2009 for path 184, row 28. The dates were chosen to reveal moisture, vegetation and temperature characteristics of the earth surface during summer. Data used in this research were downloaded from the relevant website of United State Geological Survey (USGS). Downloaded satellite data quality was highly acceptable. The first image from 7 of July 2009 overlap to the Carpathian arch, selected because of the inventory of several cases of vector-borne diseases come up in this region. The other image was acquired for one week later, in the Western part of Romania, which registered no cases of the indicated public health diseases, in order to provide the contrast with the other selected region in terms of EO data environmental indicators.

Of the seven bands available on the Thematic Mapper (TM) sensor, channels 1,3,4, and 6 were selected for each image. Bands 2, 5 and 7 did not significantly contribute to the analysis of extracting and analysing the indicators of interest and so were omitted. Therefore, the other bands were used for assessing the Normalized Difference Vegetation Index, a measure of the amount and vigour of vegetation at the surface. The index is defined by equation 1.

$$NDVI = \frac{\text{band4} - \text{band3}}{\text{band4} + \text{band3}} \quad (1)$$

The result of the NDVI calculation is given as a number that ranges from -1 to 1; no vegetation gives a value close to 0, while values close to 1 indicates the highest possible density of healthy vegetation. The premise behind NDVI is explained by the low reflectance in the visible red wavelength in the electromagnetic spectrum, representing healthy vegetation because photosynthetic pigments in plant absorb such light and reflect it strongly in the near-infrared wavelength (Patz, J. A., *et al.*, 1998). Generally, at 0.2 and lower the pixel is considered as bare soil and the emissivity is obtained from reflectivity values in the red region, while pixels with NDVI values higher than 0.5 are considered as fully vegetated, covered by forest, greenery or other vegetation.

Another remotely sensed factor is land surface temperature, an estimate of actual ground temperature, precisely, can be defined as the temperature of the interface between the Earth's surface and its closest atmosphere and thus it is a critical variable to understand land-atmosphere interactions, which involves energy fluxes (Valiente *et al.*, 2010). Estimation of land surface temperature can be completed by various formulas, but anyway in the first phase it should be calculated the emissivity, without considering it, estimation will be inaccurate for land surface temperature because emissivity represents surface variation.

The process of estimating land surface temperature consist of three steps, beginning by converting Digital Number (DN) values to radiance and estimating radiant temperature, following the equation 2.

$$L_{\lambda} = (LMAX - LMIN) / (QCALMAX - QCALMIN) \times (QCAL - QCALMIN + LMIN) \quad (2)$$

where,

QCAL = quantized calibrated pixel value in DN

LMIN = the spectral radiance scaled to QCALMIN in watt / (meter squared x ster x  $\mu\text{m}$ )  
(1.238 for Landsat 5 TM)

LMAX = the spectral radiance scaled to QCALMAX in watt / (meter squared x ster x  $\mu\text{m}$ )  
(15.303 for Landsat 5 TM)

QCALMIN = the minimum quantized calibrated pixel value in DN = 1

QCALMAX = the maximum quantized calibrated pixel value in DN = 255.

The output of the above equation was converted into B6 – Surface Temperature (Kelvin).

$$T(\text{Kelvin}) = K2 / \ln ((K1 * E) / B6\text{Rad} + 1) \quad (3)$$

where,

T (Kelvin) = kinetic surface temperature in degree Kelvin, while K2 and K1 are constants

K1 = 607.76; K2 = 1260.56

E = thermal emissivity (typically 0.95)

B6Rad = radiance band

The third step consists in converting Kelvin degrees in Celsius by applying the following deduction:  $B6 - 273.15 \text{ K}; 1^\circ\text{C} = 273.15 \text{ K}$ .

The last remotely sensed factor considered in this research is soil moisture that can predict possible suitable habitats for mosquito eggs and larvae. Different types of remote sensing sensors are used to detect soil moisture, for example Landsat TM, Spot, NOAA-AVHRR, ENVISAT-1 ASAR, and RADARSAT.

Surface soil represents the amount of water in the top layer of the soil surface, determined as an important bridge between the land surface and the atmosphere with several impacts in weather and land cover/land use patterns. Estimates of soil moisture using satellite data have been conducted using various methods (Tucker, 1980; Crist and Cicone, 1984; Levit *et al.*, 1990; Seguin *et al.*, 1991; Nemani *et al.*, 1993; etc.) and can lead to significant cost savings in environmental management. The relationship between surface temperature ( $T_s$ ) and vegetation cover (NDVI) has been widely used for soil moisture estimates (Nemani *et al.*, 1993; Gillies and Carlson, 1995), this interdependence relationship, being used and described to estimate soil moisture in this study.

$$\text{SMI} = \frac{T_{s \max} - T_s}{T_{s \max} - T_{s \min}} \quad (4)$$

where,

$T_{s \max}$ ,  $T_{s \min}$  are the maximum and minimum surface temperature for a given NDVI;

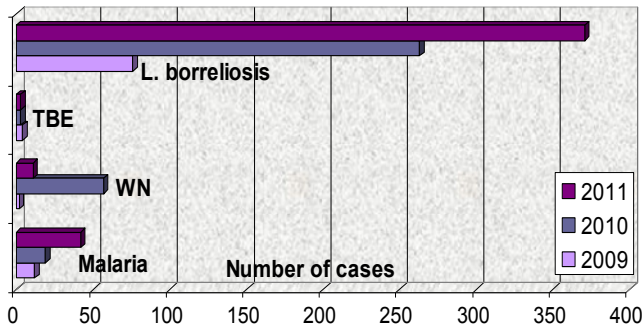
$T_s$  is the remotely sensed data derived surface temperature at a given pixel for a given NDVI.

#### 4. DISCUSSIONS

The most important vector-borne diseases in Romania are infections transmitted by the bite of infected arthropod species, in particular, mosquitoes and ticks. Arthropod vectors are cold-blooded and thus especially sensitive to climatic factors. To that effect, climate is one of many important interacting variables that affect people's risk for vector-borne diseases, having a direct effect on physical conditions (temperature, rainfall, etc.) and an indirect effect on biologic conditions (plants, animals). Most arthropod vectors of disease are sensitive to physical conditions, such as levels of humidity, daily high and low temperatures, rainfall patterns, severity and snowpack of winter.

Romania is a country which has not registered extreme cases or situations with regard to vector-borne diseases. During the period of time studied, in Romania were registered cases of tick-borne encephalitis, Lyme diseases and West Nile, most of them tracked down on population from the localities situated in Transylvania region (inside the Carpathian arch), along the course of the Danube, and in north-western Romania.

As observed in figure 3, Lyme borreliosis disease is the most spread in Romania, having most of vector-borne disease cases, which has increased starting with 2009 (Vlad-Şandru, 2014).



**Figure 3.** Distribution of vector-borne diseases 2009-2011 in Romania  
Data source: National Center for Infectious Diseases Surveing and Control in Bucharest

It is well known that mosquito abundance is associated with the climate variables, mainly the amount of rainfall and thus the number of larval breeding sites, the spatial relationship between larval habitat availability and adult mosquito abundance (Palaniyandi M., 2014).

*Ixodes ricinus*, the tick that cause Lyme borreliosis, requires a relative humidity of at least 80% to survive during its off-host periods, being restricted to areas of moderate rainfall with vegetation that retains a high humidity. Rising temperature can accelerate the tick's life cycle and also these can adapt to sub-zero temperatures, a tick snow cover may facilitate tick survival over winter by preventing repeat freeze. Typically, habitats include deciduous and coniferous woodland, headland, moorland, rough pasture, forests and urban parks.

Tick-borne encephalitis (TBE), human viral infectious disease involve the central nervous system, caused by tick-borne encephalitis virus, a member of the family Flaviridae, occurring during the highest period of tick activity, between April and November.

This research study tries to assess the possible impact of a selected number of environmental indicators on the disordered distribution of vector-borne diseases. It can't be observed significant different characteristics (tab. 1) of the Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST) and Soil Moisture (SMI), even if the two areas of interest present quite uncommon geographical attributes.

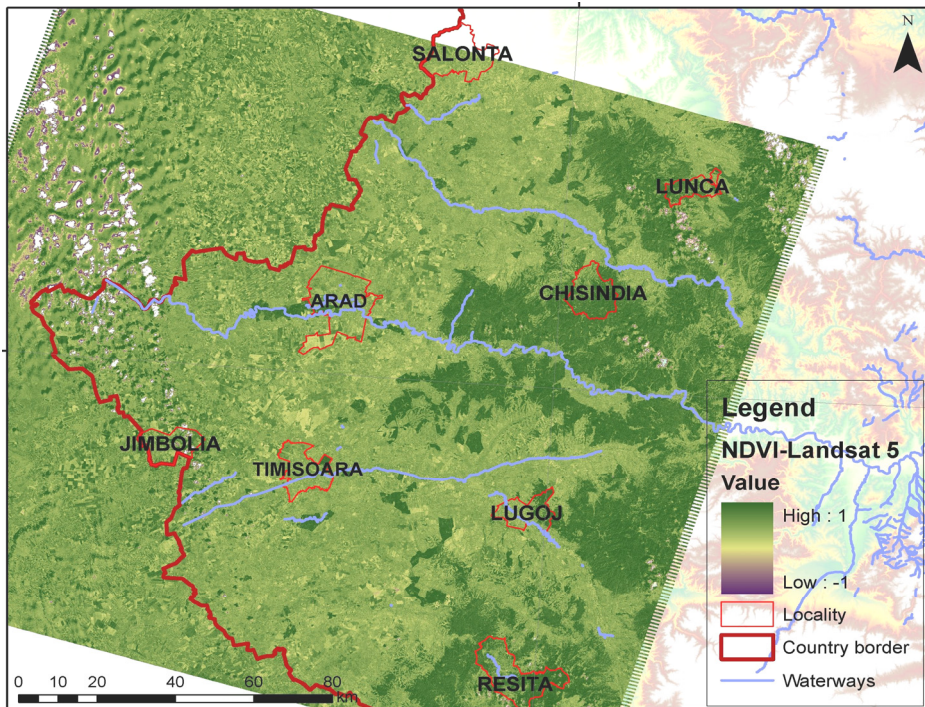
The vegetation in the two areas of study lay on differences regarding the structure of the vegetation steps. Within the Carpathian Arch the average of the NDVI Index reach the value of 0.37 generated by the submontane (foothills) belt chlorophyll of oak-hornbeam and mixed oak-pine forests which ranges from 400 to 650m. The Normalised Difference Vegetation index, which is the measure of photosyntetic activity of vegetation, is the most common index of vegetation growth. An important issue on NDVI condition is that a low reflectance in the visible red wavelength is the electromagnetic spectrum representing healthy vegetation because photosynthetic pygmments in plant tissue absorb light and reflect it strongly in the near-infrared wavelength, constituting a phenomenon commonly found in vegetation. Having a value very close to 0.4, without in-situ evidence, it is thought that the area is almost entirely covered by forest and other vegetation (Nihei, N., 2002).



**Table 1.**

**Average values of NDVI, LST and SMI for Landsat 5 image, July 2009**

July 2009			
AOI in Romania	Min	Max	Average
NDVI Index			
Carpathian arch	-1	1	0.37
West	-1	1	0.24
Land Surface Temperature (°Celsius)			
Carpathian arch	7.71	43.95	25.83
West	3.06	48.40	25.73
Soil Moisture			
Carpathian arch	0	1	0.47
West	0	1	0.46



**Figure 4.** NDVI Index for the Western region

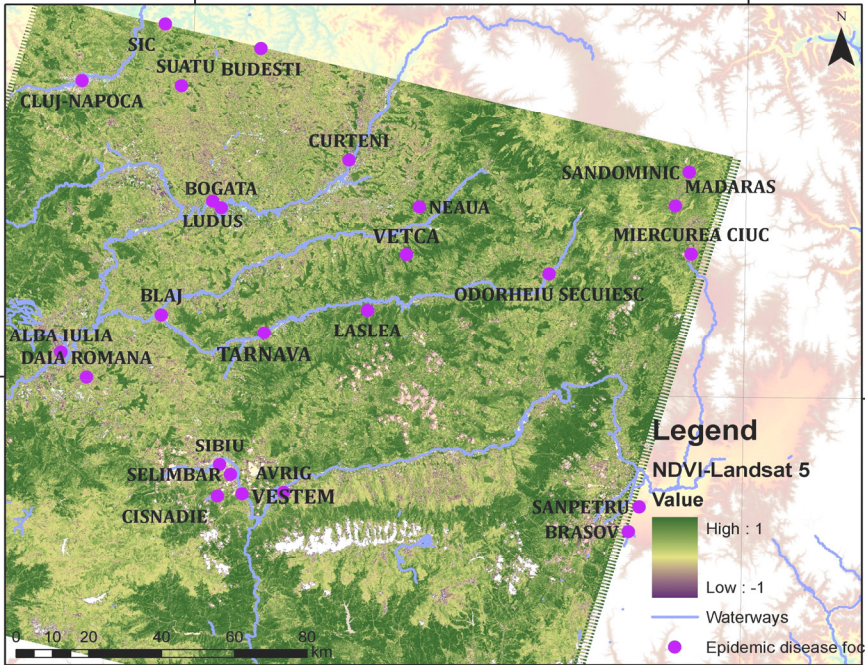


Figure 5. NDVI Index for Carpathian arch region

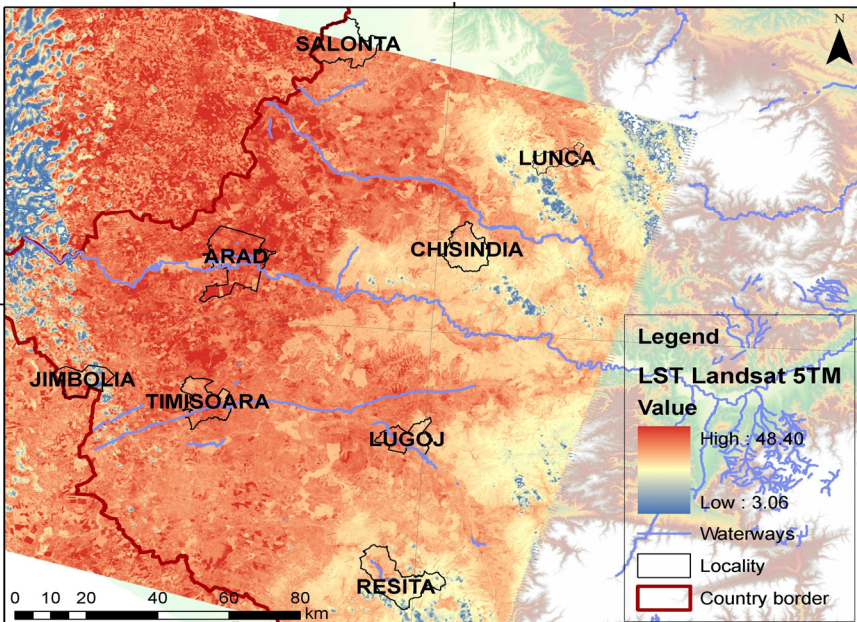


Figure 6. LST Index for the Western region



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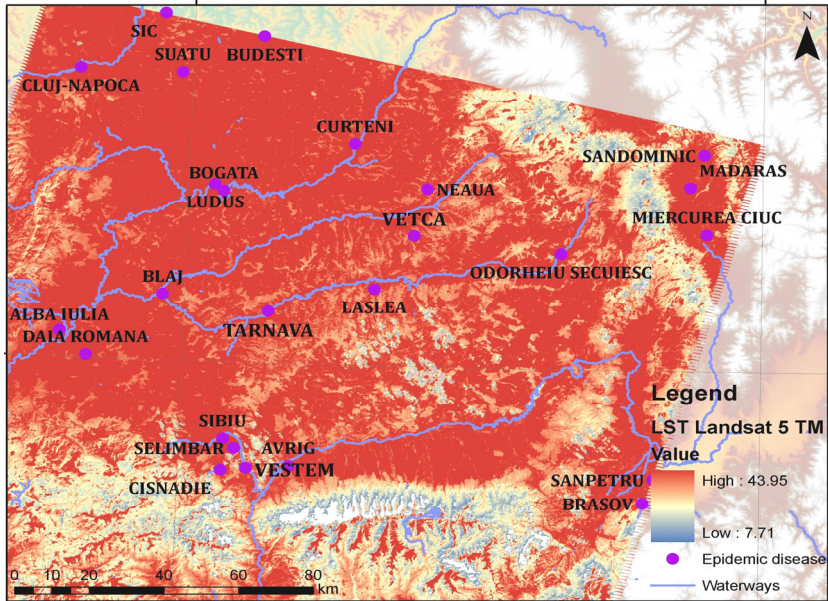


Figure 7. LST Index for the Carpathian arch region

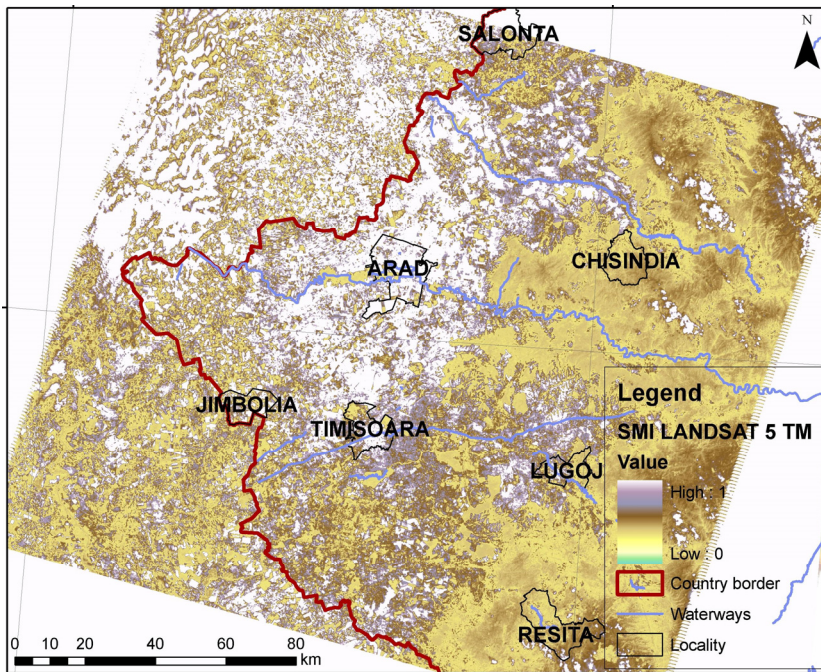
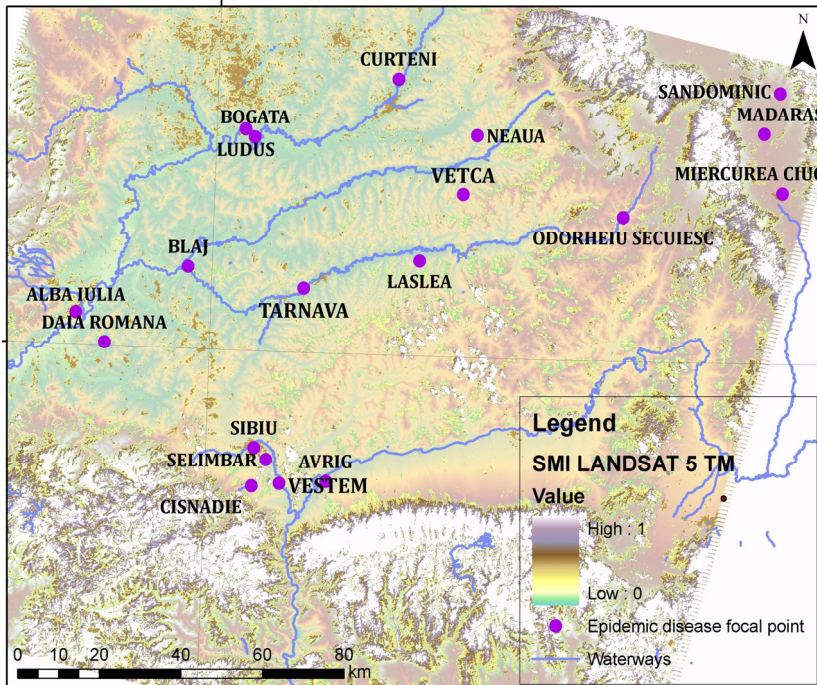


Figure 8. Soil Moisture Index for the Western region



**Figure 9.** Soil Moisture Index for the Carpathian arch region

The second area of interest, the Western part of Romania, where no cases of vector-borne diseases were registered in 2009, geographically is divided between Western Plain and Carpathians with an average NDVI Index of 0.24, due to the reflectance of plain and steppe vegetation with a patches area of mesophilic-oak forest with submediterranean climatic influences. Applying NDVI Thresholds method which obtains the chlorophyll emissivity values from the NDVI, considering the values within  $0.2 \leq NDVI \leq 0.5$ , it indicates the habitation of shrub, grassland and possibly bare soil on an 0.66% average.

By analyzing LST variable counted on Celsius degrees for the two area of study, it can be remarked quite the same average temperatures, around 25 °C. The areas with high levels of LST (in red) can be correlated to urban areas, while the blue to white areas equate to either a vegetated or a water body. The LST map shows that the temperature ranges from 43.9°C to 7.7 °C within the Carpathian arch region and to 48.4 °C to 3.06 °C in the West part of Romania.

Soil Moisture is used to estimate the surfaces particularly relevant to mosquito borne disease but also to the breeding success of other vectors and tick species, the SMI map showing the variation of the values between 0 and 1. The areas with high levels of SMI are related to the white extents on the map associated to the high mountain peaks in

the Carpathians. The selected areas of study has approximately the same humidity average of 0.47, the epidemiological cases laying on areas with low soil moisture, but in close proximity to a water course.

The induced concept of Informational Health Platform generated within this research lie in presenting a detailed image of the vector-borne disease cases occurred in Romania and their relation with the environment, including variables as population densities, number of vector-borne disease cases, accessibility to health care and environmental parameters (NDVI, SMI, LST). By using, quantitative-comparative method is underlined the level of susceptibility in case of a vector-borne disease outbreak. Therefore, by using the Sustainability Dashboard analysis application, an analytical method, it is set up a susceptibility index, consisted of subindices areas, appropriate for inclusion in the Informational Health Platform. The subindices mentioned above were figured out by aggregating a number of points, when applying the formula:  $P = 1000 * (x - \min) / (\max - \min)$ , where, P=points awarded, x=analyzed unit value; min=the value considered the worst ; max=the value considered to be the best.

For approaching vector-borne disease developing circumstances, they are pointed values that contributes to the aggregation of the susceptibility index, which consist in the best result (pursuant to this particular analysis): for example the minimum value of soil moisture index reflects the best result. Each analyzed unit indicator is automatically ordered on the range 0 – 1000, 0 points are going to the indicator with the lowest value (respectively, the highest value of soil moisture), while the maximum is going to the indicator with the highest value (respectively, the lowest unemployment rate).

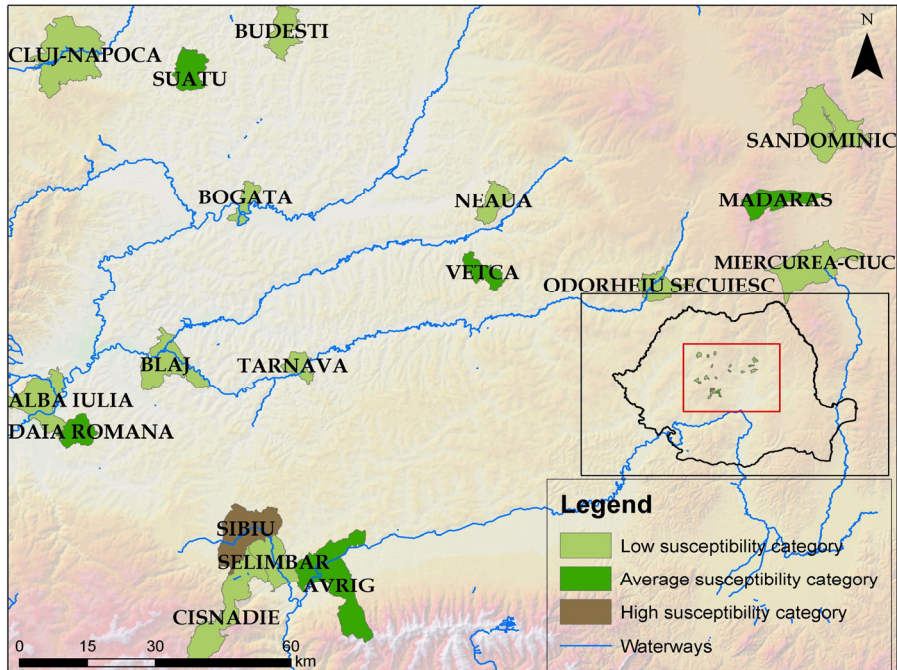
Among the localities, where the population was affected by vector-borne diseases, Cluj-Napoca registered the lowest susceptibility rank, ruled by a critical LST Index of 26,6° Celsius and a good susceptibility rank concerning SMI Index of 0,152, beside an insignificant distance to the nearest hospital. On the other part, represented by the lowest number of points and the highest susceptibility rank, Sibiu is described by 88 cases of Lyme disease and a high LST Index.

As shown in figure 10, the average susceptibility category of localities prone to vector-borne disease outbreak includes examples which reflect high values of LST and more important, they are prevailed of difficult access to a health care departments or to a hospital, for instance having the population from Suatu locality, which reach the nearest hospital, on 36,3 km distance.

## 5. CONCLUSIONS

Earth Observation data issued from satellite images offers interesting perspectives for health-environment studies. Therefore, the purpose of this research was to demonstrate why several types of vector-borne disease occurred in a certain environmental area, while in another haven't been registered any cases. By analysing, three relevant EO parameters (LST, NDVI, SMI), connected to the vector habitat development, respectively within the Carpathian Arch region, it was obtained quite similar values as in Romanian Western part, where any cases of vector-borne disease were't registered, except NDV Index which inside the Carpathian arch met a higher value.





**Figure 10.** Susceptibility index categories distribution

Focusing on the vector-borne disease particular areas, it was accomplished a susceptibility index for analyzing the level of predisposition in each locality, on the chance of a vector-borne disease outbreak in the future. By aggregating the susceptibility index component indicators, Cluj-Napoca showed the lowest susceptibility, while Sibiu indicates the highest susceptibility.

Therefore, remote sensing environmental parameters can contribute to epidemiological decision support tools, by adding a spatial component in providing analysis and description of the geographic variations of the disease, which allows a more substantial health risk assessment for predicting future outbreaks. It is well-known that EO data have been available for over a decade by now, though spatial epidemiological observation field hasn't make use of a complete exploitation yet, epidemiological monitoring describing a promising research gate when thinking about preventing communicable diseases.

### Abbreviations

VBD, vector-borne disease; WHO, World Health Organization; EVD, Emerging and Vector-Borne Disease; ECDC, European Centre for Disease Prevention and Control, USGS, United States Geological Survey, TM, Thematic Mapper, NDVI, Normalized Difference Vegetation Index, SMI, Soil Moisture Index, LST, Land Surface Temperature, TBE, Tick-borne encephalitis; EO, Earth Observation.

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