PROMOTING SPATIAL DATA SYNTHESIS FOR VECTOR-BORNE DISEASE ASSESSMENT IN ROMANIA

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ABSTRACT – Given the continually human interaction with the environment, the present paper reveals the spatial data integration of environmental factors such as topography, vegetation and surface temperature with epidemiological statistical data for assessing vector-borne diseases in Romania, monitored between 2009 and 2011. This study is a small piece of a big puzzle, part of an extended research that evaluates the contribution of geospatial and ground observation data to public health assessment. It is intended to implement a useful and innovative system for Romania's public health, which provides information on various aspects such as the prevalence of diseases, facilities that are available in order to take decisions on, either for creating infrastructure facilities or for taking immediate actions to handle situations.

Keywords: spatial data, vector-borne disease, NDVI, LST, WestNile, Tick-borne encephalitis, Lyme borreliosis, population

INTRODUCTION
Spatial data support
Nowadays, geographical or spatial data is getting more interest and is considered to be very important as being applied at multidisciplinary level, playing a vital role in many parts of daily life (Waller L., Gotway C., 2004). Spatial analysis of data is a collection of techniques and models that use the spatial referencing associated with each data value or object that is specified within the system under study (Haining R., 2003).

The location where an event happens may provide some indication as to why that particular event occurs. Spatial information use location information to detect and quantify patterns in public health data to investigate the degree of association between potential risk factors and disease.

Geographic Information Systems (GIS) are, in the broadest sense, manual or computer based sets of procedures that permit a user to input, store, retrieve, manipulate, analyze and output spatial data (Aronoff S., 1989). GIS's advantages are that they permit large amounts of data to be maintained and retrieved at greater speeds, and at a lower per unit cost than manual systems. They also provide the means of manipulating spatial data and the corresponding attribute information, and integrating these different types of data in a single analysis.

Nykiforuk C. (2011) promotes the sharing of ideas through maps, which enables communication about the characteristics of people and places over time, so that strengthening issues of setting on the policy maker's agenda and in the priorities of researchers and practitioners. 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. Earth observation data can be incorporated into models to help detect, monitor or predict disease, providing policy makers with the opportunity to control an epidemic, respond more quickly to disease outbreaks, and act to prevent or mitigate the occurrence of disease. The areas in which Earth observations can most readily benefit public health are air quality, water quantity and quality, infectious disease, waterborne and insect disease vectors, and temperature.

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Satellite imagery provides a method for obtaining up-to-date information throughout the globe and can be used to evaluate a variety of conditions such as land use patterns, crop conditions, rainfall patterns and insect outbreaks. Remotely sensed data come primarily from three types of sensors: LANDSAT, supported by NASA, EROS and EOSAT; NOAA, supported by the U.S. National Oceanic and Atmospheric Administration; and SPOT, supported by the French National Space Agency (Glass G. et al., 1993).

GIS and Remote Sensing have been used in public health management field in order to help health authorities in surveillance and mitigation actions. The use of remotely sensed data in epidemiological studies is becoming very useful as it provides information on the environment, through monitoring, surveillance and risk mapping, particularly of vector-borne diseases. Using remote sensing imagery, the information on sea and land surfaces can be identified at different spatial scales (Machault V. et al., 2011), as for surface and air temperature, precipitation, elevation, land use and land cover, surface water and soil moisture, atmospheric humidity, vegetation, wind velocity.

State of the art

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).

GIS has been used in public health care arena, for example, to assist in epidemiology (Castillo-Salgado, 1996; Moore & Carpenter, 1999; Richards & Croner, 1999), to enhance community-based child welfare services (Robertson & Wier, 1998), and for community program evaluation of changes in alcohol outlet distribution (Millar & Gruenewald, 1997). GIS has been used in the surveillance and monitoring of vector-borne and water-borne diseases, quantifying lead hazards in a neighbourhood, predicting child pedestrian injuries, and analyzing disease policy and planning (Clarke K.C. et al., 1996). Therewith, GIS techniques were utilized to analyze the spatial distribution and relationships based on health service locations and populations for analyse the access to health facilities in Uganda aiming to demonstrate how geospatial tools and information can aid planning, decision-making and delivery of health service (Lwasa S., 2008).

Health mapping has evolved from Dr. John Snow's cholera death mapping in mid-nineteenth century to the latest internet-based mapping where data have been shared across the internet (Johnson C.P et al., 2001).

The first use of a remotely sensed image (an aerial photograph) to study the potential breeding sites of a mosquito was done in 1971 by NASA, and by the end of the 1970s satellite images were being applied for similar studies (Hay, Snow and Rogers, 1998). After this initially study, the literature shows a varied uses of remotely sensed data for public health assessments, using aerial photographs, satellite images, and radar images. To this end, it seems interesting and appropriate to mention the development of a dengue risk map for Malaysia, using environmental parameters that were obtained from remote sensing data to identify the high risk areas of the dengue outbreak, showing a very promising potential for health agencies and local authorities to determine and plan the requirements of performing dengue surveillance activities as well as required mitigation programs in the hotspot areas (Umor S., 2007).

Vector-borne infections (VBI) were first described in 1877 when lymphatic filariasis was found to be transmitted by mosquitoes from human to human. For the past 128 years several VBI have been described involving a wide variety of infectious pathogens, together with a wide range of arthropods. It is assumed (Pherez F., 2007) that vector-borne diseases must be influenced by climatic and seasonal changes in the same way as vectors are.

Vectors and insects (mosquitoes, ticks, fleas, black flies, and sandflies) carry and transmit diseases to humans: parasitic vector-borne such as malaria, arboviral diseases such as dengue fever, yellow fever, West Nile Virus, Rift Valley fever and tick-borne encephalitis, bacterial diseases such as Lyme borreliosis, tularemia, and plague.

Vector-borne diseases in Romania

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. Although the relationship between vector-borne diseases and climate is strongly related, the disease is also a cause and effect of poverty, and therefore constitutes a major burden on the economic and social dimensions of development (Patz J. et al, 2011).

The global warming has implications in vector-borne disease transmission. Higher temperatures trigger an increase in global average rainfall, which promote transmission of vector-borne pathologies by creating ground pools and other breeding sites for insects. Drought may cause flowing water to stagnate and stimulate people to store water in cisterns that also serve as breeding sites for mosquitoes (Schvoerer E. et al., 2008).

Malaria is an infectious disease caused by parasites of the genus Plasmodium, transmitted to humans by the bites of infected female mosquitoes of the genus Anopheles. The clinical symptoms of persons with malaria include fever, shivering, pain in the joints and headache.

Malaria cases registered in Romania are all imported, mainly due to travel increases in malaria endemic areas and due to the fact that the preventive measures are not brought into use or are being ignored by travellers. Malaria deaths are mainly caused by retraction of possible clinical signs and insufficient investigation of the patient. In this sense, between 2007 and 2011, 110 cases of malaria were registered in Romania (Figure 1), the highest tide being registered in 2011, mostly imported from Africa and Equatorial Guinea due to work trips, tourism, study travels, and immigrations.

In order to prevent deaths and for decreasing the number of illnesses, it is necessary to increase the actions of the national surveying system, with the cooperation and involvement of the prevention services.

West Nile meningitis is caused by the West Nile virus, of the family Flaviviridae that is part of the Japanese encephalitis antigenic group. West Nile fever mainly infects birds and infrequently human beings through the bite of an infected Culex spp mosquito (Semenza J., Menne B., 2009). West Nile virus can cause neurological diseases and death in people. It is commonly found in Africa, Europe, the Middle East, North America, and West Asia. Human infection is most often the result of bites from infected mosquitoes, which become infected when they feed on infected birds.

Suspected outbreaks of West Nile virus infection have been reported in Romania since the 1950s, recorded in central Transylvania in 1955, followed by an outbreak in Banat county in 1964. The largest outbreak of WNV infection in Europe was in Romania, when in 1996 over 800 clinical cases were reported, 393 of which were confirmed for WNV. A total of 17 deaths were reported in this outbreak. The epidemiological situation between 1997 and 2011 was characterized by sporadic cases reported from the southern part of the country (ECDC, 2010).

There is no specific treatment for West Nile virus infection and a vaccine is not available. In more severe cases, people usually need to be hospitalised for supportive treatment including intravenous fluids, help with breathing and nursing care. The best way to prevent West Nile virus infection is to avoid mosquito bites.

Tick-borne encephalitis (TBE) is caused by an arbovirus of the family Flaviviridae, and is transmitted by ticks, that act both as vectors and as reservoirs (Semenza J., Menne B., 2009). TBE affects people off all ages, but the disease has a tendency to be more severe in the second half of life. Ticks become carriers of the TBE virus when they suck blood from infected animals. The virus circulates between the ticks and the host animals on which the ticks feed, including rodents, deer and birds. Ticks do not prey on humans, but will take a human blood meal when the opportunity arises.

The risk of TBE infection is influenced by multiple factors including climatic conditions and human behaviour, the first being influenced by annual variations in the weather, but most of the cases

occurring in people who venture into forest and grasslands for recreation (ECDC, 2013). Potential causal pathways include changing land-use patterns, increased density of large hosts for adult ticks, habitat expansion of rodent hosts, alterations in recreational and occupational human activity (habitat invasion), public awareness, vaccination coverage and tourism (Semenza J., Menne B., 2009).

Lyme borreliosis is caused by infection with the bacterial spirochete Borrelia burgdorferi, which is transmitted to human beings during the blood feeding of hard ticks of the genus Ixodes (Semenza J., Menne B., 2009). The disease can be found mainly in Europe, North America and temperate Asia. Typical symptoms include fever, headache, fatigue and a characteristic skin rash called erythema migrans (ECDC, 2013). Lyme borreliosis disease is the most spread in Romania, having most of vector-borne disease cases, which have increased starting with 2009.
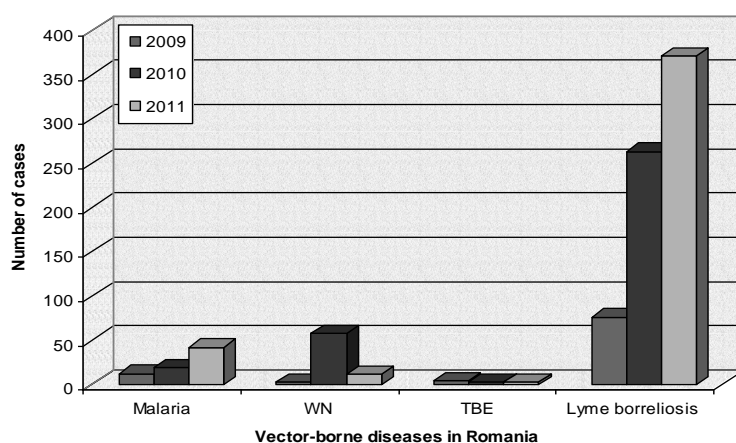
Figure 1. *Distribution of vector-borne diseases in Romania between 2009 and 2011*

Romania is the country that does not have extreme cases or situations with regard to vector-borne diseases. During the period under analysis, cases of tick-borne encephalitis, Lyme diseases and West Nile were recorded in Romania, most of them being spread in the localities situated in Transylvania (inside the Carpathian arch), along the course of the Danube, and in the western part of Romania (Figure 2).

METHODOLOGY AND STUDY AREA

The methodology used in this study comprises data acquisition, diseases mapping, spatial analysis and modelling. Satellite data of MODIS from TERRA sensor were processed and analysed to produce information on Land Surface Temperature (LST), Normalised Difference Vegetation Index (NDVI). Images for three years (2009, 2010 and 2011) were purchased for each of the summer months. The Normalized Difference Vegetation Index data used was available on 1 km and 0.25° resolution monthly between 2009 and 2011. The product is derived from bands 1 and 2 of the MODerate-resolution Imaging Spectroradiometer on the board of NASA's Terra satellite. The time-series on NDVI observations were exploited to examine the vegetation abundance in the epidemic diseases focal points.

The MODIS Land Surface Temperature product provides pixel temperature in a sequence of swath-based to grid based global products, gridded in the Sinusoidal projection and produced daily at 1 km spatial resolution, employed for July 2013.

Shuttle Radar Topographic Mission (SRTM) was used to determine the distribution of the epidemic disease cases on elevation databases. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during a 11-day mission in February 2000.

Corine Land Cover database was used to determine the land cover classes prone to vector-borne diseases snuggling.

The area of study covers the whole country, Romania, located at the intersection of Central and Southeastern Europe, bordering on the Black Sea. With an area of 238,391 square kilometres (92,043 sq mi) it is the eighth largest country of the European Union by area.

ENVIRONMENTAL PARAMETERS

The first major phase of the data collection is to identify the environmental factors that influence the vector-borne distribution pattern (land use, elevation, vegetated or non vegetated areas, land surface temperature).

Elevation

The elevation map was derived from Shuttle Radar Topographic Mission data. This data is provided in an effort to promote the use of geospatial science and applications for sustainable development and resource conservation in the developing world.

The spread of the vector-borne diseases found in Romania is represented in Figure 2, with a high concentration inside the Carpathian arch and along the Danube river course.
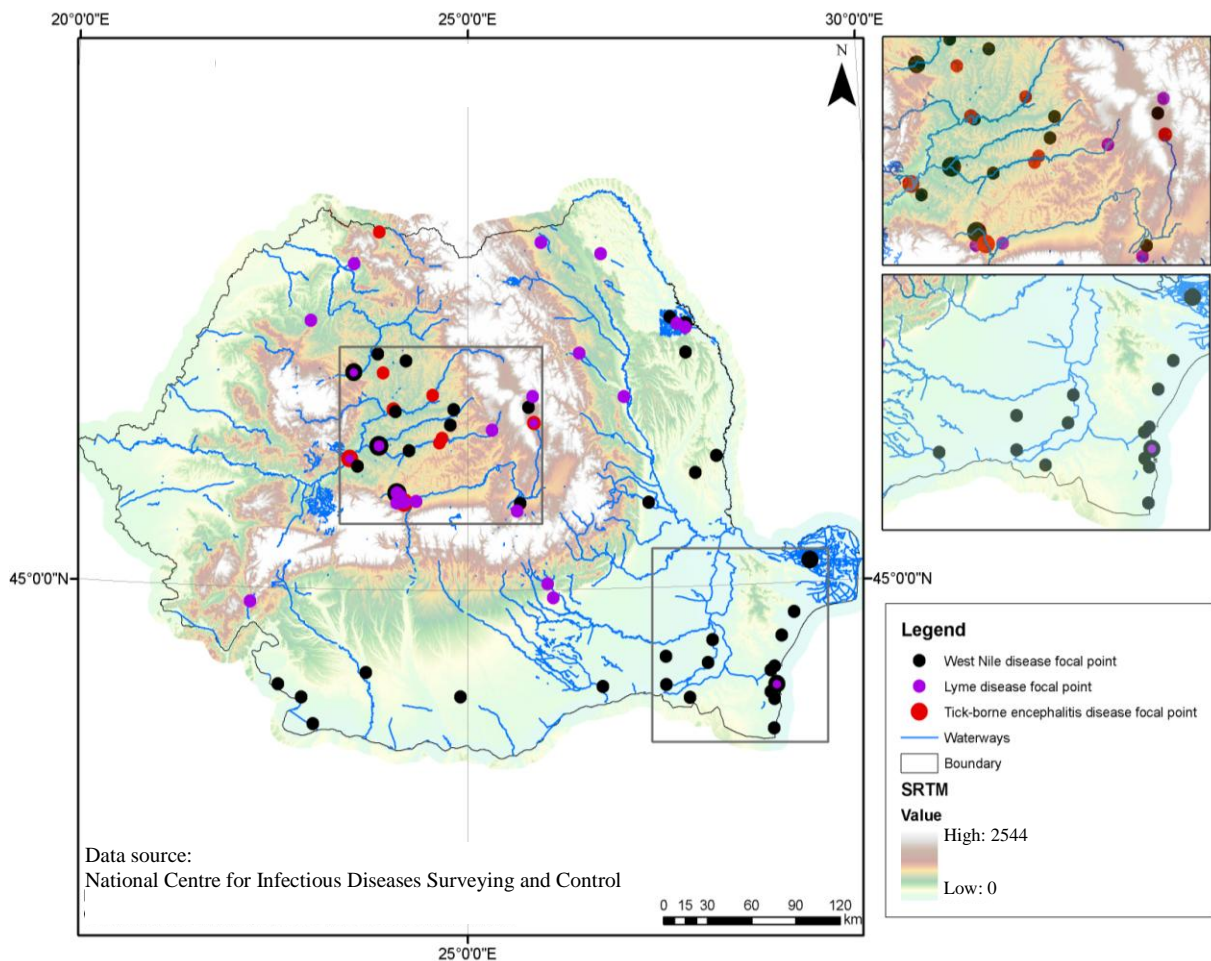
Figure 2. *Geographical distribution of vector-borne diseases in Romania between 2009 and 2011*

The elevation of landforms varies between the lowest point, the Black Sea shore, and the highest point, Moldoveanu Peak in the Făgăraş Mountains (2544 m). Most of West Nile disease cases were recorded in the low land areas, along the Danube river course, in Gârla Mare, Ghidici, Cetate, in the Romanian Plain, between 76 and 116 m altitude corresponding to the following localities: Craiova, Măldăieni, and Curcani. Continuing with the south-east part of the country, the West Nile cases occurred in Constanţa County, in Lipniţa, Techirghiol, Mangalia, Constanţa, Lumina, Năvodari, respectively, followed by the Danube Delta region. The Danube Delta is a low alluvial plain, mostly covered by wetlands and water, consisting of marshes, channels, streamlets and lakes, all these providing suitable mosquito breeding sites. The average altitude is 0.52 m, with 20% of the territory

below the sea level, and more than half not exceeding one meter in altitude, prone to forming stagnant water pools. Cases were reported between 2009 and 2011 in Jurilovca and Maliuc localities.

Land cover

Land Cover map is used for generally revealing the spread of vector-borne diseases among Corine Land Cover classes. As seen in Figure 3, the cases recorded in Romania between 2009 and 2011 are scattered in rural and urban areas, at the side of water courses and water bodies, mixed forest, non-irrigated land, coniferous forest.
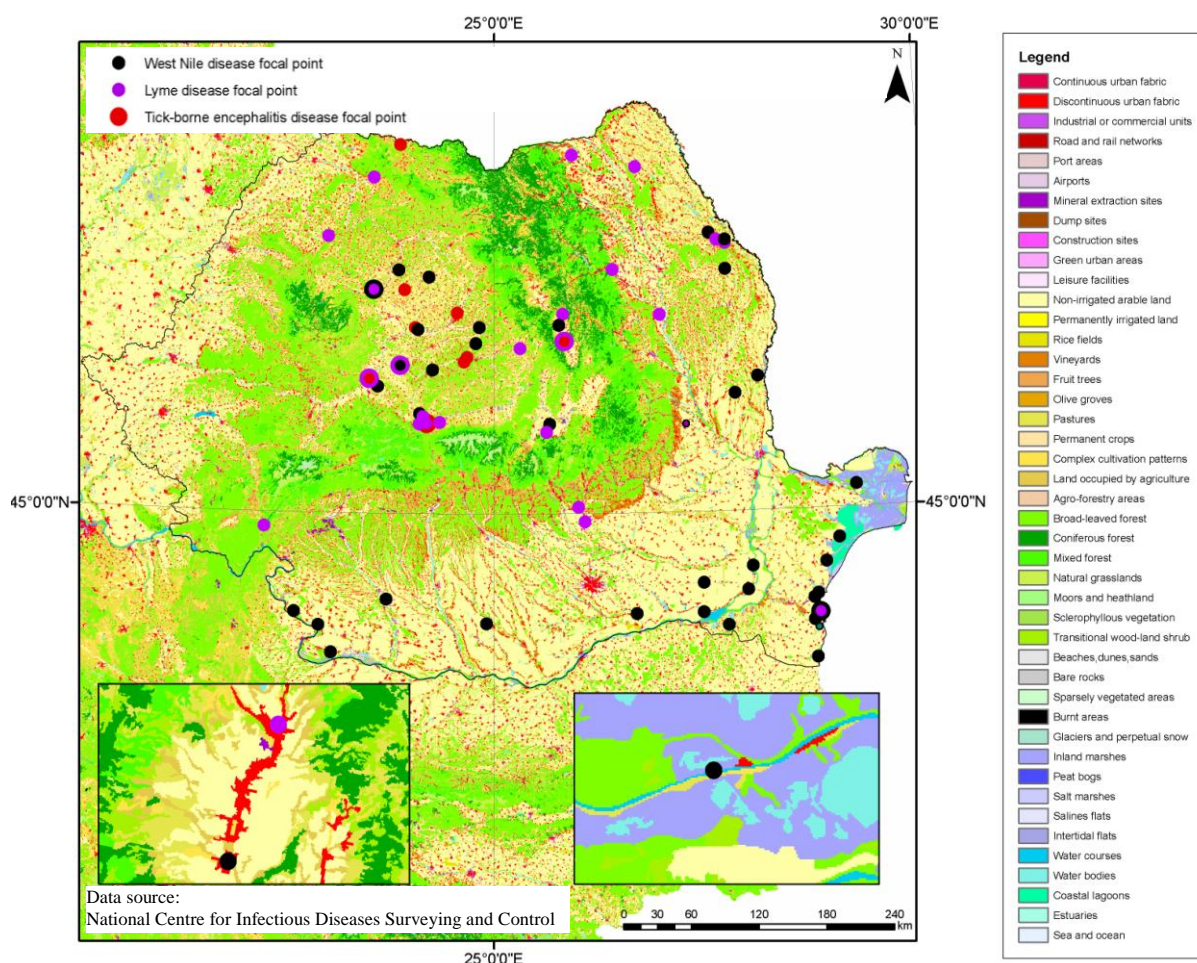
Figure 3. *Vector-borne diseases distribution in Romania between 2009 and 2011 based on Corine Land Cover database*

According to F.A. Murphy's research studies, when ecosystems are altered, disease problems arise (Lemon S. et al, 2008). The usual vertebrate hosts for most vector-borne pathogens that infect humans are wild or domestic animals. Sometimes, people get infected when they interfere in habitats where pathogens exist, while many vector-borne diseases of wildlife have now spread to domestic animals.

Mainly, in the case of Lyme disease, the land use factors are associated with the increase in deer population and the movement of human residences into tick habitat. The deer tick vector requires high humidity at ground level in spring and summer, provided by deciduous leaf litter.

The risk of contacting West Nile disease is increased by living in low-density housing in the presence of vegetation. In urban areas and not only, the presence of storm water or wastewater catchments, which serve as productive mosquito habitat, increase the risk as well. Considering water a

mosquito prone habitat, there are several cases tracked down on the Danube course, especially in the Danube Delta.

In 1996, the most extensive West Nile epidemic in Europe emerged in Romania. Consequently, in 1997, the Ministry of Health implemented a system for monitoring and controlling the infection with West Nile virus within the risk area, especially in the counties bordering the Danube, functioning from May to October. The monitoring system was constant, human cases being confirmed annually.

The endemic in 1996 was followed by another one in 2010 and new affected territories were identified, Transylvania and the north of Moldova. Therefore the monitoring continued aiming to prove the West Nile virus infection in humans in order to implement security control measures of donated blood according to COMMISSION DIRECTIVE 2004/33/EC.

**Normalised Difference Vegetation Index (NDVI)**

Normalized Difference Vegetation Index is one of the best instruction factors of the vegetation growth condition and the degree of vegetation cover (Song D., 2008). NDVI was developed by Rouse et al. in 1974 and currently it is one of the most common used band indices for the detection of vegetated areas. It has also the advantage of being less sensitive to atmospheric and radiometric errors.

The NDVI map was derived from MODIS image by using bands 1 and 2 for the three-year period between 2009 and 2011. NDVI information was used to differentiate vegetated areas from non-vegetated areas varying from -1, corresponding to lack of vegetation, to +1, which stands for vegetation cover increasing, based on the vegetation optimum absorbance in the red wavelengths (R) and maximum reflection of near infrared (NIR), as in the following formula: NDVI: $(NIR-R)/(NIR+R)$. The images below represent the NDVI stack layers display for each year summer months. Comparing the NDVI index, the slow difference of the vegetation abundance can be shown for the years analysed, the highest of it restored in 2009 (Figures 4-6), along the Carpathian arch, in the western part and in the centre of the country. Even so, the highest number of vector-borne disease cases based on statistical data (Figure 1) was recorded in 2011.
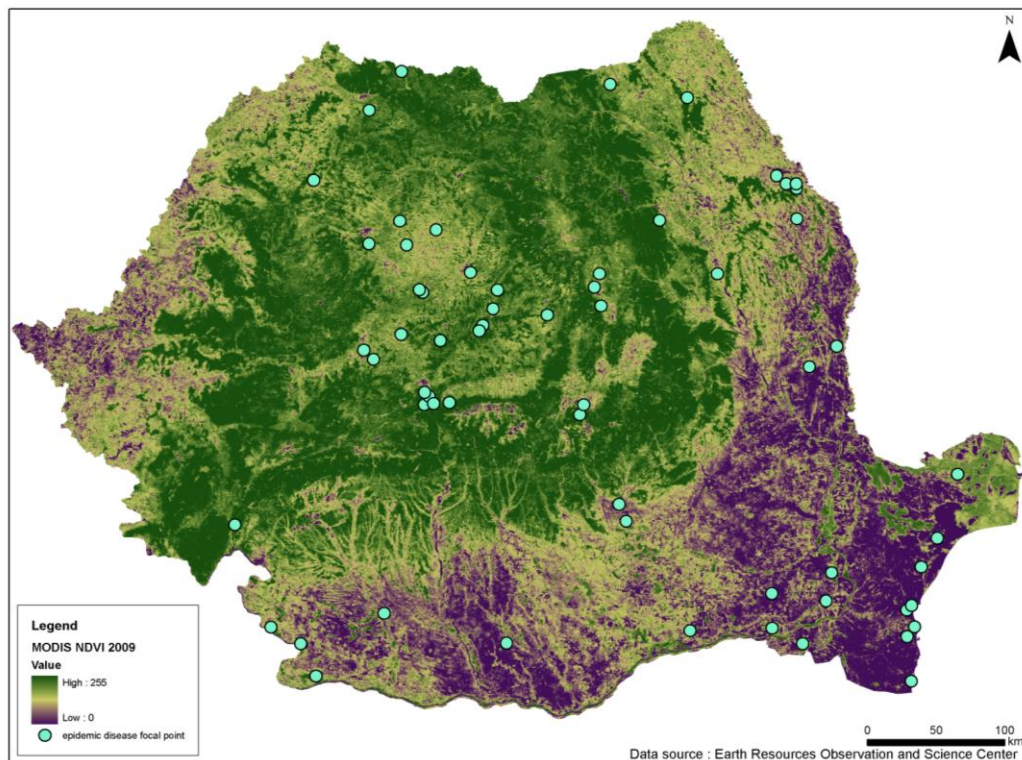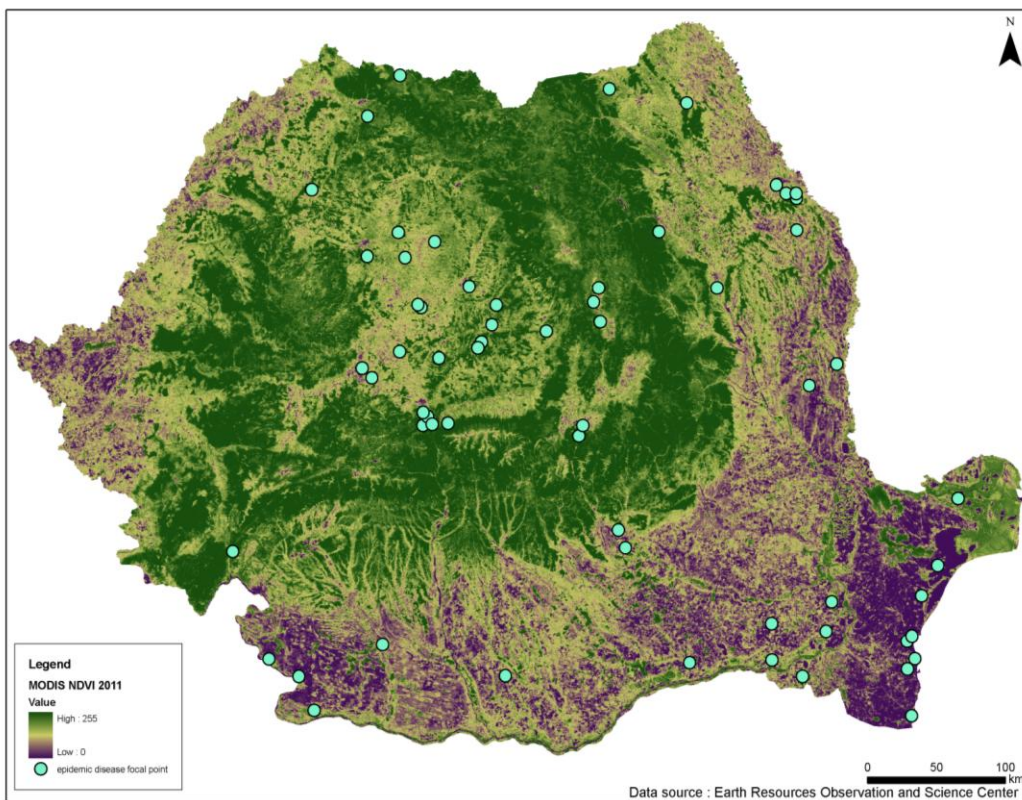

Figure 4. *NDVI for 2009 summer months*
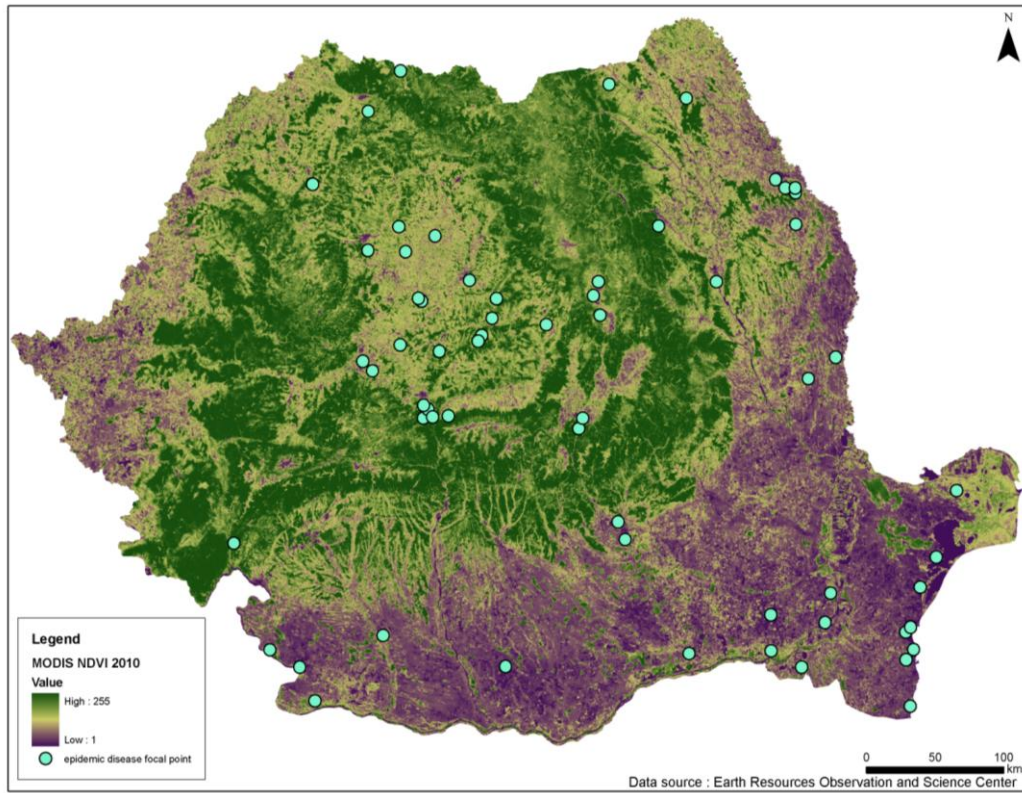
Figure 5. *NDVI for 2010 summer months*

Figure 6. *NDVI for 2011 summer months*

Land Surface Temperature Index (LST)

Land Surface Temperature is a good indicator of both the energy balance at the Earth's surface and the greenhouse effect because it is one of the key parameters in the physics of the land-surface processes. LST is defined on radiation basis emitted by the land surface observed by MODIS at instant viewing angles (Akhoondzadeh M. et al., 2008). In the present study, it was used a MODIS/Terra LST L3 Global 1 km Grid (short name: MOD11B1) image from June 2012, this product incorporating 6 km pixels, produced daily using day LST algorithm. This algorithm extracts average temperature (in Kelvin) and applies them to a pair of daytime and nighttime observations. MOD11B1 product is a gridded version of the level-2 LST product mapped and projected on Sinusoidal grids comprising bands 20, 22, 23, 29, 31 and 32 (Wan Z., 2004).

Temperature varies between 0 and 1, the values identified along the country standing for normalization between day and night temperatures. It can be noticed that in the north-eastern part of Romania there are agglomerated red points representing high land surface temperatures, favourable area for ticks propagation, contrasting with the south and south-eastern part (Figure 7), where temperatures are lower, due to presence of watercourses nearby (the Danube River, the Danube Delta, the Black Sea). Land surface and air temperature influence the feeding behaviour of the mosquito, its survival and the length of the cycle the parasite needs to develop in the mosquito before it can be infective to humans. Mosquito survival is low at extreme temperatures. The optimum mosquito survival rate is found at 32˚C. Frost with temperatures below 5˚C and temperatures above 40˚C are deadly for the mosquito.

Population

Population density is another factor considered in preventing vector borne outbreaks. For this matter, the 2002 census data was used to determine the density of each locality. Seven division thresholds were settled, the most common illustrated by the affected localities with a population density between 50 and 100 inhabitants/sq km and 500 – 1,000 inhabitants/sq km (Figure 8). A densely populated area creates a higher chance of experiencing an epidemiological outbreak even if the vector house index is low in that area. The respective vector does not have to travel far to search for its victims. The hereby research substantiate the possibility of vector-borne diseases spread in localities with over 1,000 inhabitants/sq km, where early preventive measures for mitigation of an expected outbreak could be passed by.

THE ASSOCIATION OF ENVIRONMENTAL FACTORS TO VECTOR-BORNE DISTRIBUTION. CONCLUSIONS

Remote sensing satellite data such as Terra MODIS, SRTM and LANDSAT ETM+ are capable of providing information on environmental factors: land surface temperature (LST), NDVI, topography, land cover, which influence and reveal vector-borne disease distribution and deployment. An important influence in assessing epidemiologic outbreak is population density data. All these indicators were analysed and validated with epidemiological statistical data containing the locality and the number of cases of infectious diseases recorded in Romania between 2009 and 2011, especially in the summer months. The data was delivered by the National Centre for Infectious Diseases Surveying and Control.

This research reveals that most of the cases were located in the continuous and discontinuous urban densely populated areas, located at topographically low land areas and inside the Carpathian arch or next to a water source. The distribution of vector-borne disease in Romania between 2009 and 2011 shows an ascended line for malaria with 42 cases, while West Nile had the highest spread period in 2010 with 57 cases, overtaken by Lyme borreliosis with 371 cases in 2011.

According to MODIS Normalised Difference Vegetation Index for the three years analysed, the existing cases of vector-borne disease infections are not met in areas with high vegetation abundance, but in the medium and low vegetation areas.
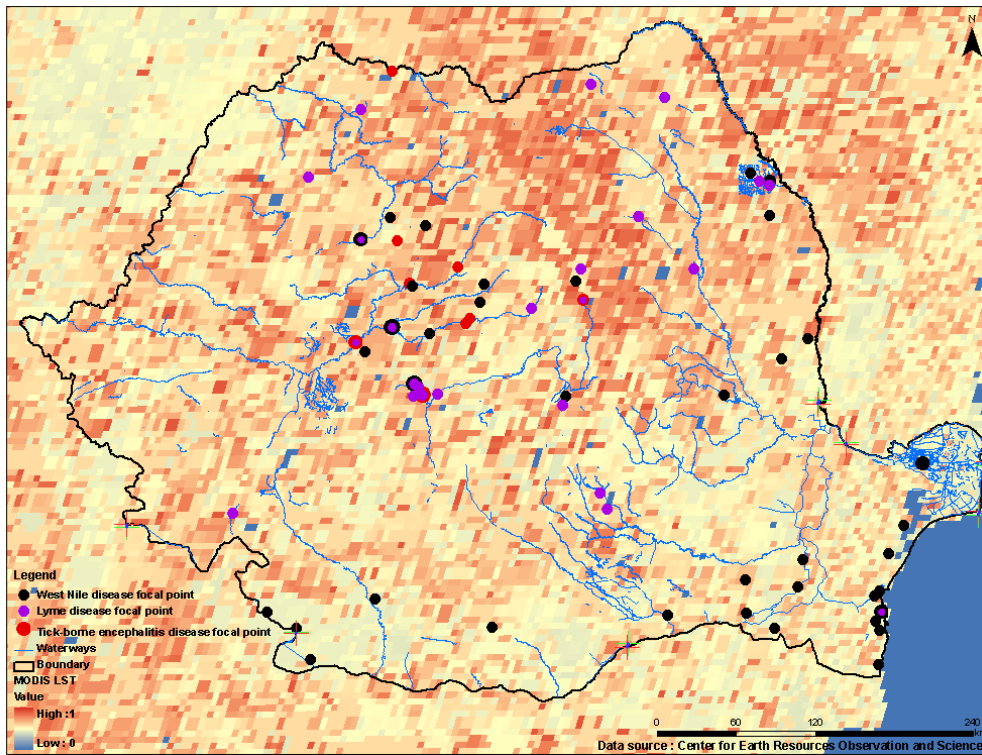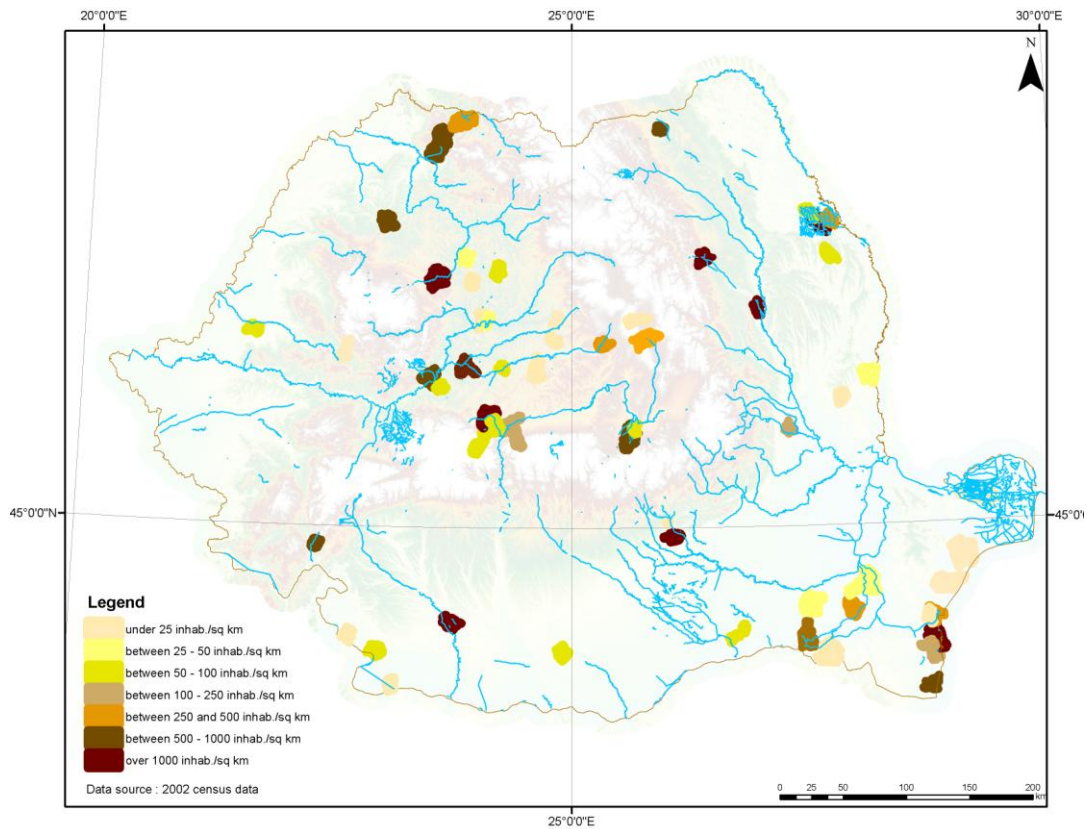
Figure 7. *MODIS/Terra LST Index*

Figure 8. *Population density in localities with vector-borne registered diseases*

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The LST map shows that temperature ranges from 0 to 1 and the vector-borne diseases are mainly distributed based on the type of agent corresponding to arthropod vectors which create the virus, then possibly inducing fatal diseases. Consequently, West Nile virus cases were mainly located in the low surface temperature part of the country due to the presence of watercourses and water ponds, while Lyme borreliosis and tick-borne encephalitis are mainly located in the high surface temperature part, in the presence of high vegetation cover.

The present paper draw a primary overview of spatial data contribution to vector-borne diseases in Romania, based on national assessment between 2009 and 2011. Spatial data was found to be an important tool for surveillance and prediction of vector-borne diseases in order to reduce the dispersion of fatal cases, considering the association with environmental factors such as vegetation, land surface temperature and topography.

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