ENVIRONMENTAL CHANGE AND VECTOR-BORNE DISEASES: THE CONTRIBUTION OF REMOTE SENSING AND SPATIAL ANALYSES

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Summary

Emerging and re-emerging vector-borne diseases still constitute an important threat to human health in the 21st century, causing well over a million death and considerable morbidity worldwide. Vector-borne diseases are linked to the environment by the ecology of the vectors and of their hosts, including humans. Human activities are reflected in the landscape by land use. Three elements have therefore to be considered in vector-borne disease transmission: the vector, the host/human, and the landscape that offer the habitats necessary for both and which facilitates contacts. Remote sensing, used to study the earth's surface for several decades, is a useful tool for studying

environmental properties relevant to vector as well as host development. Important spatial aspects of vector-borne transmission make Geographical Information System (GIS) an important help in studying this issues. Examples of studies of vector-borne diseases or vector ecology using remote sensing and GIS data and tools are presented.

1. Vector-borne Disease in the 21st Century

At the dawn of the 21st century, vector-borne diseases still constitute a serious threat to human health. Out of about 11 million annual deaths due to infectious diseases (about 19% of total annual deaths), 1.43 million can be attributed to vector-borne diseases (including malaria, trypanosomiasis, Chagas disease, leishmaniasis, lymphatic filariasis, onchocerciasis, dengue and Japanese encephalitis). Among these, 1.30 million are caused by mosquito-borne diseases (WHO, 2004). The leader of this deadly procession is malaria, with an annual death toll of 1.27 million (WHO, 2004). These figures however possibly underestimate the situation and great variation can be found between sources. Important mortality is also caused by trypanosomiasis (around 48 000 deaths per year), leishmaniasis (around 51 000 deaths), and dengue (19 000 deaths) (WHO, 2004). The World Health Organization (WHO) Roll Back Malaria program estimates that malaria causes 300 million acute illnesses each year, but higher figures have also been suggested. Other diseases, even though they cause less mortality, have important disabling effects, such as onchocerciasis ("river blindness") or lymphatic filariasis, which annually causes the loss of 484 000 and 5 777 000 Disability Adjusted Life Years (DALY's), respectively (WHO, 2004). The paucity of health and reporting systems in many countries where these diseases are prevalent makes estimation of the number of cases difficult. In temperate areas, other diseases have recently been drawing attention due to sharp increases over since the last quarter of the 20th century They include the West Nile virus in North America and tick-borne diseases, in both North America and Europe.

Some vector-borne diseases are considered newly emergent; others have been classified as re-emergent/resurging. Re-emerging and resurging infections are existing infections that, at some point, increase rapidly either in incidence or in geographical or human host range. Following the understanding of transmission of diseases by vectors, at the end of the 19th century, prevention and control programs based on vector control were organized, and many were successful. Onchocerciasis, Guinea worm, and Chagas disease are currently considered under control, thanks to region-wide special programs, and efforts are being put in the maintenance of the situation. However, many other vector-borne diseases, such as malaria, dengue fever and yellow fever, started re-emerging at the end of the 20th century. The reasons for this are complex and not well understood, but probably include the appearance of insecticide-resistant vectors and drug-resistant pathogens, a decrease in resources in public health, demographic and societal changes, changes in agriculture and deforestation, and increase in international travel (Gubler, 1998).

Most of these factors eventually determine vulnerability to the disease at the individual, household, community and regional level. Vulnerability is the degree to which a system is likely to experience harm due to exposure to a hazard, either a perturbation or stress. In the case of diseases, the infectious agent represents the hazard. The perturbation can be the introduction of a new pathogen in the study unit, and the stress can be a change in the disease pressure on the unit (e.g. increased contact with the pathogen). In studying infectious diseases, epidemiology addresses vulnerability through the study of risk factors, or determinants.

These are the factors that are positively associated with the risk of development of a disease but that are not sufficient to cause the disease (Beaglehole et al., 1993). This however only addresses one end of the vulnerability concept, and does not include the response capacity of the system once the hazard has occurred.

2. Vector-borne Diseases and Environmental Change

Among the factors mentioned for the re-emergence of vectors-borne diseases, some are related to changes of the environment, such as land-cover change or changes in weather patterns. The health impacts of climate change are debated. Arthropods are dependent on weather for their survival and development, and weather could influence the virus, the vector, the people, and the contacts between each of these. Impacts of climate change on vector-borne diseases however remain a controversial issue.

Several models have been based on variation of just a few parameters such as temperature and humidity, whereas key variables such as poverty, land-use changes, and public health programs should be considered along with climatic factors. Hay et al. (2002) suggested that many associations between local malaria resurgences and regional climate change are overly simplistic. Reiter (2001) indicated that a great complexity of factors influences transmission, and that many factors other than climate have to be considered, such as human life-style and vulnerability.

Land cover is determined by the attributes of the earth's land surface and immediate subsurface, diagnosed by a set of categorical or continuous attributes per spatial unit. Environmental changes caused by natural phenomena or human intervention, such as climate change or land-cover change could affect vector abundance, diversity and competence.

Environmental factors that could cause changes in transmission could be related to the vector, such as the expansion of geographic distribution of vectors related to change in breeding habitat available, or to the infectious agent, for example the introduction of infectious agent into new areas (Patz et al., 2004). Environmental factors that could cause changes in transmission could also be related to the host, such as change in demographic patterns (including natural change and migrations), or in health service (control and education programs). The combination of these factors would determine the rate of contact between vector and susceptible host.

Protozoa of the genus *Plasmodium* cause malaria when transmitted from infective to susceptible host by the bite of *Anopheles* mosquitoes. Malaria has been associated with land covers such as forest and tree-crop plantations and with irrigation. Changes in land use have also been incriminated for changes in malaria transmission: road building, deforestation, mining, irrigation projects and new agricultural practices (Patz et al., 2000). However, these changes in land use or land cover are not always associated with the same changes in transmission. In different regions of the world, deforestation can be associated with a decrease in malaria transmission linked to a destruction of vector habitat or to an increase in mosquito biting rate, linked with more favorable habitats. The following aspects of deforestation can be distinguished (Coosemans and Mouchet, 1990): forest penetration, edge effect (offering to the vector favorable breeding and resting conditions in the forest and feeding sources outside) and forest clearance (suitability of breeding habitat increased for some vector species).

Irrigated farming has been assumed to be linked with an increased malaria risk; however the picture is not that clear and irrigated farming is not always related to an increase in malaria. In most of the cases, these effects can be investigated by studying vector ecology, but require consideration of other factors such as transmission stability, wealth, use of preventive measures, etc. (Ijumba and Lindsay, 2001).

African trypanosomiasis, or sleeping sickness, has been impeding social and economic development in Central and Eastern Africa for a long time. Although the disease was controlled in the mid-1960s, major epidemics have occurred recently, mostly due to the disruption of control programs (Gubler, 1998).

The transmission of this disease is linked to the ecology of the fly-vector (*Glossina* spp.) and to livestock-raising and farming. Cattle ranching is still often restricted to areas where tsetse flies are absent.

The replacement of forest by permanent tree crops can have dramatic effects by bringing the humans and the vector together (Patz et al., 2000), and the invasion of such plantations by shrub can have similar effects.

Dengue fever (DF) is an arbovirus transmitted by *Aedes* mosquitoes. Changes in dengue infection over time and space could potentially be caused by land use or changes in land use. Only a few attempts have been made at linking land cover or spatial features to dengue infection since it was generally assumed that dengue transmission was restricted to urban areas and settlements rather than being associated with natural or agricultural environments.

However, dengue is now found endemic is rural as well as urban areas in parts of the world. In Asia for example, orchards could provide hospitable habitat for some *Aedes* species.

Tick-borne diseases are a particular case due to the feeding pattern of ticks. Ticks only take three large blood meals over their life course, that is, they feed once per life stage and several months can elapse between two meals. Various factors have been evoked for the increases of Lyme borreliosis and tick-borne encephalitis observed in North America, in Scandinavia and in Eastern Europe.

These factors range from climatic change to biological factors such as the increase of hosts (deer, roe deer) and to changes in human-tick contacts. The relative importance of each of these factors in various areas remains to be elucidated (Randolph, 2003).

3. People, Vectors and Landscape: A Conceptual Model

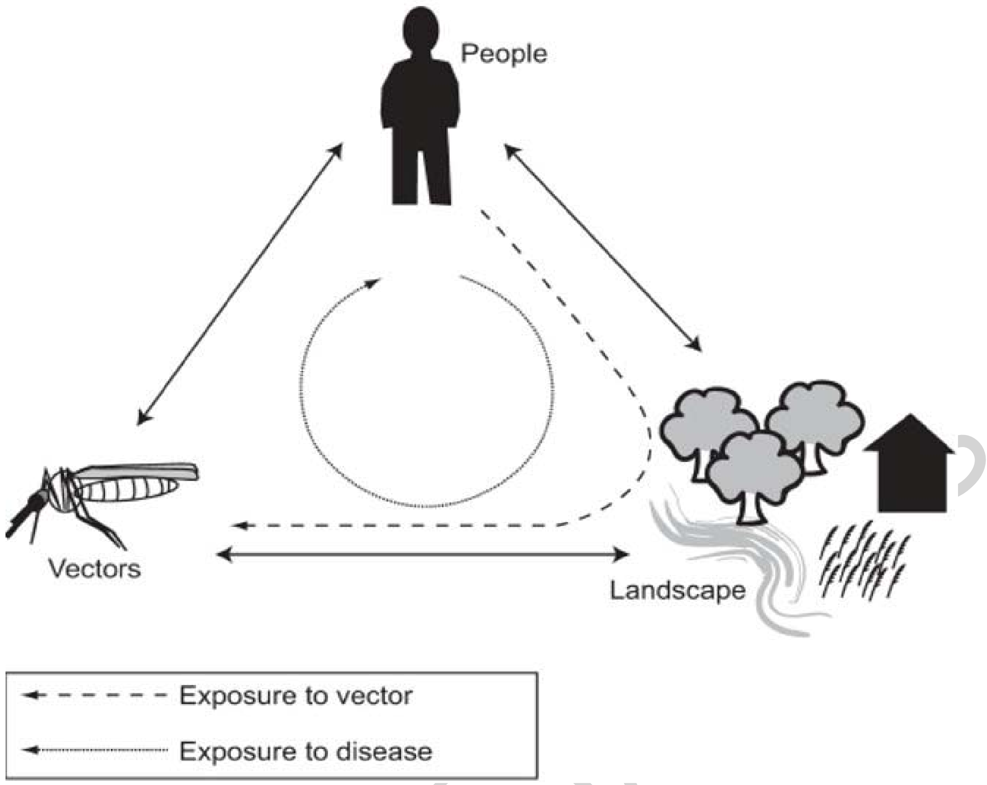

Figure 1. Conceptual model linking people, landscape and vectors

A simple conceptual model linking landscape, people and vectors, can graphically be presented as Figure 1. Each arrow on the graph is detailed below.

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Biographical Sketches

Sophie O. Vanwambeke (PhD) is a professor in Geography in the department of Geography in UCL since 2007. Her PhD research focused on the impacts of land use changes on two major mosquito-borne diseases of the tropics: malaria and dengue fever. She then participated in the EDEN (http://www.eden-fp6project.net/) project, working on the integration of landscape-level environmental aspects into various European disease systems: tick-borne diseases, canine leishmaniasis and cowpox. Interdisciplinary research is a major aspect of her experience to date, and Sophie Vanwambeke has collaborated with entomologists, epidemiologists, public health specialists, and biologists.

Eric F. Lambin (PhD) is Professor at the Department of Geography at the UCL. He was previously Assistant Professor at *Boston University* and Expert for the European Commission at the *Joint Research Center* (Ispra). In 2002-03, he was resident as Fellow at the *Center for Advanced Study in the Behavioral Sciences* at Stanford, California, USA. Eric Lambin is the Chair of the « Land-Use and Land-Cover Change » (LUCC) programme of the *International Geosphere-Biosphere Programme* (IGBP) and *International Human Dimensions Programme on Global Environmental Change* (IHDP). He contributes to many other international scientific projects and initiatives. His research interests include the monitoring of land-cover changes by remote sensing, and the modeling of land-use changes and some of their impacts on coupled human-environment systems. Eric Lambin has published more than one hundred papers and book chapters in leading scientific journals in environmental sciences, remote sensing, and geography. Eric Lambin has supervised several completed PhD theses and directs a team of fifteen researchers. He recently published a broad audience book on the human impact on the Earth System " *La Terre sur un fil* " (Ed. Le Pommier, Paris, 2004).