Sci Parasitol 11(1):7-13, March 2010
ISSN 1582-1366

REVIEW ARTICLE

Geospatial tools in parasitology: highlighting their usefulness at the beginning of the third millennium

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Abstract. Nowadays, at the beginning of the third millennium, significant advances have been made in the development and application of geospatial tools, e.g. geographical information systems (GIS), remote sensing (RS), global positioning systems (GPS) and virtual globes (VG). In this review, we first summarize general aspects of GIS, RS and VG, and emphasize the most important applications of these tools in human and veterinary parasitology, including recent advances in disease mapping, territorial sampling and spatial epidemiology.

Keywords: Geographical Information Systems; Remote sensing; Disease mapping; Ecological analysis; Forecasting; Surveillance.

Received 26/02/2010. Accepted 05/03/2010.

Introduction

The application of geospatial tools, as Geographical Information Systems (GIS), Global Positioning System (GPS), Satellite-based Remote Sensing (RS) and Virtual Globes (e.g. Google Earth™) to spatial epidemiology in human and animal health have been firmly established for geo-positioning, collating, exploring, visualizing and analyzing health data in a spatially explicit manner (Rinaldi et al., 2006; Brooker and Utzinger, 2007). The new geospatial technologies came about as "spin-offs" from the electronics industry, the launching of satellites and the rise of computer technology in the 1980s (Bergquist and Rinaldi, 2010). The last 25 years have seen an increasing reliance on the application of GIS and other geospatial tools to study the distribution of infectious and parasitic diseases and their vectors. Today, few medical and veterinary scientists working in the field of epidemiology can manage without geospatial tools as they rapidly provide answers or clues with regard to the questions: "what?", "where?" and "when?" (Rinaldi et al., 2006; Bergquist and Rinaldi, 2010). Global availability of geospatial health resource data and improved software analysis methodologies have enabled the development of digital "health maps" and transmission models for several parasitic diseases. With relatively modest investment in resources it is now possible for health workers to depict where and when health problems may arise and how to better target control interventions (Malone, 2005). Many parasitic infections, either directly transmitted or vector-borne infections, can be considered "environmental" infections because a considerable fraction of their burden can be attributed to environmental factors and their distribution patterns are strongly associated with the spatially heterogeneous environment in which they are applied (Brooker and Clements, 2009; Stensgaard et al., 2009). The present review highlights the importance of geospatial tools in the era of global changes and within the transdisciplinarity approach "One Medicine–One Health" to global health.

Geographical Information Systems (GIS)

Depending upon the application area, a number of discordant definitions of GIS have appeared in the literature (Cringoli et al., 2005; Rinaldi et al., 2006). Blakemore (1986) provided a broad definition of GIS as "computer packages which integrate the storage, manipulation, analysis, modeling and mapping of digital spatial information". Burrough (1986) defined GIS as "a powerful set of tools for collecting, retrieving at will, transforming, and displaying spatial data from the real world". Smith et al. (1987) considered GIS as "database systems in which most of the data are spatially indexed upon which a set of procedures are operated in order to answer queries about spatial entities in the database". Antenucci et al. (1981) defined GIS as "computer systems that stores and links non-graphic attributes or geographically-referenced data with graphic map features to allow a wide range of information processing and display operations, as well as map production, analysis and modeling".

Overall, GIS are systems consisting of hardware, software, data and people and encompass a fundamental and universally applicable set of value-added tools for capturing, transforming, managing, analyzing, and presenting information that are geographically referenced (geo-referenced) (Rinaldi et al., 2006; Bergquist and Rinaldi, 2010). What separates GIS from other types of information/databases is just that everything is based on location.

GIS can be constructed with several data-layers, thus permitting the simultaneous visualization of health data with environmental data, which holds promise to understand environmental-health linkages and to generate new hypotheses to be tested in future research. Perhaps one of the most powerful benefits of GIS is its ability to integrate different databases into one environment. In effect, a GIS database may be thought of as a "database of databases" (Cox & Gifford, 1997).

Remote Sensing (RS)

The concept of RS was used for the first time in the United States during the 1960' to designate the technique allowing the study of objects without any direct contact, through image capture. In 1970, in an article entitled "*New eyes for epidemiologists: aerial photography and other remote sensing techniques*", Cline recognized that RS could have applications in detecting and monitoring disease outbreaks (Cline, 1970; 2006). In 1971, scientists of the National Aeronautics and Space Administration (NASA) of USA, used colored infrared aerial photographs to identify the habitats of the mosquito *Aedes sollecitans* (Hay et al., 2000).

Aerial photography was the first source of RS data. Subsequently, the development of satellite RS has improved both spatial and temporal coverage of the Earth's surface, generating a continuous and almost full cover. Satellite-borne radiometers measure the amount of electromagnetic energy reflected or radiated at earth surface. There is a high number of satellites with different temporal and spatial resolution (i.e. Landsat, NOAA, Modis, SPOT, Quickbird) that can be used to characterize climate and land surface variables at different spatial resolutions. They permit the calculation of vegetation indices, land surface temperatures, atmospheric and soil moisture, rainfall, etc. Among the about two-dozen vegetation indices obtained from RS, the most used is the Normalized Difference Vegetation Index (NDVI). It is defined as the difference between the visible (red) and near-infrared (nir) bands of satellite information over their sum: NDVI = (nir - red)/(nir + red). NDVI is a specific measure of chlorophyll abundance and light absorption, but its use has been extended to quantify herbaceous vegetation biomass, vegetation primary productivity, vegetation coverage and phenology. NDVI is usually associated with the presence and distribution of many parasites (e.g. flukes, ticks, etc.) because it is often associated with suitable moisture availability to external stages of these parasites. Land cover classification refers to the natural vegetative cover, topography, soil or local climate. It also refers to the description of land use (crops, lying fallow, irrigated, etc.) and human settlements such as cities, rural areas, roads and other infrastructures (Herbreteau et al., 2005). The Corine Land Cover (CLC) is a map of the European landscape with a spatial resolution of 100 m. It is based on visual interpretation of widely used satellite images (SPOT, LANDSAT, etc.) and it is widely used for ecological analysis of parasitic disease, either vector-borne or directly transmitted (Pozio et al., 2009).

The RS data are increasingly used for investigations in the field of environmental health sciences for risk mapping, surveillance or monitoring, particularly of vector-borne diseases (Beck et al., 2000). Since the disease vectors have specific requirements regarding climate, vegetation, soil and other edaphic factors, RS can be used to determine their habitat (Rinaldi et al., 2006). However, after thirty years of use and improvement of RS as applied to epidemiology, there is the risk that a generalized use of pre-processed spatial data and low-cost images, results in a limited adaptability when addressing biological questions (Herbreteau et al., 2007).

Virtual globes

A virtual globe is a 3D representation of the Earth, usually based on satellite imagery, upon which various types of information with a spatial character can be superimposed (i.e. positivity or prevalence data for a given parasite) (figure 1).

A virtual globe provides the users with the ability to add their own data, to share the added data layer with other users, and to freely move around in the virtual environment by zooming and changing the position and viewing angle. Although several virtual globes of different origins are now available, Google Earth (http://www.google.earth.com) currently dominates this market. Compared to conventional world maps, virtual globes have the capability of presenting a multitude of different views related to the surface. The views can show geographical features, man-made features (roads, buildings, etc.) and the information can consist of quantitative data sets regarding demography, economy or any other measure.

Figure 1. Map obtained from Google Earth™ showing the Calabria region of southern Italy and the geo-referenced farms (represented as points) positive for a given parasite

Recent advances in the development of virtual globe technology, provides an opportunity for a relatively inexpensive and easily accessible method to communicate epidemiological data more effectively to non-specialists (Stensgaard et al., 2009). For these reasons, the literature on virtual globes is growing rapidly. However, although most applications are general-purpose applications with limited analytic functions, they cannot replace professional GIS software in any way (Bergquist & Rinaldi, 2010).

Mapping and sampling

One of the most useful functions of GIS in epidemiology continues to be its utility in basic mapping. Representation of health data (i.e. positivity, prevalence, etc.) in the form of a map, facilitates interpretation, synthesis and recognition of frequency and clusters of phenomena (Rinaldi et al., 2006). However, GIS is not only a digital cartography but is indeed a

Sci Parasitol 11(1):7-13, March 2010
ISSN 1582-1366

tool for information and analyzing which permits the processing of space-related data.

Parasitological maps may be qualitative: point maps, distribution maps, point distribution maps (figure 2), indicating location but without specifying the amount of disease. Other maps can be quantitative: distribution maps with proportioned peaks, maps with proportional circles (figure 3), choroplethic maps, choroplethic maps with proportioned peaks, isoplethic maps, displaying the number of cases of disease, the population at risk, infection prevalence or intensity or incidence (Cringoli et al., 2005; Rinaldi et al., 2006).

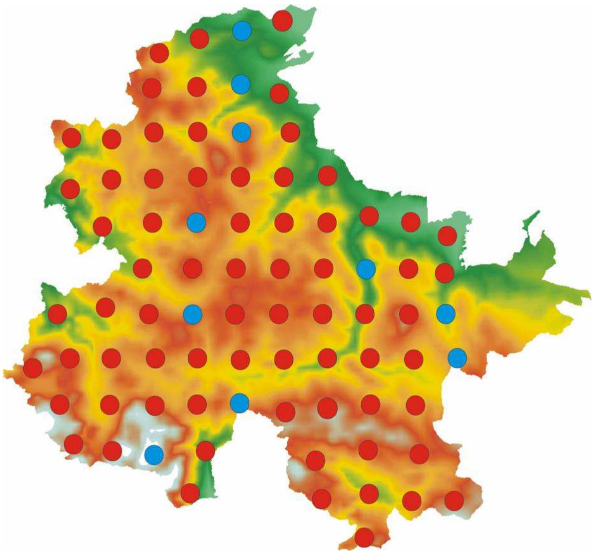

Figure 2. Point distribution map: distribution of *Eimeria bovis* in cattle farms from an area of southern Italy

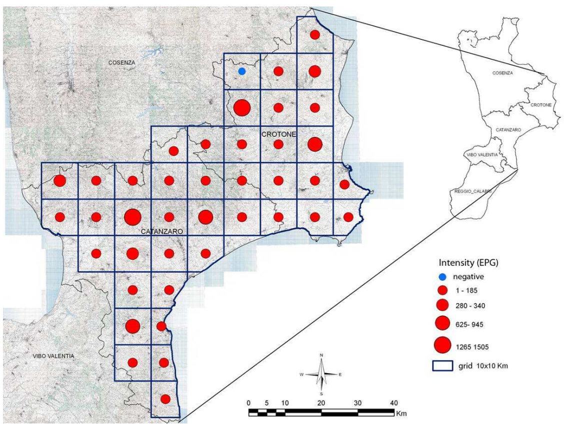

Figure 3. Map with proportional circles: intensity (eggs per gram of feces) of gastrointestinal strongyles in ovine farms from an area of southern Italy

The fundamental steps which can be used to produce quality descriptive disease maps within GIS are the following (Cringoli et al., 2005): (1) selection of the study area; (2) selection of the study population and calculation of the sample size, using as parameters the study population, the expected prevalence, the confidence level, and the standard error; (3) selection of the sample in the study area (i.e. random sampling, systematic sampling, proportional allocation, use of grids, etc.); (4) laboratory and/or field survey; (5) geo-referencing of the study units (i.e. farms; counties, municipalities, regions or any other administrative unit); (6) drawing maps by GIS.

The sampling procedures in the study area play a key role in the disease mapping. The methods of spatial sampling have been in practice for a while, but their applications have been restricted to sampling natural phenomena, such as plants, soil types and mineral deposition and continuous phenomena, such as air pollution (Kumar, 2007). Nevertheless, epidemiological studies through the use of spatial sampling in parasitology as well as in veterinary medicine are relatively new (Rinaldi et al., 2006).

Spatial sampling differs from non-spatial sampling methods because a sample is selected based on geographic locations and/or their associated characteristics., a number of spatial sampling methods adapted from the theory of conventional sampling have been developed and tested so far (Kumar, 2007).

The main spatial sampling schemes are systematic grid sampling, random sampling, proportional allocation, and judgmental sampling based on "judgments and choices" of the researcher.

Systematic grid sampling is set to a geometric pattern default, represented by a sampling grid placed on the territory under study. The basic parameters to be defined are: (1) origin and geometry of the grid (square, rectangular, triangular, hexagonal); (2) the spacing of the grid (i.e. the distance between two adjacent centroides in the directions x and y); (3) the density of sampling. The samples are usually collected at regularly spaced locations, corresponding to the center of the mesh grid. This approach requires no knowledge ahead of the territorial distribution of population, it is easy to implement and provide "not biased" samples. These types of sampling, used mainly for soil and plants, are now also used for the collection of biological material such as feces, blood or milk for the detection of parasites (figure 4).

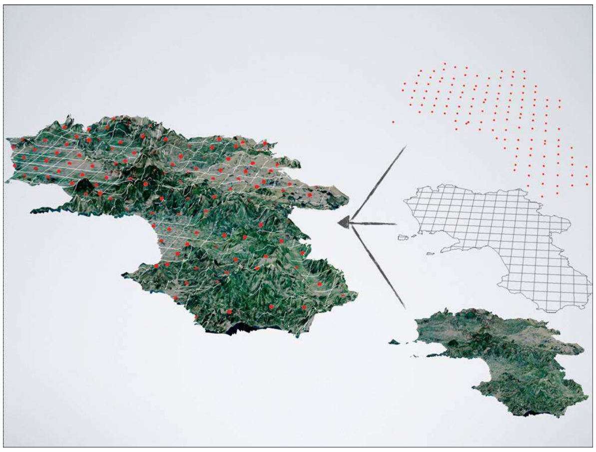

Figure 4. Grid sampling: the Campania region of Southern Italy with a grid (10 x 10 km) for samplings (each point represents a farm)

Another approach is spatial random sampling, which provides the selection and the distribution of sampling randomly of the sites in the territory. Regarding this type of sampling, which leads to "not biased" samples, it is necessary to use software and apply appropriate algorithms in order to locate the sampling points. The only problem could be that the samples are randomly distributed in the study area.

The judgmental sampling is based on opinions and personal choices. It is driven by prior more or less detailed knowledge about the characteristics of the phenomenon under study (i.e. greater concentration of farms or animals in the studied area).

There are also patterns of composite or mixed samples. An example might be a systematic grid sampling with proportional allocation of the number of farms to be sampled (Cringoli et al., 2009).

Spatial epidemiology

Spatial epidemiology can be defined as a sub-discipline of epidemiology whose primary purpose is to describe and explain the spatial patterns of diseases. There are several competing terms that are widely used in the medical literature, namely geographical epidemiology, environmental epidemiology, and landscape epidemiology (Durr, 2004). In particular, spatial epidemiology refers to the study of spatial variability in disease occurrence, mainly addressing methodological issues. Geographical epidemiology is a branch of descriptive epidemiology regarding the distribution of risk between or within countries. Environmental epidemiology is a more specialized field, studying the disease determinants which are present in the environment (indoor or outdoor). With landscape epidemiology the parent discipline is parasitology and the concern is predominantly with vector-borne diseases (Kriton, 1998).

Landscape epidemiology involves the integration of epidemiological data (i.e. surveillance or field survey data) and climatic, topographical and other information related to the environment, such as land cover and NDVI in a GIS. Subsequent statistical analysis of the relationships between the epidemiological and environmental data is conducted, leading to inference about the relationships and, often, predictions of disease outcomes in non-sampled locations (Clements and Pfeiffer, 2009).

Knowledge of the prevailing climate and environmental characteristics of an area, which can be provided by GIS and RS, can help predicting diseases' seasonality by comparing this information with the known requirements of the species under study. Climate-based forecast systems have been developed using the concept of Growing Degree Days (GDD), a heuristic tool in phenology first used by horticulturists to predict the date that a flower will bloom or a crop reach maturity. GDD are calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature (i.e. the threshold temperature for a given species), T_{base} using the equation GDD = $(T_{max} + T_{min})/2$ -

T_{base}. When applied to parasites whose growth is also strongly influenced by the ambient temperature, the GDD concept can be useful in predicting risk and in deciding on disease intervention. GDD have been applied to several vector-borne parasites, including *Fasciola hepatica* (Malone and Zukowski, 1992; Malone et al., 1998) and *Dirofilaria* spp. (Genchi et al., 2005; 2009).

Global warming

Climate change (or climate variability) is a very common natural phenomenon. However, after years of critical reluctance and intense discussions it has become clear now that climate change and in particular global warming exceeding the natural variation is a reality. It is now almost 20 years since WHO published its first report on the health implications of climate change (WHO, 1990).
In the current era of global warming, global movement and globalization, pathogens can move further, faster and in greater numbers than ever before (Tatem et al., 2006) and thus the use of geospatial tools for mapping, forecasting, monitoring, early warning and surveillance is strongly advocated. It is therefore imperative that human and veterinarian public health services establish centers for regular monitoring of parasitic and other communicable diseases using geospatial tool technologies.

Conclusions

Health is an outcome of multiple determinants. Individual biology and behaviors, physical and social environments, policies and interventions and access to quality healthcare are predisposing factors that can contribute to the health of people and communities. The predisposing factors of health status are often interdependent and interrelated, creating a complex web of causation. Geospatial tools can answer questions about the complex web of causation of many health issues (reviewed in Graves, 2008). In conclusion, this review showed that geospatial tools might help researchers in gaining a better understanding of the epidemiology and control of organisms of human and veterinary importance. Many factors have contributed to an increasing appreciation of the interdependency of human, animal and ecosystem health within the transdisciplinary “One Medicine–One Health” approach to global health (Conrad et al., 2009).

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