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Review Article

A Perspective on Applications of Geographical Information System (GIS): an Advanced Tracking Tool for Disease Surveillance and Monitoring in Veterinary Epidemiology

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ABSTRACT

The spatio-temporal distribution patterns of most of the livestock diseases are complex. In this regards, the application of Geographical Information System (GIS) is valuable as it has many features that make it an ideal tool for use in animal disease surveillance, monitoring, prediction and its control strategy. The GIS can store demographic information, etiological factors and prevalence records of disease on a geographical setting, which enables a range of spatial analysis purposes. A GIS provides noteworthy additional value to general purpose routine data that is perceived to be inadequate epidemiologically or for supervision purposes in veterinary profession and noticeably increases the efficacy of networking and communication strategies. Descriptions of the dynamics of geographical diseases occurring from time to time and the risk / predisposing factors owing to spatial correlation along with sketching of risk and damage maps become realistic due to various applications of GIS. This gets reflected in cartography, neighborhood analysis, buffer generation, overlay and network analysis, three dimensional modeling, surface area distance calculation, three-dimensional surface modeling and so on. Introduction of GIS as an alternative-tracking tool for animal disease surveillance and monitoring is of utmost importance, given current lack of proper disease surveillance system in the veterinary sector. The GIS may provide a momentum to disease reporting, recording, cluster analysis, modeling the spread of the infection, assessing outbreak situation, and planning control strategies including disease prediction, vaccination, alerting authorities for preparedness, etc. With the advancement of GIS, mapping for the location of herds, flocks and other related facilities is possible which proves to be helpful in management of disease outbreak along with the improvement of management practices as well as veterinary service tasks during emergency. Moreover, it can also be used as powerful tool to assess various approaches being followed for preventing the spread of infectious and communicable diseases. This manuscript aims to bestow an overview of the promising and potential applications and usages of a Geographical Information System in veterinary epidemiology for advancing the knowledge of epidemiologists, diagnostician, clinicians and researchers about this novel approach of disease surveillance and monitoring.

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INTRODUCTION

The world is currently undergoing demographic and ecologic changes, including population growth with subsequent increasing problems of food scarcities, public health insufficiencies, climate changes and biodiversity losses, and the impacts on ecosystems which alltogether affects human and animal health (Patz et al. 2005; Myers and Patz, 2009; Bloom 2011; Mahima et al., 2012). There also seems to be increasing numbers of events with emerging and re-emerging infectious diseases (Dazak et al. 2000; Jones et al., 2008; Safronetz et al., 2013) that are causing increased disease incidences in existing or in new populations or new species or increases in geographical range (Lederberg and Shope 1992, Morse 1995). Many a pathogens are having high economic impact, are emerging/re-emerging and even with variant strains and antimicrobial resistant strains are upsurging viz., foot and mouth disease virus (Pattnaik et al., 1998; Sangare et al., 2001; Ul Islam et al., 2009; Verma et al., 2010), *Salmonella, Campylobacter, Mycoplasma, Arcobacter,* Chicken anaemia virus, Marek's disease virus, Infectious bronchitis virus etc. These infectious pathogens have created challenges and severe threats to animal health and production systems (Dazak et al. 2000; Dhama et al., 2008a; Jones et al., 2008; Bhatt et al., 2011; Patyal et al, 2011; Singh et al., 2012; Verma et al., 2012a). Emerging infectious diseases of wildlife and wild/migratory birds are also threat to biodiversity as well as health of humans (Dazak et al. 2000; Dhama et al. 2008b). It has been shown that the majority of emerging infectious diseases are zoonotic in nature (Dazak et al., 2000; Taylor et al., 2000; Jones et al., 2008), which include salmonellosis (Verma et al., 2007; 2008; 2011b), campylobacteriosis (Kumar et al., 2012a and 2012c), brucellosis (Kumar et al., 2009, Deb et al., 2012c), rabies (Sadkowska-Todys and Kucharczyk, 2012), leptospirosis (Deb et al., 2012a; Verma et al., 2012b), listeriosis (Deb et al., 2012c; Dhama et al., 2013a), tuberculosis (Dhama et al., 2011; Deb et al., 2012d), West Nile virus (Ziegler et al., 2012), rotavirus (Dhama et al., 2009), vector-borne diseases (Herbreteau et al., 2006; Chochlakis et al., 2009; Zhang, 2012; Kilpatrick and Randolph, 2012; Schmidt et al., 2013), parasitic infestations (Kamiya, 2007; Cringoli, 2007), the pandemic influenzas (avian/bird flu, swine flu) (Dhama et al., 2005; Dhama et al., 2008b; Pawaiya et al., 2009; Dhama et al., 2012a; Kahn et al., 2012; Dhama et al., 2013) and pandemic threats of *Yersinia pestis* (plague) and other agents. Biological warfare agents like Anthrax, botulinum, plague, tularemia, smallpox, brucellosis, glanders, melioidosis, Q-fever, viral encephalitis etc. are also having serious public health concerns to the global population (Rossow et al., 2012; Anderson and Bokor, 2012; Doganay and Doganay, 2013). Apart from this Hanta virus, Hendra virus, Ebola virus, Dengu, Chicken guinea, Japanese encephalitis and others are creating havocs for human beings (Dazak et al., 2000; Jones et al., 2008; Wei et al., 2011; Dhama et al., 2013b). All these zoonotic pathogens pose major threat to global health. Though advancement in molecular biology and genomics has given several sophisticated tools for rapid and confirmatory diagnosis, yet disease surveillance, monitoring and the networking approaches are much more important for implementing effective prevention and control strategies (Belák, 2007; Bollo, 2007; Schmitt and Henderson, 2005; Ratcliff et al., 2007; Dhama et al., 2008c; Balamurugan et al., 2010; Dhama et al., 2012b; Deb and Chakraborty, 2012; Deb and Chakraborty, 2012; Deb et al., 2013; Dhama et al., 2013b).

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. Due to advancement in technology, digital maps have replaced these paper maps by the use of computers many a years back (Tobler, 1959). In 1970's, Geographical Information System (GIS) emerged as a tool with multidisciplinary field with practical potential to be applied for any discipline handling data related to geographical locations (Norstrom, 2001). As GIS can map a variety of epidemiological information like morbidity, mortality, prevalence and incidence of the diseases, there is an emerging need of GIS in the veterinary field. The possible application of GIS in veterinary medicine was first described in 1994 for foot-and-mouth disease epidemic (Sanson et al., 1994). Due to recent advances in satellite communication system, and information technologies, GIS has a high potential for being applied in various fields.

As a valuable tool, GIS is useful for all the disciplines dealing with information and data relative to geographical settings and locations like countries, areas or regions and communities or which simply co-ordinates the situation (Briggs and Elliott, 1995; Amin et al., 2012). It helps the epidemiologists and public health professionals in the veterinary sector in analyzing associations between various locations, environment and disease pattern by using different types of maps particularly for the spatial analysis and before adopting any disease control planning policy (Gatrell and Bailey, 1995; Herbreteau et al., 2006; Cringoli, 2007; Sadkowska-Todys and Kucharczyk, 2012). There has been a remarkable progress in GIS application in relation to mathematical modeling and spatial analysis/statistics. Noteworthy, modern stochastic modeling offers a potent move toward studying historic disease outbreaks that was not feasible to be attained in earlier times due to missing information/data and databases originating from multi-sources. During bubonic plague epidemic in India (1896-1906), utilizing GIS, spatio-temporal maps revealing mortality rates could be generated which gave new perceptions on the circulation and spread of this epidemic (Yu and Christakos, 2006). Today this methodology can well be be applied for assessing the risk of plague in the current scenario (Rahelinirina et al. 2010) and thereby, the spatio-temporal changeability in the distribution of plague can be correlated with increased activity in the endemic foci together with ever increasing populations of the foremost rodent host (*Rattus rattus*) of *Yersinia pestis*.

Nowadays, GIS is becoming popular in the surveillance, tracking and monitoring of vector-borne (such as Lyme disease) as well as water-borne diseases (such as Campylobacteriosis) (Cliff and Haggett, 1988; Cliff et al, 1993; Sarkar et al., 2007; Chochlakis et al., 2009; Wei et al., 2011; Gubbels et al., 2012; Sadkowska-Todys and Kucharczyk, 2012). For this, a risk model can be generated with the help of ecological data, such as location of land, soil type, source of water and geology to forecast development of any disease or epidemic (Wei et al., 2011). Along with GIS, global positioning system (GPS) acts as a powerful tool for public health work, by displaying the regions of high disease prevalence and keep an eye on control programs being carried out. Combined endeavor of GIS and GPS provide an integrated approach enhancing the quality of data analysis and decision making to control the disease and its prevalence at regional or national level. In the present review, an attempt has been made to present useful applications of this novel technology in the field of Veterinary epidemiology, disease surveillance, monitoring, prediction and control, taking into account the current and future perspectives.

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

GIS definition usually focus on the tasks that can be done by GIS rather than what it stands for. GIS is comprised of computerized information systems that allows the capture, collection, store up, manipulation, investigation, interpretation, demonstration, recording and reporting of geographically available data (Marble, 1984; Parker, 1987; Walsh, 1988). It is a potent tool retrieval, interrogation, transformation and display of spatial data obtained from worldwide sources. GIS can act as a decision support system that involves the integration of all the referenced data in an atmosphere where problems are solved (Cowen, 1988; Clarke, 1995; Burrough and McDonnell, 1998). With its computer softwares the collective geographical /

spatial data can be easily managed, edited, assessed and interpreted based on various reports, maps and charts accessible. GIS are used to map, analyze and interpret data related to some particular geographical location and disease distribution (Maguire, 1991; Alizadeh and Moghaddam, 2012). . They have a range of powerful functions in addition to simple mapping, which include graphical analysis based on spatial location, statistical analysis and modeling.

Although, GIS may be defined in many ways, it is most commonly described with focus on its purposes, which may be to collect spatial data, store this in a computerized system, where the information can be retrieved, transformed, analyzed, integrated and displayed (Marble, 1984; Parker, 1987; Clarke, 1995; Burrough and McDonnell, 1998; Walsh, 1988; Alizadeh and Moghaddam, 2012). Through GIS, the functions for solving problems and supporting decision making (Cowen, 1988), the issue of emerging infections, to map and spatially analyze disease occurrences and distribution can be achieved (Maguire, 1991).

STRUCTURE OF GIS

Input data in GIS are either primary or secondary. Primary data are directly retrieved from the real world, for example by GPS (Gregory and Ell, 2007). Primary data may also be directly sensed from field sketching, interviews and measurements or remotely sensed. Remotely sensed data have been used in identifying villages at high risk for vector-borne diseases, such as malaria transmission (Aimone et al., 2013). Meteorological satellites have also been used to detect niches of ticks, mosquitoes, trematodes (Hugh-Jones, 1989) and Tsetse flies (Rogers, 1991). Secondary data are derived from indirect sources, such as maps (Gregory and Ell, 2007). In addition to cartographic data describing the location, there may be textual attribute data describing characteristics of the features.

All geo-referenced data are stored in the database management system (DBMS) of the GIS in a form that can be graphically queried and summarized. Cartographic data is stored in digital form on computers in two fundamental formats of digital maps viz., grid-based (raster-based) system where information is stored uniformly in relation to each cell that forms the grid, and vector-based system in which points and lines (arcs) are used to represent geographical features (Thrusfield, 2007).

APPLICATIONS OF GIS IN EPIDEMIOLOGY

As has been mentioned, GIS can provide important information in epidemiology. The benefits of different methods has been reviewed by Sanson et al. (1991).

- *Cartography*: With the use of GIS, thematic maps can be produced and updated very quickly (Tomlin, 1990). Compared to conventional cartographic (map-drawing) methods maps generated with GIS are having user friendly and utility display features which can be modified easily to create new maps (Kasturi et al. 1989).
- *Neighbourhood analysis*: It allows the researcher to catalog all the attributes related to particular criteria like recognition of livestock components neighboring infected farms)
- *Buffer generation*: Risk of infection can be defined in the region besides definite features like within a specified distance of infected premises or along a path used by infected animals.
- *Overlay analysis*: For this purpose two or more data are overlapped crossroad areas/features are recognized, for example overlaying animal farms, flora/vegetation and watering spot locations, which help categorize areas where animals are difficult to muster like for tuberculin testing.
- *Network Analysis*: This feature allows best possible map-reading along networks of linear attributes.
- *Three-dimensional (3D) modeling*: Construction of isoplethic maps with highest proportional to disease incidence or other characteristics.
- *Surface area distance calculation:* Measuring distances very precisely between two or more spots or areas with selected characteristics on a three-dimensional (3D) surface is highly valuable in epidemiological disease investigation studies, for example in case-control studies.
- *Three-dimensional (3D) surface modeling:* Three-dimensional (3D) modelling potential can be used as triangulated irregular networking (TIN) or digital terrain models (DTM). The 3D surfaces constructed on the basis of contour or point z-values can help study topography or pathogen load in a particular area, which can be utilized for demonstrating necessary information regarding diseases over a geographical region. Contour maps, otherwise known as isopleths, can be inferred from the 3D surfaces. For Midway locations between the identified points can also be exclaimed from z-values. TIN helps to execute 3D surface area, gradient/slope and calculations of dimensions along with determining the features of TIN triangles, which are the useful variables in epidemiological investigations (Sanson et al., 1994).

LANDSCAPE EPIDEMIOLOGY

An important role and influence on the occurrence, maintenance and transmission of many diseases is played by the interactions of host, pathogen, place and time. Landscape parameters influence by large the patterns of movement and behaviour of host and pathogen spread and survival along with land use practices. The concept of landscape epidemiology is almost half-a-century old (Pavlovsky, 1966). Delimiting effects of physical (abiotic), biological (biotic) and geographical components on spatial variation on maps is a part of landscape epidemiology that greatly helps in predicting the current and future risk assessment and control of diseases (Eisen and Eisen 2011, Emmanuel et al., 2011).

The data obtained from remote sensing (RS) and GIS have been successfully used by the National Aeronautics and Space Administration (NASA's) Centre for Health Applications Aerospace Related Technologies (CHAART) in diseases mapping - Spatio-temporal/dynamic approach or Static risk map (Castronovo et al., 2009; Clements and Pfeiffer, 2009; Wang et al., 2011); disease modelling, ecological niche modelling (ENM) (Soberón and Peterson, 2005; Christopher et al., 2007) and spatial risk interpolation models and space-time risk models (Eisen and Eisen, 2011). Thus, the application of RS and GIS technologies have led to effective disease prediction, establishment of early warning system, successful planning, and prevention of disease incidences and epidemics (Rushton, 2003; Ostfeld et al, 2005; Cringoli, 2007; Danson et al., 2008; Jerrett et al., 2010; Eisen and Eisen 2011; Emmanuel et al., 2011; Wang et al., 2011; Zhang et al., 2013). A multi-agent simulation model has been created using foot and mouth disease (FMD) for demonstrating the spatial and temporal dynamics of pathogens between human-domestic animals and wildlife interfaces at the periphery of large wildlife sanctuary (Dion et al., 2011; Dion and Lambin, 2012).

GIS-MULTI-CRITERIA DECISION ANALYSIS (GIS-MCDA) OR SPATIAL MCDA

The uneven distribution of vectors, disease causative agents, animal and human populations in different geographical areas and time cause spatially heterogeneous risk and predisposition for exposure to vector-borne and zoonotic diseases (Pavlovsky, 1966; Chochlakis et al., 2013).

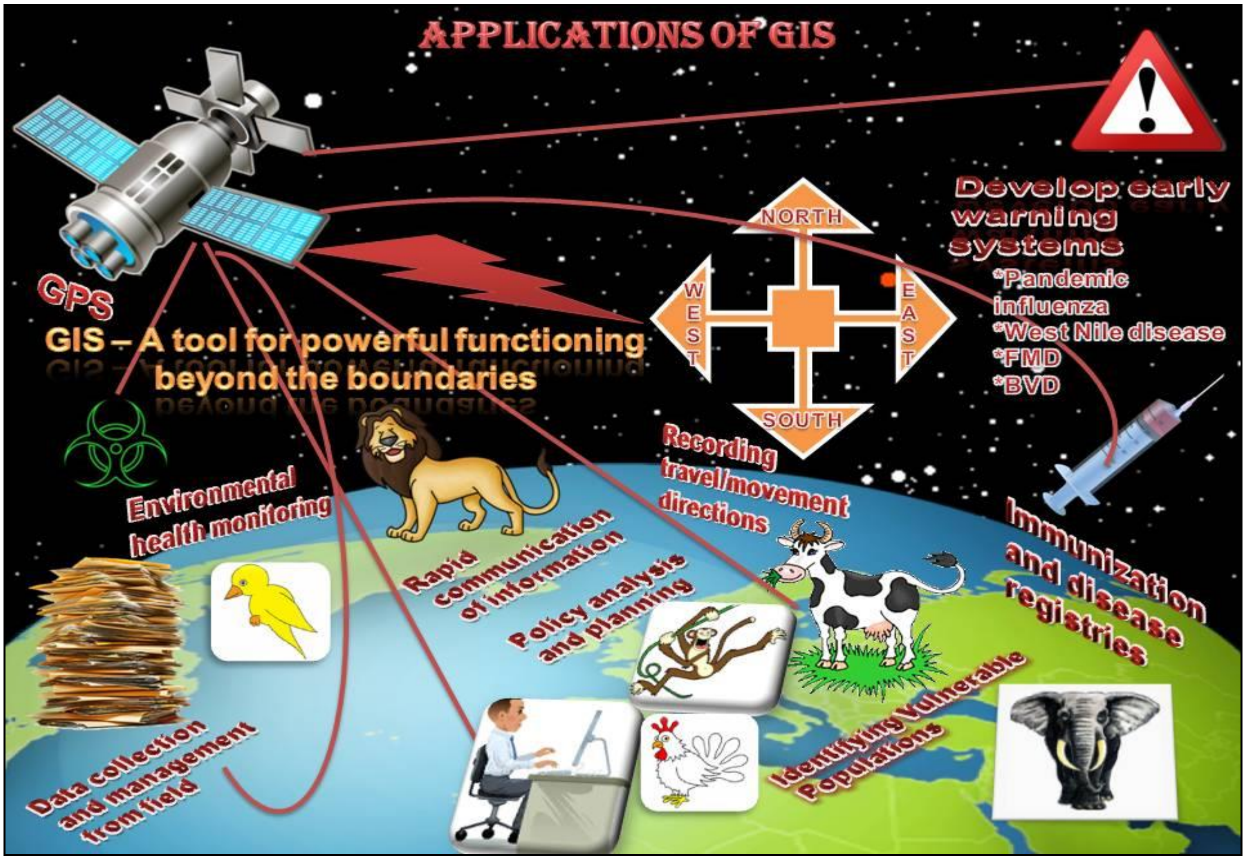

Figure 1: Applications of Geographical Information System

The GIS has provided many spatial models in the form of risk maps of anticipated geographical distribution of vectors in high numbers and/ or risk for contacting a pathogen. The geo-spatial technologies were applied to understand and predict the factors affecting the vector populations and vector-borne diseases (Reisen, 2010; DeGroote et al., 2012). Though, these risk maps provide valuable technical knowledge regarding spatial allocation of disease risk itself but may not give complete scenario of complex situations which may hinder decision makings particularly. Their complicated nature goes ahead of the geographical distribution and factors of disease risk and makes public health assessment and priority-preparedness for vector- borne diseases a very complex and complicated issue. Multi-criteria decision analysis (MCDA) is an important tool that supports decision inferences and which incorporates uncertain, subjective and qualitative information and perspectives from multiple stakeholders into an explicit and transparent decision-making course of action for evaluating alternative strategies. Risk maps are very useful to inform risk-based disease surveillance and control systems. However, there may be failure in risk map construction, if suitable disease data are scanty or unavailable or if inaccessible. In such circumstances, alternative to data-driven approaches can be the knowledge-driven spatial models provided alternatively by MCDA and are usually used to inform risk-based disease surveillance and control strategies (Mourits et al., 2010). The application of the MCDA predicted that most suitable areas for the incidences of H5N1 highly pathogenic avian influenza virus (HPAIV) in domestic poultry spread from Bangladesh, Vietnam, Thailand and large parts of eastern China (Stevens et al., 2013). The potential and utility of a unified strategy that integrates GIS with MCDA (GIS-MCDA or spatial MCDA) as a decision support tool for public health priority-setting and planning and executing control programs in and around the vector-borne diseases has been demonstrated recently (Hongoh et al., 2011).

USE OF GIS IN THE SURVEILLANCE OF ANIMAL DISEASES

To prepare a control strategy, the exact disease status is compulsory to be known (Verma et al., 2008). Today, various monitoring and surveillance networking programs are active. Some of these are Global Early Warning System (GLEWS) for surveillance of animal diseases comprising not only zoonotic diseases such as Avian influenza and BSE, but also important animal diseases such as FMD, Global Network for Avian Influenza Surveillance (GNAIS), EMPRES Global Animal Disease Information System (EMPRES-i), ArcIMS^{TM}-based web mapping system for swine diseases surveillance (Davies et al., 2007), EpiScanGIS geographic surveillance system for meningococcal disease (Reinhardt et al., 2008), All India Co-ordinated Research Project on FMD (AICRP-FMD) (Verma et al., 2008), Michigan-System to Report Integrated Disease Events (MI-STRIDE) for reaching right decisions related to public, animal and environmental health (www.stchome.com), and the arbo-zoonet (http://www.arbo-zoo.net).

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GIS can be used to combine the information of computer maps with geographical data in order to support the spatial relationships along with patterns and trends in predicting future health status that need to be explored. Use of geo-coded data with coordinates is being promoted. The geo-referenced data are used as theme layers. Moreover, they can be displayed singly or one above the other. Such data include overhead projector that requires a geo-relational database and each of its features has linkage of attributed data for storage in a table and joining with the geographical data via a common identifier (ID). A farm or region can act as ID with respect to animal disease data. Points can be used to visualize particular animal holdings in which disease outbreaks actually occur whereas regions like veterinary districts and municipalities or countries can be viewed as polygons (Norstrom, 2001). With the increase in public access to GIS information, new insights in developing strategies are provided specific to particular geographic areas.

DISEASE REPORTING AND RECORDING

GIS can be used to produce maps of epidemiological information such as morbidity, mortality, prevalence, incidence of disease on farm, regional or national basis. With the use of maps, the information is easy to understand. Disease incidences at a particular place can be represented alternatively via density maps.. A grid having a definite cell size is created by density function and provides a density value concerning infected farms to every cell within an area. An overall population based density map at risk can be created with similar size of cell in order to adjust the underlying population. Subsequently, division of density maps provides map showing the disease incidence in every unit of area at the selected unit of time. The GIS also uses notification of outbreak as previously used in North Carolina in an Aujeszky's disease (Mad itch) eradication campaign (McGinn et al., 1997). Maps highlighting the up-to-date position and status in an area along with farm informations are useful tools for field workers and for preparing reports for administrators and media persons.

OUTBREAK SITUATION

GIS is an important tool to locate the farm or place of outbreak and identification of areas at risk if an infectious disease occurs (Musekene and Tessema, 2009; Schimmer et al., 2010). The GIS provides excellent tool to identify the location specific to case farm along with those at risk within a particular area within outbreak zone, classical example in this regard being FMD, wherein, buffer zones including the farms where outbreaks have occurred can be designed. The farms that are at risk can get receive notification of outbreak within a short period with linkage to addressing tables (Sanson et al. 1994; Sharma, 1994). A zone can be drawn around areas at risk or point sources or roads for driving cattle that are ill or around markets and with the hyperlink to the list of addresses of farms / market places, these can be informed in shortest possible period following the outbreak condition. The maps can also assist the veterinary officers and staffs of animal husbandry department for planning activities in outbreak situation and in handling the outbreak.

With an objective of establishing models for predicting risk of any disease (Avian influenza, and foot and mouth disease being classical examples) with respect to maintaining integrity of spatial risk variables buffer zone must be established. This in turn facilitates surveillance as well as eradication of such pandemic disease.

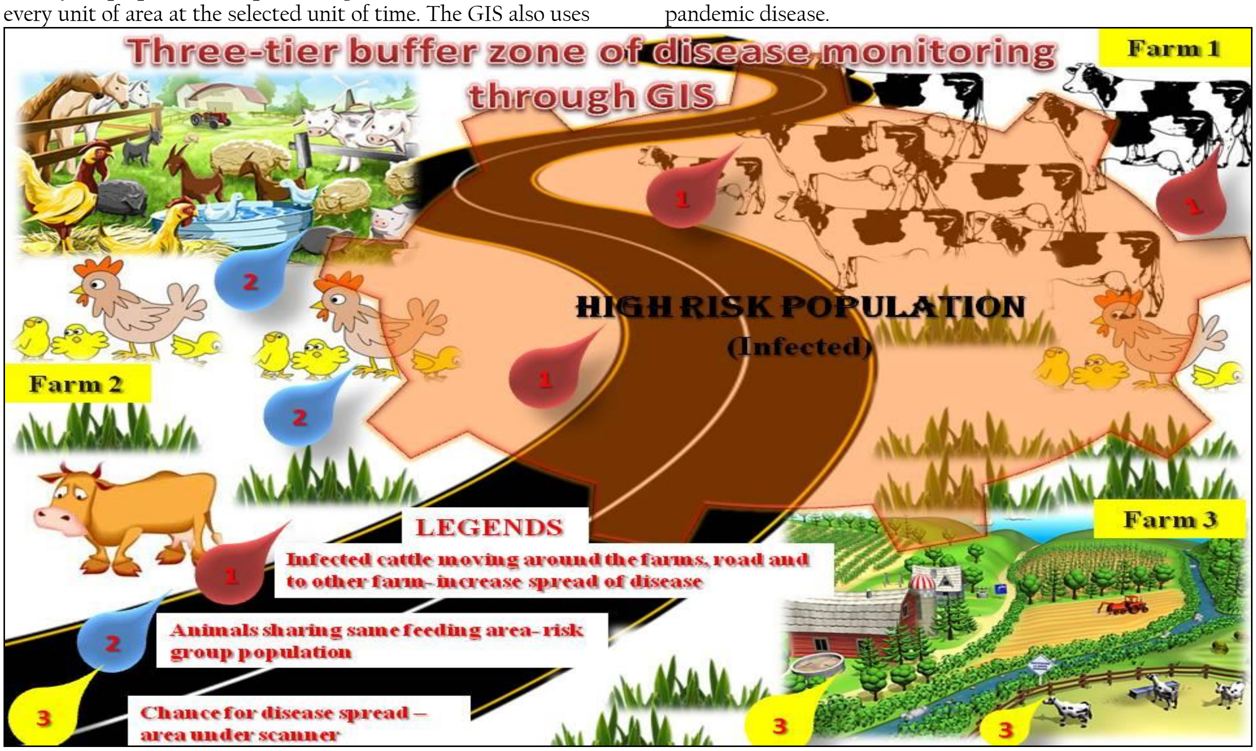

Figure 2: Three tier buffer zone of disease monitoring through GIS

DISEASE CLUSTER ANALYSIS

With the help of other programs, GIS may aid in analysis of disease clusters in terms of space and time. Geographic analysis machine (GAM) is an important method from epidemiology as well as public health point of view to identify space-time relationship concerning disease. To explore the analysis of disease patterns of various infectious diseases, space-time correlograms depicting patterns of spread of infectious disease should be made and interpreted.

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MODELING THE SPREAD OF DISEASE

Within a GIS some models using program packages as at risk (Palisade Corporation, Newfield, NY, USA) requires simulation and integration. These models include data regarding number of animals, type of animals, along with spatial data such as distance from outbreak sources along with population density and environmental factors, including climatic conditions as well as vegetation and landscape provided they are risk factors or determinants for disease spread. Sanson et al. (1994) described a model in relation to potential FMD outbreak in New Zealand. GIS have been extensively used in veterinary epidemiology for the study of different diseases, their etiology, association with ecology, transmission patterns, disease forecasting as well as the role of soil, vegetation types and other environmental factors in disease occurrence. Several viral, bacterial, parasitic and protozoal diseases have been studied to identify their spatial distribution, characteristics, and risk factors such as temperature, soil type, elevation, slope and land use. Examples are Aujeszky's disease in US, fascioliasis in Brazil, bovine tuberculosis in New Zealand and UK, FMD in France, UK, Brazil and New Zealand; Campylobacteriosis in Sweden; Rift valley fever in US (Malon et al., 1992; Zukowski et *al.* 1993; Sorensen et al., 2000; Nygard et al., 2004; Musella et al., 2011; Konrad et al., 2012; Martins et al., 2012).

Further, there are possibilities to study geographical distribution of vector, which has been done previously viz., habitat of snails (*Fossaria bullimoides*), the intermediate host of *Fasciola hepatica* in US, mosquito population dynamics in US, and Lyme disease tick distribution *Rhipicephalus appendiculatus* in US, Czechoslovakia and Africa; and distribution of arthropods in Europe (Beugnet et al., 2009; Charlier et al., 2011).

Integration of epidemiological data along with the spatial and ecologic data plays important roles in analysis of variables responsible for disease transmission (Konrad et al., 2012). Spatial analysis involves three basic steps; the preparation of an appropriate model, its proper visualization, and an exploratory data analysis, which range from simple map overlay to statistical models (Bailey, 1994; Law *et al.* 2004). Tool like visualization is crucial for depicting disease distribution changes over time. Spatial interactions as well as diffusion models are particularly important in studying emerging infectious diseases. Spatial analysis interprets and predicts population movements and inanimate objects from one place to another (Marshall, 1991; Ord and Getis, 1995). For example, the movement of people between rural and urban areas is a form of spatial interaction, which has a crucial role in disease transmission. By accurately projecting these movements, high-risk areas for disease transmission can be identified well in advance and thus intervention efforts can be planned and implemented.

PLANNING OF CONTROL STRATEGIES

The neighborhood analysis function is useful in order to identify all adjacent non-infected herds. Patterns of contact viz. shared grasslands, water ponds or purchasing sources etc can be visualized with the help of spider diagrams. This may aid in understanding the transmission possibilities of disease between herds. In planning the control of disease, GIS may be helpful in identifying areas at high or low risk for any disease based on geographical factors. For example, studies related to trypanosomiasis (Rogers 1991), dracunculiasis (WHO, 1990), theileriosis (Perry et al., 1991, Lessard et al., 1990), dengue fever (Khormi and Kumar, 2012; Alzahrani et al., 2013), GIS can be used to plan control strategies depending on vector and wild animal's habitats. GIS is proven helpful to design a national surveillance system in Israel in order to monitor and control malaria on the basis of locations of breeding sites of mosquitoes along with imported malaria cases and population centers at several locations (Washino and Wood, 1994). The National Aeronautics and Space Administration (NASA) established the Global Monitoring and Disease Prediction Program at Ames Research Center DURING 1985 in response to the call of World Health Organization to develop innovative solutions for surveillance and control of malaria (Kitron *et al.* 1994). Information on hotspots, regions and time of epidemics will help in forecasting the risk of diseases. Trends in epidemic, seasonal characteristics and variation in *Vibrio cholera* in China guided the prevention and control strategies (Li et al., 2012). The GIS can also be used to investigate the coexistence of pathogens and disease interactions that can be helpful for developing the control strategies: for example, implementation of anemia control programs in malaria endemic areas (Aimone et al., 2013); implementation of anthelminthic distribution to control zoonotic alveolar echinococcosis (Kamiya, 2007). Similarly, various diseases are successfully being predicted by GIS technology, including highly pathogenic H5N1 avian influenza in poultry (pandemic or seasonal influenza), poliomyelitis, tuberculosis, Legionnaire's disease, Shigellosis, Guinea worm disease, blinding trachoma, African trypanosomiosis (sleeping sickness), onchocerciasis (river blindness), swine flu, FMD, West Nile fever, BSE (mad cow disease), sexually transmitted diseases (STD) viz. Chlamydia, gonorrhea, syphilis and HIV/AIDS infection, MRSA infection in pigs, cattle and human, malaria, Lyme disease, lymphatic filariasis (elephantiasis), cystic echinococcosis and many other vector-borne diseases (McKee et al., 2000; Sipe and Dale, 2003; Moonan et al. 2004; Gesink et al. 2006; Cringoli, 2007; Konrad et al., 2012).

Re-emerging diseases pose a major threat in various parts of the world, partly due to climatic changes, as well as the recent spread of several vector-borne diseases into new or previously controlled areas (Rogers and Randolph 2006). The current capabilities of GIS (especially collection of satellite data with respect to spatio-temporal and spectral resolution) make it appropriate for epidemiological research regarding brucellosis (Abdullayev et al., 2012) and vector-borne re-emerging diseases (Bergquist, 2011), including schistosomiosis (Yang et al., 2006), malaria as well as leishmaniasis and dirofilariasis (Genchi et al., 2009). The GIS also helped researchers to identify areas having high prevalence and risk groups apart from identifying areas having shortage of resources and to make decisions to allocate resources in case of vector-borne diseases. The ARC GIS version-9.3 has the ability to present data spatially in case of dengue (Boscoe et al., 2004).

Application of GIS technologies in cartography revolutionized the field of epidemiological investigation of animal diseases such as Rift valley fever (Brooker and Michael, 2000; Konrad et al., 2012). It is particularly used to study parasitic infestations where intermediate hosts are involved to complete the life cycles or there is involvement of vectors to expand the distribution. In this regard, terrestrial and climate variables like temperature, rainfall, humidity, and vegetation influence the distribution of vector-borne diseases such as leishmaniasis, malaria and schistosomiasis (Hendrickx et al. 2004; Cringoli et al. 2005, Rinaldi et al. 2006, Bergquist and Rinaldi 2010), and such spatio-temporal distribution of variety of animal diseases can be sensed by the application of GIS.

Georeferencing of animal data allows the determination of spatial sampling plans too. In this regard, VETGIS Styria has been used for the determination of protection and surveillance zones during outbreaks of classical swine fever, and for epidemiological investigations relating to bovine viral diarrhea (BVD), for screening of *Salmonella* in pork and poultry meat and finally for the antimicrobial resistance monitoring programme in certain parts of North America (Kofer et al., 2000). GIS has also been found useful in management of oral fox vaccination campaign against rabies, including the management of flights, real time monitoring and identification of suboptimal bait density areas (Mulatti et al., 2011).

USE OF GIS IN ONE HEALTH

As there is an interaction between human, animal and ecosystem, the scientists are thinking of One Health concept, which involves the collaborative effort of various disciplines acting at local, national, and global level to obtain optimal health for human, animals, and environment and to better get idea about their dynamics and interactions (Dhama et al., 2013b).

However, many diseases in humans and animals are difficult to control. For example, there are no antiviral drugs available for widespread application in the field conditions, and if there were, the risk of resistance would be imminent. Hence, spread of zoonotic viral diseases such as influenza from animals to humans needs to be identified at an early stage, and strict control measures enforced, which could be aided using GIS. Furthermore, with the increasing problem of antimicrobial resistance among zoonotic bacteria such as *Salmonella* (Verma et al., 2007), *Campylobacter* (Kumar et al., 2012a), *Mycoplasma* (Kumar et al., 2012b), use of antibiotics in the treatments of animals or as growth promoters has be questioned and need to be revised. To prepare a control strategy, knowledge of the exact status of diseases is very crucial. Various studies have been conducted to know the prevalence of diseases, including brucellosis (Kumar et al., 2009; Abdullayev et al., 2012), FMD (Verma et al., 2008, Alizadeh and Moghaddam, 2012), campylobacteriosis (Kumar et al., 2012a and 2012c), salmonellosis (Verma et al., 2008; Verma et al., 2011a; Verma et al., 2011b), canine parvovirus (Singh et al., 2013), porcine respiratory and reproductive syndrome (PRRS) (Davies et al., 2007), tick-borne diseases (Daniel et al., 2004), *Echinococcus multilocularis* (Tackmann et al., 2001), lyme disease (Rizzoli et al., 2002), tuberculosis (Cadmus et al., 2011), rabies (Mungrue and Mahabir, 2011; Sadkowska-Todys and Kucharczyk, 2012), trypanosomiasis (Roger and Williams, 1993; Santana et al., 2011), visceral leishmaniasis (Hartemink et al., 2011).

In brief, it can be summarized that GIS has many applications mentioned as below:

- Rapid disease surveillance and its tracking
- Optimize data collection and management from field
- Strengthen data analysis
- Policy analysis and planning
- Rapid communication of information
- Environmental health monitoring
- Immunization and disease registries/notifications
- Population health research
- Recording travel/movement directions
- Disease management
- Situational awareness among population
- Identifying vulnerable populations
- Develop early warning systems
- Communicate complex information in comparatively simple and readily understandable form
- To assess rehabilitation service delivery
- Management of vaccination campaign

GIS IN VETERINARY EPIDEMIOLOGY IN INDIA

In India, GIS is being successfully utilized for surveillance of diseases, investigation of outbreaks and control of various infectious diseases. In certain parts of the country, disease-recording systems have been generated including the results of all samples collected during a particular disease outbreak in accordance with surveillance programs as well as disease investigation for diagnosis. Specific informations to status of disease in the district, municipalities, area or in every farm need to be recollected from this database and imported into software programs like ArcGIS or ArcView as text files in order to join with a theme of geo-referencing that include farm and municipality; veterinary district or region (Amin et al., 2012). The decision support system (GeoCREV) has been designed by the unit of Veterinary Epidemiology of the Veneto region (CREV) with the purpose of integrating the geographic information with veterinary data (Ferre et al., 2011). The distributions of vector-borne disease cases have been presented by certain workers on vector-borne disease density maps for in depth studies of the disease conditions in certain parts of India. District boundary maps, as well as block and village boundary maps, can be digitized using software like ARC GIS-9.3, for example the use of disease incidence report from different years to cover important vector-borne diseases like Kala-azar (Sudhakar et al., 2006).

Maps available from Google and other commercial sources may be more advantageous than conventional maps because of their capability to allow rapid import of data of interest viz., demographics and climate changes. Digital maps of India can be obtained from government of India or purchased from the website http://www.mapsofindia.com. Indian administrative boundaries can be divided into states, districts, tehsils and blocks.

CONCLUSIONS AND FUTURE PERSPECTIVES

GIS technology is efficient in collecting and presenting data and disease incidences, which help to formulate corrective and preventive approaches immediately for disease prevention and control. Interestingly, GIS can add a significant value to epidemiological data which lacks a spatial component, and may therefore be perceived to be inadequate for either epidemiological or management purposes. GIS is supposed to play an increasingly crucial role in three situations viz., for solving epidemiologically critical disease related issues, to monitor quickly and assess infectious diseases perhaps crossing international borders, and to aid in rapid handling of diseases which requires instant accurate reporting from a political and economic perspective. In this context, the ability of GIS to link graphic and non-graphic data facilitates powerful analysis of spatial disease distribution and related issues. These systems are being increasingly applied to animal disease control as an integral component of supporting system concerning decisions in the field of veterinary science. It may definitely improve the communication in case of an outbreak situation. It will be feasible and quite easy to draw the maps and visualize possible temporal and spatial risk factors. The lacunae in the surveillance and monitoring system can be strengthened and the collection, storage and management of data can be improved. Although over the last decade there is increase in the application of the GIS in the field of veterinary epidemiology at local and country level, a global level application to co-ordinate the notification and management of diseases of pandemic importance needs to be developed. There is a need for the specialized user-friendly GIS software to become more affordable and readily available for the application of this technology in resource-limited developing countries. Training of the veterinary epidemiologists and other staffs of disease surveillance programs should also be a top priority for the optimal use of this technology. Thus, GIS can be viewed as a potential tool for a novel approach of science, to promote the

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public health in terms of disease monitoring, surveillance as well as control policies.

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