Geographic Information Systems for the Study and Control of Infectious diseases

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Abstract
An infection process is the interaction of a pathogenic microorganism with a macro organism under certain environmental and social conditions. Infectious diseases are classed as anthroponoses (source: man), zoonoses (source: animal), and anthropozoonoses (sources: man and animal). For the epidemic to break out it is not sufficient to have a source of infection alone, but also an appropriate mechanism of transmission. Four mechanisms of infection transmission are: (i) faecal-oral; (ii) air-borne; (iii) transmissive; and (iv) contact and the main factors involved in transmission of infection are: air, water, foods, soil, and arthropods.

Recently, GIS has emerged as an important component of many projects in public health and epidemiology. GIS is particularly well suited for studying these associations because of its spatial analysis and display capabilities. Medical geography is relatively a new concept in India. The sheer size of our country, varied life styles, climatic zones and environmental conditions (all of which have a direct impact on health and ill-health) make it all the more important for India to have a health GIS.
In this investigation, the authors discuss 50 diseases, of epidemic nature and the feasible application of GIS in identifying catchment area. The paper discusses the common methodology with a special treatment to different diseases using GIS.

Introduction
An infection process is the interaction of a pathogenic microorganism with a macro organism under certain environmental and social conditions. Microorganisms causing infectious diseases parasites on host and persist due to continuous reproduction of new generation which change their properties in accordance with evolution of the environment conditions. Living inside its host, the microorganism persists for a definite period of time then moves to another host via a corresponding transmission mechanism. Hence, three obligatory factors are necessary for the onset and continuous course of an epidemic process: source of pathogenic microorganism, the mechanism of their transmission, and microorganisms susceptible to infection. Basic concepts in disease emergence are: Emergence of infectious diseases is complex; Infectious diseases are dynamic; Most new infections are not caused by genuinely new pathogens; Agents involved in new and reemergent infections cross taxonomic lines to include viruses, bacteria, fungi, protozoa, and helminthes; The concept of the microbe as the cause of disease is inadequate and incomplete; Human activities are the most potent factors driving disease emergence; Main factors are: Social, economic, political, climatic, technologic, environmental factors, shape, disease patterns and influence emergence; Understanding and responding to disease emergence require a global perspective, conceptually and geographically. In designing prospective studies careful consideration needs to be given to the following factors: Range of pathogens is potentially unlimited so microbial indicators need to be selected; Health outcomes are uncommon; Participant selection: general population, susceptible groups such as children or immuno-compromised, a representative sample; Case definition and ascertainment; Exposure assessment; Data analysis.

In this ever increasingly complex world, it is no surprise that the problems that face public health researches are becoming more and more intricate to solve. A cross-disciplinary approach may be one of the ways to discover new methods. Recently, GIS has emerged as an important component of many projects in public health and epidemiology [1, 2, 3, 4, 5, 6, 8, 13, 15, 16, 20]. Epidemiologists have traditionally used maps when analyzing associations between location, environment, and disease. GIS has been used in the surveillance and monitoring of vector-borne diseases, water-borne diseases, in environmental health, analysis of disease policy and planning, health situation in an area, generation and analysis of research hypotheses, identification of high-risk health groups, planning and programming of activities, and monitoring and evaluation of interventions. GIS enabled researchers to locate high prevalence areas and populations at risk, identify areas in need of resources, and make decisions on resource allocation. Good epidemiology science and good geographic information science go hand in hand. Many development agencies and government institutions are exploring Health GIS in India. However, the sheer size of our country, varied life styles, climatic zones and environmental conditions make it all the more important for India to have a health GIS.

Data and Files Required for a GIS and their Sources

A GIS contains four types of information and computer files: geographic, map, attribute, and data-point files. In general, modeling involves the integration of GIS with standard statistical and health science methods. Spatial interaction models analyze and predict the movements of people, information, and goods from place to place. By accurately modeling these movements, it is possible to identify areas most at risk for disease transmission and thus target intervention efforts. Spatial diffusion models analyze and predict the spread of phenomena over space and time and have been widely used in understanding spatial diffusion of diseases. By incorporating a temporal dimension, these models can predict how diseases spread, spatially and temporally, from infected to susceptible people in an area. Spatial variation in health related data is well known, and its study is a fundamental aspect of epidemiology. Representation and identification of spatial patterns play an important role in the formulation of public health policies. Some of the graphic and exploratory spatial data analytic techniques are:

- **Point Patterns:** As the name implies, also known as dot maps, attempt to display the distribution of health events as data locations. The ability to overlay data locations with other relevant spatial information is a general tool of considerable power. It is useful for delimiting areas of case occurrences, identification of contaminated environmental sources, visual inspection of spatial clusters, and analyzing health care resources distribution. A classical example of point pattern analysis in epidemiology is the identification of the source of cholera spread in London.
- **Line Patterns:** Vectors or lines are graphic resources that aid in the analysis of disease diffusion and patient-to-health care facilities flow. In their simplest form, lines indicate the presence of flow or contagion between two subregions which may or may not be contiguous. Arrows with widths proportional to the volume of flow between areas are important tools to evaluate the health care needs of different locations. Use of line pattern analysis is quite common in epidemiology to describe the diffusion of several epidemics, such as the international spread of AIDS.
- **Area Patterns**: The first stage of data analysis is to describe the available data sets through tables or one-dimensional graphics, such as the histogram. For spatial analysis, the obvious option is to present data on maps, with the variable of interest divided into classes or categories, and plotted using colours or hachures within each geographic unit, know as a choropleth map. The use of stem-and-leaf plots to classify data before area pattern analysis is more intuitive, easier to use and presents another method of incorporating dynamic graphics into GIS for use.
- **Surface and Contour Patterns:** Data of epidemiological or public health interest often occur as spatial information during each of several time epochs. The analytical techniques described previously require the pooling of information in administrative areas with well-defined geographic boundaries, and the presentation of the spatial process with maps constrained to them.
- **Statistical Monitoring:** A common measure used by epidemiologists to identify increases in case occurrence of diseases, is the ratio of case numbers at a particular time to past case occurrence using the mean or median.
- **Time Series Analysis:** The common analytical framework uses time series models to forecast expected numbers of cases, followed by comparison with the actual observation. Detection of changes from historical patterns through forecast error uses the difference between the actual and

estimated values at each point in time. In contrast to other monitoring schemes, time series methods use the correlation structure of the data at different time intervals in making estimates.

- **Temporal Cluster Analysis:** Detection of temporal clusters, understood as a change in the frequency of disease occurrence, is important to stimulate research into the causes, and to encourage the development of preventive strategies. Detection of increases in the rate of occurrence of a disease uses either the time interval of successive events, or the number of events on specified time intervals.
- **Spatio -Temporal Analytic Techniques:** Space-time interaction among health events or between health events and environmental variables is as an important component for epidemiological studies and public health surveillance. The bulk of the development in spatio-temporal patterns of health problems has been based on modeling and simulation because of the paucity of available data sets.

A number of papers [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20] discuss the applications of GIS in controlling, monitoring, and surveillance of infectious diseases. However, no research is directed towards a common methodology with special treatment to a disease with respect to GIS application. The present paper is a step towards to find a common method to identify the vulnerable area of infectious disease using GIS.

Methodology

Many factors contribute to the emergence of infectious diseases. Those frequently identified include microbial adaptation and change, human demographics and behavior, environmental changes, technology and economic development, breakdown in public health measures and surveillance, and international travel and commerce. Factors that can influence receptivity include climate and environmental conditions, sanitation, socioeconomic conditions, behavior, nutrition, and genetics. The human population is more vulnerable because of aging, immuno-suppression from medical treatment and disease, the presence of prostheses, exposure to chemicals and environmental pollutants that may act synergistically with microbes to increase the risk of diseases, increased poverty, crowding and stress, increased exposure to UV radiation, and technologic changes. Table 1 lists the different infectious diseases, its Aetiology (cause of disease), epidemiology, and vulnerable group/ conditions. A common methodology could be to develop the related databases regarding climate and environmental conditions, sanitation, socioeconomic conditions, behavior, nutrition, genetics, etc. according to the factors given in column (2). Spatial parameters like environmental conditions, temperature, soil conditions, etc. have to be interpolated using a suitable spatial analytical technique. Column (3) epidemiology provides the information regarding the carriers. The database regarding sanitation, socio-economic, behavior, etc. should be created and related maps should be digitized accordingly. The movements of the carriers should be interpolated, which could be done by using the buffer operations. Last column (4) provides the information about the group, which is vulnerable. These groups/ conditions could be easily identified and can be located on maps/ images. Temporal features like rainfall, low-high temperature, etc, should be identified in regions/ zones. Overlaying these images will give a good picture of the vulnerable area to that disease.

Table 1 Infectious diseases, its Aetiology, epidemiology, and vulnerable group/ conditions

Disease (1)	**Aetiology** **(2)**	**Epidemiology** **(3)**	**Vulnerable group/ conditions** **(4)**
Typhoid fever	Stable in environment; water, food, soiled hands, environmental objects	Patient	
Paratyphoid fevers A and B	Stable in environment; water, food, soiled hands, environmental objects	Patient, animal	
Salmonellosis	Low temperature, dry dung, home dust, animal faeces,	Man, animal, contact infection	

	food		
Pseudo-tuberculosis	Vegetables, milk, water, low temperature,	Cats, cattle, sheep, goats, wild animals	Army, boarding schools, collective bodies
Yersiniosis	Low temperature, optimum 25 C	Dogs, cats, cattle, rodents, human	Canteen, restaurant, collective bodies
Intestinal infections	Soil, open water bodies, food, milk products, Common in nature, optimum 20 to 37 C	Soil, open water bodies, food, milk products	Food catering establishments
Staphylococcal Toxaemia	Stable to heat	Patients with supportive foci, diseased animals, dairy products	
Botulism	optimum 28 to 37 C	Pickled mushrooms, home-canned vegetables, home-smoked meat	
Dysentry	Soil, utensils, food	Humans, food, water, soiled hands, environmental objects	
Amoebiasis	Water, moist faeces, low temperature	Contact, sanitary conditions,	Common for countries with hot climate
Escherichia Coli infections	River, well and tap water, foods	Food, water, calves, pig, poultry, milk products, meat	
Cholera	Faeces, soil, milk products, food	Patient, carrier	
Rotaviral Gastroenteritis	Faeces, food	Patient	
Viral Hepatitis	Water sources, soil	Vegetables, berries, soiled hands, dishes, toys	
Poliomyelitis	Water, milk, faeces	Dishes, toys,	5-7 years children
Non-poliomyelitis Enteroviral Infections	Faeces, nasopharyngel discharge, blood	Water (swimming pool), food, direct contact	
Brucellosis	Soil, milk, sheep cheese, wool, food	Domestic animal (Goats, sheep, cattle, swine, cats, dogs, camels, deer, horses)	
Leptospirosis	Water bodies, soil, foods	Rodents, cattle, dogs, cats, rats, poultry, bird	Vicinity of rivers, lakes, swamps
Respiratory			
Influenza	Chick embryo, hamsters, mice, pole cats, air	Diseased humans (sneezing, coughing, talking)	Living conditions, overcrowding, intensive migration of population
Parainfluenza	Human embryo kidney (lab conditions)	Air-borne	Infants
Adenovirus	Air	Diseased humans (nasal, nasopharyngel mucus, sputum, conjunctival discharge): contact, food, water	Infants: 6 months -3 years
Smallpox	Dry pustules and exudates, water	Diseased humans (sneezing, coughing, talking), dust	Eradicated
Diphtheria	Objects (toys, dishes), food (milk)	Diseased humans (sneezing, coughing, talking), overcrowding	
Scarlet Fever	Food (milk & sugar)	Diseased humans, fomites, foods (ice-cream, sweets)	

Measles	Human and monkeys, food	Diseased humans	Morbidity increases in Cold season
Rubella	Tissue cultures	Diseased humans	
Whooping cough	Pathogenic to human	Diseased humans	Preschool children
Parapertusis		Diseased humans, sporadic cases	Kinder gardens, school
Chickenpox	Food	Diseased humans, highly contagious	Large cities, cold season
Mumps	Highly contgiosity	Diseased humans, sporadic cases	5-15 years
Meningococcal infection		Diseased humans	
Psittacosis	Low temperatures	Birds (pigeons, ducks, etc.,)	
Legionellosis	Natural conditions, open water (blue-green algae)	Inhalation of minutest droplets of infected water	Alchol, diabetes mellitus, smoking
Blood Infections			
Rickettsioses			
Epidemic Typhus and Brill's disease	Lice faeces	Diseased humans	
Endemic Typhus		Rodents, fleas & gamasoidea ticks,	Food contaminated with urine of infected mice
Q fever	Drying & ultra violet radiation, tap water, milk, oil & meat	Animals & birds, ixodes & birds, milk, faeces, urine, placenta, amniotic fluid of animals	
Borrelioses			
Relapsing fever	Human beings, lice	Diseased humans, lice	
Endemic relapsing fever	Human beings	Diseased humans, rodents, animals	
Tick-borne Encephalitis	Low temperature & freezing	Albino mice, hamsters, monkeys, sheep, goats, horses, cows	
Malaria	Protozoa of the genus Plasmodium	Diseased humans, mosquitoes	
Leishmaniasis (Mediterranean, kala azar, Indian kala azar, East African, Chinese & American	Rodents, dogs, cats, monkeys & human beings	Diseased humans, dogs, jackals, foxes, rodents,	1- 5 years
Haemorrhagic Fever			
Tick-borne: Crimean-Congo, Omsk, Kyasanur Forest disease.	Wild animals and domestic animals, ticks of 20 species	Human beings, animals, blood transfusion, air-borne route, rodents, birds, monkeys	
Mosquito-borne: Yellow fever, Dengue Fever, Chikumgunya, Rift Valley	Blood serum	Monkeys, rodents	
Contagiouszoonotic: haemorrhagic fever with renal syndrome, Argentinian, Bolivin, Lassa, Marburg, and Ebola		Voles, mice, rats (faeces, urine and saliva), Diseased humans, food, contacts, dust inhalation	

Plague	Dead rodents, dead (frozen) humans, pus, water	Rodents, sousliks, voles, marmots and rats, animals, fleas	
Tularaemia	Water, frozen foodstuffs, dried pelts, grains & straw	Rodents, water rats, hares, muskrats, hamsters	
Skin Infections			
Anthrax	Uncultivated soil, underlying soil layers	Cattle, goats, sheep, horses, deer, pigs, camel	
Rabbies	Central nervous systems of human and animals	Animals (foxes, wolves, jackals and polar foxes, etc.)	
Tetanus		Dust, soil, and animal faeces	Woman during labor & gynecological manipulations
Erysipeas		Cooling, fatigue, and other disease	Woman
Acquired Immune Deficiency Syndrome	Blood, semen, urine, saliva	Transfusion of bloods, sexual intercourse, coagulation factors, erythrocytes, leucocytes, thrombocytes	

Conclusions

GIS is an effective tool to monitor and control the various infectious diseases. A number of papers discuss the applications of GIS in controlling, monitoring, and surveillance of infectious diseases. However, no research covers a wide number of contagious diseases with a common methodology with special treatment to a disease with respect to GIS application. The present paper is a step towards to find a common methodology to identify the vulnerable area of infectious disease using GIS. However, in some cases the method may not be very effective due to the need of high accurate data.

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