The application of Geographic Information Systems (GIS) to illustrate geographical distribution of notifiable diseases in KSA, during the 1990s

Introduction:

Geographic information system "GIS" have been defined in different ways, based on their functions, basic components and uses. Antenucci et al defined GIS as a computer system that stores and links non-graphic attributes or geographically referenced data with graphic map features to allow a wide rang of information processing and display operations, as well as map production, analysis, and modeling [1]. Parr defined a GIS according to its basic components, which include: 1)data input and editing, 2)data management, 3)data query and retrieval, 4)analysis , modeling, and synthesis, and 5)data display and output functions [2]. Cowen viewed GIS as the integration of spatial data for decision-support systems[3].

In the most restrictive usage, GIS refers only to hardware and software. In common usage, it includes hardware, software, and data. In some organizations GIS also implies the people and procedures involved in GIS operation[4].

Computers were first applied to geography as analytical and display tools during the 1960s. GIS emerged as a multidisciplinary field during the 1970s due to several factors combined to reinforce GIS development. First, computers became more accessible and less costly. Second, mainframe computers gave way to minicomputers and then workstations, which gave great power to the user and included the access to networks that has led to its own revolution in technology. Third, the types of user interface required to operate technical software changed from batch, command-line, and remote access to windowing systems and "point and click" graphic interaction[4, 5].

The current GIS list hundreds of system suppliers and sources of information and catalogs system capabilities. GIS has now developed to the extent that the contributions of a growing number of parallel disciplines have both influenced and been influenced by GIS. Disciplines now affecting GIS include forestry, transportation planning, emergency services delivery, natural hazards planning, marketing, archeology, surveying, and criminal justice[4, 5].

The power of GIS lies in its ability to 1) integrate and display the spatial and other kind of information within a single system-offering a consistent frame work, 2) allows for manipulating and displaying geographical knowledge in new and exciting ways by putting maps and other spatial information into digital form, 3) makes connections between activities based on geographic proximity, 4) allows for access to administrative records [6].

GIS functional capabilities:

GIS functional capabilities follow the standard GIS definitions; data can be input into the GIS by importing the data formats both for image-type (raster) and line-type (vector) digitized maps. These maps are commercially available. If such a map is not available, the clear alternative is to prepare a map independently. This can be done through one of three methods: electronic digitizing, data conversion, or the use of global positioning systems (GPS) [7].

GIS system captures spatial data for map preparation; Storing, handling, and integrating geographically referenced data from different sources, that is, it performs some functions of a database manager system; Retrieving or locating geographic data. GIS Produces various types of data analyses, including a capability for defining certain conditions as adjacency, inclusion, and proximity; Producing output in several formats such as maps, graphs, and tables[5].

Spatial analysis refers to the "ability to manipulate spatial data into different forms and extract additional meaning as a result. Spatial analysis capabilities allow users to examine and display data in new highly effective ways. It encompasses the many methods and procedures, developed in geography, statistics, and other disciplines, for analyzing and relating spatial information[5].

Gatrell and Bailey described three general types of spatial analysis tasks: visualization, exploratory data analysis, and model building. These ranges in complexity from simple map overlay operations to statistical models such as spatial interaction and diffusion models [8].

Visualization can be used to explore the results of traditional statistical analysis. It determines geographical distribution and variation of diseases, and their prevalence and incidence. Ranged color maps or proportional symbol maps can be used to denote the intensity of disease or vectors. The second general class of GIS methods addresses exploratory spatial analysis. These methods allow the analyst to shift meaningfully through spatial data, identify "unusual" spatial patterns, and formulate hypotheses to guide future research. Among the most important exploratory methods for epidemiology and public health are methods for identifying space-time clusters. Modeling, the final class of spatial analysis methods, modeling involves the integration of GIS with standard statistical and epidemiological methods. Spatial interaction models analyze and predict the movements of people, information, and goods from place to place, spatial interactions are central to disease transmission. By accurately modeling these flows, 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 disease [5].

GIS software:

GIS software has improved remarkably and will undergo still more changes. The following GIS software are used in the public health domain:

ArcView/Arc GIS and various extentions: this software is produced by Environmental Systems Research Institute (ESRI). It is used extensively by researchers and to a lesser extent by practitioners.

MapInfo: this is another popular commercial GIS package developed by MapInfo. It has many capabilities in public health domain, but not as many as some of the ESRI products.

EpiInfo/EpiMap: this software was developed by U.S Centers for Disease Control. It is freely available to help public health professionals develop questionnaires, customize the data entry process and analyze and map data. Data values may be entered from the keyboard or supplied in Epi Info or dBase files.

HealthMapper: It is a joint WHO/UNICEF programme based within the Department of Communicable Diseases of WHO. It is available at no cost to public health departments, and provides an excellent means of analyzing epidemiological data, revealing trends, dependencies and inter-relationships that would be more difficult to discover in tabular format.

ChildInfo: It is a database initially developed in India as a database on indicators related to nutrition and eventually expanded to include over 100 indicators on women and children. The database was developed by UNICEF, and has simple tools to link with features that allow users to easily make tables, graphs and maps based on the data[9,10].

Data and files required of a GIS in their sources:

There are essentially two types of data used in a geographical information system: cartographic data and descriptive or attribute data. Cartographic data provide a spatial or geographical reference for an object, whereas descriptive or attribute information indicates the characteristics of the object.

In general, a GIS contains four types of information and computer files: geographic, map, attribute, and data-point files. Geographic files are the heart of a GIS; they contain the data, including the coordinates defining each unit that are going to be mapped. The map files contain information on the names of geographical files and other related files forming the GIS; e.g., names or labels, coverage, colors, map scale, and lines. Attribute files are rectangular data files whose columns list variables and whose rows correspond to individual cases or geographical points. Finally, data-point files are those produced by linking interfacing attribute files and geographic files through a process called geocoding, using an identifier [7].

GIS in Health:

The idea that place and location can influence health is a very old and familiar concept in Medicine. As far back as the time of Hippocrates, (460-370 BC), the father of Modern Medicine, when he observed that certain diseases seem to occur in some places and not in others. In 1854, John Snow demonstrated the utility of mapping disease outbreaks to gain insights as to their cause. Snow, an anesthesiologist, mapped the highest density of cases that occurred in households, which used the public pump on Broad Street as their water source (figure 1)[10].

Since the 1990s, GIS have been increasingly used in public health settings [11]. The WHO and UNICEF created the Public Health Mapping Programme in 1993, to establish a GIS to support management and monitoring of the Guinea worm Eradication programme. This has been expanded to a much wider range of public health applications and now includes the promotion and use of GIS for other disease control programmes and in public health departments of a number of countries[12].

The ability of GIS to combine different entities based on their common geographic occurrence makes it a very valuable tool in epidemiological research, disease surveillance and monitoring. Some recent applications of GIS include vector borne diseases, water borne diseases, environmental health and modeling exposure to electromagnetic fields [13]. Also GIS is highly relevant to meet the demands of outbreak investigation and response, where prompt location of cases, rapid communication of information, and quick mapping of the epidemic's dynamics are vital [12.]

GIS is being used by public health administrators and professionals, including policy makers, statisticians, epidemiologist, medical and district medical officers. Some of its applications in public health are to: find out geographical distribution and variation of diseases, analyse spatial and temporal trends, identify gaps in immunization, map populations at risk and stratify risk factors, document health care needs of community and assess resource allocations, forecast epidemics, plan and target interventions, monitor diseases and interventions over time, monitor the utilization of health centers, route health workers and equipments supplies to service locations, publish health information using maps on the internet and locate the nearest health facility [14].

Spatial and Temporal Analysis in epidemiology:

Public health practice needs timely information on the course of disease and other health events to implement appropriate actions. Most epidemiological data have a location and time reference. Knowledge of the new information offered by spatial and temporal analysis will increase the potential for public health action. GIS are an innovative technology ideal for generating this type of information[15,16].

Spatial Analytic Techniques:

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: 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[15, 16].

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 sub regions, 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 Acquired immunodeficiency syndrome (AIDS) [15, 16].

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 colors or hachure within each geographic unit, know as a choropleth map[15,16].

Surface and Contour Patterns: Surface and contour analysis assumes that a health event is a continuous process observed at a set of geographic points, known as sampling points. Using the x and y coordinates of these sampling points, with an associate z value corresponding to the health event, the estimated spatial relative risk is depicted as a three-dimensional map or surface. The contour map, known as an isoline or isopleth, is the projection of the surface in a plane, and corresponds to constant z values of the defined surface.

Temporal Analytic Techniques:

Surveillance of diseases requires continuous systematic collection and analysis of a series of quantitative measurements. The detection and interpretation of changes in the pattern of the constructed time series is very important and therefore this presents a major challenge to the public health systems, as late detection of the 'disease' may result in missed opportunities for intervention.

Quality Control Charts: Industrial quality control has developed a series of methods for monitoring. Among them, three major methods appeared in the public health surveillance literature — the Shewhart test, the simple cumulative sum test, and V-mask. These methods are based on a comparison of incoming values from the time series with constant values, usually defined empirically from historical data. The advantages of these methods are that they can provide graphic information, and as such can be incorporated into an information system, helping public health professionals in the surveillance process[15, 16].

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. Based on this concept, a monitoring technique has been developed and is currently in use at CDC (Centers for Disease Control and Prevention, USA). Expected values for the current month are computed as the average of data from the corresponding, previous, and subsequent months for the last 5 years[15, 16].

Time Series Analysis: To account for the evolving nature of surveillance data, time series analysis is an alternative for monitoring case occurrence of health events. 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[15, 16].

Temporal Cluster Analysis: This method consists of counting the number of cases in each possible time interval of fixed length. The largest number of cases in any such intervals is tested under the null hypothesis that this value is likely to occur in a case of no epidemic. Application of this method involves the assumption of a constant population at risk and a constant detection rate of cases. A modification of the method has been suggested to avoid the restrictive assumptions involved in the scan statistic. Studies of temporal clusters based on the time interval between events have also been described in the literature. These methods assume that the random time intervals of successive cases form an independent and identically distributed sequence of exponential random variables[15,16].

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. Similarly with time series analysis, the basis of spatio-temporal analytical techniques is the assumption that observed spatial patterns arise from an underlying process. Modeling this underlying spatial processes allows for the study of disease diffusion process, and the estimation of linear spatial transfer functions which best transform a map at time t into that at time $t + 1$ [15,16].

Limitation in using GIS:

Data problems in the world:

In the developed world many data sets that can form at least the skeleton of a GIS project are available. Geographic data is not of equal quality, and can contain errors and uncertainty that need to be recognized and dealt with. Sources of error may be either in the positioning of objects, errors in the attributes associated with objects, and errors in modeling spatial variation. While locational data for GIS are easy to obtain in the United States, health data are not. Public policies and legal guidelines regarding confidentiality and privacy of health care information are neither clear nor complete. In the developing world, lack of data is the biggest problem. Complete data on disease conditions and health at fine scales of resolution are rare. For example, because lack of reliable data made it impossible to determine the level of malaria incidence and mortality in African countries [13].

Training on how to use the software:

There are two levels of training issues; the first relates to how to use a basic GIS package, and the second relates to how to use GIS software to better understand and manage the data. Appropriate training is important to promote the application[9].

GIS in epidemiological surveillance :

GIS is valuable in strengthening the whole process of epidemiological surveillance information management and analyses.

In data collection and management :

GIS provides an exellent means of collecting , updating and managing epidemiological surveillance and related information. It also serves as a common platform for convergence of multidisease surveillance activities. Standaradized georeferencing of epidemiological data facilitate standaradized approaches to data managments.

In data analysis:

GIS provides an exellent means of visualizing and analysing epidemiological data, thus revealing trends, dependencies and interrelationships that would be more difficult to discover in other formats[17].

Surveillance in Saudi Arabia:

Health surveillance programs in Saudi Arabia are as old as the Kingdom itself, beginning in 1933 (1353 Hejira) with a Royal decree implementing communicable disease prevention efforts. In 1940, Aramco began malaria control activities, particularly in the Eastern Region, to protect its employees from major endemic health problems. The Saudi Arabia government in 1952 began its own malaria control efforts to protect pilgrims on their route to Makkah and Madinah. This program was later expanded to include all malarious areas of the Kingdom. In 1963, the Saudi government and the World Health Organization agreed on a plan of cooperation along the lines of the worldwide malaria control program. In 1979, the First comprehensive annual report of communicable diseases was published by the department of Preventive Medicine, Ministry of Health, and over the years, the surveillance system has been expanded.

The surveillance system in Saudi Arabia functions on several levels. The primary health care centers (PHCCs) collect morbidity data for reportable diseases and compare that data with previous information in order to detect any change. This information is passed that on to the regional level for action in instituting preventive measures. At the regional level, surveillance data from the PHCCs are analyzed and the diagnosis and preventive measures verified. These data are passed on to the central authority for action. The data are compared with other regional and national figures. Regional health authorities also provide technical and educational support for employees.

Finally, the central level collects, tabulates and presents all regional data. Regional and national incidence rates are compared with each other and with international figures.The central authority verifies reasons for trends as described by local and regional levels and provide technical support as needed ,either by personal visit or by phone and fax. Finally, it ensures that preventive and control measures are within stated policy and decides whether changes in policy are needed (figure 2)[18].

Objectives of the study:

This study was conducted to investigate the application of the geographic information system "GIS" to illustrate the geographical distribution of some of the notifiable diseases in the Kingdom of Saudi Arabia during the period from 1990 to 1999.

Materials and Methods :

Source of data:

A spatially referenced database: Nonlocational or descriptive data refer to the features or attributes (surviellance data) of 15 notifiable diseases in Saudi Arabia in the period from 1990 to 1999, which are measles, mumps, diphtheria, chichen pox, whooping cough, hepatitis A, B, & C, brucellosis, meningococcal meningitis, syphilis, Amoebic dsentery, tetanus and tetanus Neonatorum.

Locational or spatial data is a coverage shape file for Saudi Arabia, scale 1:2,000,000 was provided from ministry of health, Saudi Arabia.

The epidemiological geographic information system (EPI-GIS) was established using the health mapper GIS software. Linking the descriptive database (on access xp) to the GIS software required the conversion data tables into Access 97, a DBF format . By using the database manager it was possible to join the DBF descriptive data tables to the features attribute tables using the command JOIN. We have used a suitable indicator of the disease which in this study was total number of reported cases yearly for health regions, or created a new indicator if it is not available. The pattern of spatial analysis used was point and area pattern. Digitised data from existing maps provided base layers (topography, land use, roads, rivers, surface water) on which other data can be overlaid. The distribution of cases was displayed as data locations through HealthMapper using the command overlay indicator. Each layer was related to one year or sum of years according to what was requested.

Notifiable diseases in Saudi Arabia:

Thirty one diseases were reported from 20 health regions in the annual health report of 1999. Twenty two of these disease have been reportable since 1990. They were from 18 health regions. Those disease are Whooping cough, tetanus neonatorum, other forms of tetanus, poliomyelitis, measles, mumps, rubella, chickenpox, brucellosis, meningococcal meningitis, other meningitis, hepatitis A, hepatitis B, unspecified hepatitis, amoebic dysentery, typhoid, paratyphoid, shigellosis, salmonellosis, purperal fever, rabies, syphilis and other venereal diseases.

In 1992, reporting health provinces were increased to 19 when Bishah was added to the previous ones (Riyadh, Makkah, Jeddah, Taif, Medinah, Qaseem, Eastern, Al-Ahssa, Hafr-Albaten, Asir, Tabouk, Hail, Northern, Jazan, Najran, Al-Bahah, Aljouf and Al-Qurayyat). Diphtheria was added to the notifiable diseases in the same year. Guillian-Barre syndrome was added in 1993, and hepatitis C, echinococcus (hyadatid disease), transverse myelitis, other suspected cases of poliomylitis, pnemococcal meningitis, haemophilus meningitis, and hemolytic uraemic syndrome were added in 1995. In 1996, health provinces rose to 20 provinces when Al-Qunfudah was added.

Results:

A sequence of maps was produced comparing density of reported cases in all health regions in the kingdom during 1990s. Dots in each health region on the maps mean presence of this number of cases in this health region but do not specify the real location of the cases in each health region.

The present study demonstrates use of GIS and spatial analysis to 15 notifiable diseases.

Measles: It is clear from measles maps that high density of measles cases were seen in 1992 and another increase were in 1997-1998 (figure 3, 4).

Mumps: In 1990, Mumps cases were high all over the kingdom with maximum levels in Jeddah (figure 5, 6).

Diphtheria: It was reported in the annual health report for the first time in 1992. By comparing six years from 1992 to 1997, there were few scattered cases, which increased to eight in 1993 (figure 7, 8).

Chickenpox: Graduated colors have been used to illustrate density of chickenpox every two years from 1991 to 1997 at all health regions. It was clear that the highest density of chickenpox cases were in 1991. Eastern province followed by Riyadh had the highest density of cases (figure 9).

Whooping cough: Maps demonstrate increase of whooping cough cases in 1992 and in 1998 compared to reported cases in other years (figure 10, 11).

Hepatitis A: Hepatitis A map has illustrated presence of cases all over the kingdom. In 1990, Najran was free of hepatitis A. Asir reported highest level of hepatitis A from 1990 till 1996 (figure 12).

Hepatitis B: By comparing hepatitis B cases every two years, it was clear that number of reported cases of hepatitis B did not decline during 1990s and maximum level was reported from Jeddah. Northern region had registered the lowest level of reported hepatitis B cases (figure 13, 14).

Hepatitis C: Comparing five years from1995 to 1999 of hepatitis C cases, it was clear that number of cases were increasing in Makkah and Jeddah (figure 15).

Rubella: Figure 16 demonstrated maximum level of rubella cases were in 1992, which were reported from Riyadh and Asir.

Brucellosis: Highest level of brucellosis was in 1990, northern region showed declined level of reported cases (figure17, 18)

Tetanus and tetanus neonatorum: Few cases of tetanus and tetanus neonatrom were reported, they were concentrated in Jeddah and Makkah (figure 19, 20, 21, 22).

Meningococcal meningitis: There was increase in reported meningococcal meningitis in 1997 with maximum level in Makkah (figure 23, 24, 25).

Syphilis: Maps of syphilis demonstrate low level at northern region. Eastern province reported maximum level particularly in1992 followed by Jeddah (figures 26, 27).

Amoebic dysentery: During period from 1990 to 1994, Asir reported maximum level of Amoebic dysentery. From 1995, Jeddah started to report the highest level of reported amebic cases (figure 28, 29).

Discussion:

This computer-based technology has been available for a number of years but it is only recently that it has been widely appreciated as a powerful new tool that supports health situation analysis, operations research, and surveillance for the prevention and control of health problems.

Health Geographic Information System (HGIS) has proven to be a potent tool for risk assessment, decision-making, intervention evaluation and health planning[19]. The use of this technology can be tailored to suit a wide range of application; some recent applications include vector-borne diseases, water-borne diseases and environmental health. One of the best examples is application of GIS in malaria control programs which worthy in many countries. In the kingdom effort has been made to implement GIS in malaria control mainly in malarious areas like Jizan and Asir.

GIS was also very efficient when it was used for planning of Jeddah health care facilities, Murad applied GIS to analyze accessability to hospitals in Jeddah, Saudi Arabia in 2001[20]. That application identified the parts of the city which require more attention regarding their health care supply. Identifying health care needs is one of the important tasks which health authorities frequently do. Information technology in general and GIS in particular can help the health authorities to make their decision.

GIS and remote sensing have been also used to study the transmission and outbreak of Rift valley fever (RVF) in Jizan region, Saudi Arabia.[21] Geographical databases and disease epidemiology have been integrated into decision support system.

The present study demonstrates use of GIS and spatial analysis to 15 notifiable diseases. It compares the density of reported cases from all health regions over time every year or every two years which provide quick and reliable information for discussion, planning, assessment, analysis and decision making.

Mapping of the incidence/ prevalence of notifiable diseases over geographic areas is the basic application but this information was not available. We therefore used reported cases of notifiable diseases from the annual health report, ministry of health. GIS could generate hundreds of maps and charts of the reported diseases and this study illustrates examples of them. Each layer represent data of one year , moving from one layer to another by activate layer or more reveal where was the density of the reported cases came from and what has changed during that period. Comparing maps of different years can provide excellent means of visualizing trends.

Quick response by activation of one layer or more was very informative when data have been displayed. Comparing maps and charts by using GIS technology has provided immediate visualization of the density difference of reported cases between the health regions during 1990s and was extremely effective in understanding the data.

Conclusions:

GIS technology has the potential to revolutionize health surveillance. It gives health professionals quick and easy access to large volumes of data. GIS is valuable in strengthening the whole process of epidemiological surveillance information management and analyses.

Moreover, these systems provide analytical support for the planning, programming, and evaluation of activities and interventions in the health sector. Thus, GIS can be considered part of the decision-support systems for people who formulate and follow health policy.

Limitations:

- Skills how to use GIS software which need training and imaginative use of the researchers.
- Lack of population size for each health region to calculate the incidence rates.

Recommendations:

- Use of GIS in collecting, updating, managing public health data.
- Completion of reporting data is a very important issue for GIS setup.
- Address many characteristics of notifiable disease into the reporting system e.g. risk factors, incidence and prevalence rate.
- GIS is a new technology that staffs with GIS training and skills are in high demand.

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