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Implementation of a Medical Geographic Information System: Concepts and Uses

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ABSTRACT

This paper introduces a medical geographic information system which has been implemented to enhance public-health research by facilitating the modelling of spatial processes of disease, environment, and healthcare systems in a rural area of Bangladesh. In 1966, a surveillance system was implemented to record all vital demographic events in the study area. Selected information on reproductive and child health, socioeconomic conditions, and health and family-planning interventions is being collected for the surveillance database. This paper discusses the conceptual design of integrating the surveillance database with the medical geographic information system and its use in conducting multidisciplinary health research. The paper is intended to help those who wish to implement a health-based geographic information system to understand the links between people and their environments and to better meet the health needs of target communities.

***Key words**:* Geographic information system; Geography, Medical; Bangladesh

INTRODUCTION

A medical geographic information system (MGIS) facilitates spatial data analysis and modelling of disease, environment, and healthcare systems. An MGIS is a computer system that can be used for employing the methods and theories of medical geography, which is concerned with geographic aspects of health and healthcare systems. Geographic methods have long been used as aetiological research tools to provide clues about the reasons for occurring diseases (1). According to Hunter, geography is a discipline that bridges the social and environmental sciences, and its integration and coherence derive from systems-related analysis of socioenvironmental interaction through time and over space (2). He argues that we should not focus only on the disease agent, but also on the pathogen, host, and the environment. Within the field of medical geography, these issues are considered to be dynamic, because they vary in space and time (3-11). By studying the link between characteristics of space and human health, we can gain insight into the relationships between environmental exposures and illness. This understanding may help improve the design of healthcare systems, health interventions, and community-based programmes.

Finding integrated solutions to health problems often requires an understanding of both environment and health parameters (12). Geographic information systems (GIS) can be used for studying people within their environment and a systems framework (13). A GIS can facilitate the modelling of relationships between environmental exposures and human health. Detailed

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spatial studies, particularly local-level studies that describe spatial variation of diseases, are rarely conducted, because appropriate GIS databases are not available. However, several studies (14-18) have shown the benefit of using detailed geo-referenced data and computer-assisted mapping for investigating spatial variation of health and disease.

Public-health professionals are increasingly recognizing the benefits of using a GIS to investigate the health and environmental issues and spatial components of health services. There is a growing awareness among health professionals about the usefulness of GIS, because most of them do not have skills in the theory and use of GIS, and the technology is not often used in the health sector (19). Implementation of a well-structured GIS requires not only collecting detailed geo-referenced data but also designing structured relationships between the entities and attributes within the GIS. A well-structured GIS design can facilitate spatial analysis of health- and environment-related data.

This paper presents concepts and uses of a well-structured MGIS that was implemented in 1994 in a rural area of Bangladesh to enhance the research capabilities of ICDDR,B: Centre for Health and Population Research in public health. The MGIS has proven useful for epidemiological investigations of diseases and for monitoring health-service systems of the research site at Matlab, Bangladesh. The following sections describe the Matlab MGIS and how it is being used.

MATERIALS AND METHODS

Matlab geographic information system

The Matlab study area presently includes 142 villages. Approximately, 213,000 people live in these villages. Since 1966, vital demographic events of the study area have been recorded in a demographic surveillance system (DSS). Specific health-related events have also been collected and are maintained in a record-keeping system (RKS). The MGIS, integrated with these databases, has widened the scope of investigating health problems. Although a multidisciplinary working team, comprising epidemiologists and social scientists, use the system, the GIS specialists are, however, its main users.

Conceptual design of Matlab MGIS

A well-structured MGIS requires the consideration of several issues, including organizational goals, data-flow mechanisms, data structures, and the way how the database will be used. The MGIS design should also be flexible enough to include new themes into the system (20). Fig. 1 shows the existing data flow of the Matlab MGIS. The figure illustrates that the MGIS integrates databases from various sources, such as health and demographic surveillance systems, hospital surveillance systems, spatial databases, and satellites. The databases are integrated at a fine spatial resolution, i.e. household addresses. Other spatial elements, such as administrative and social units (village), are also included in the system.

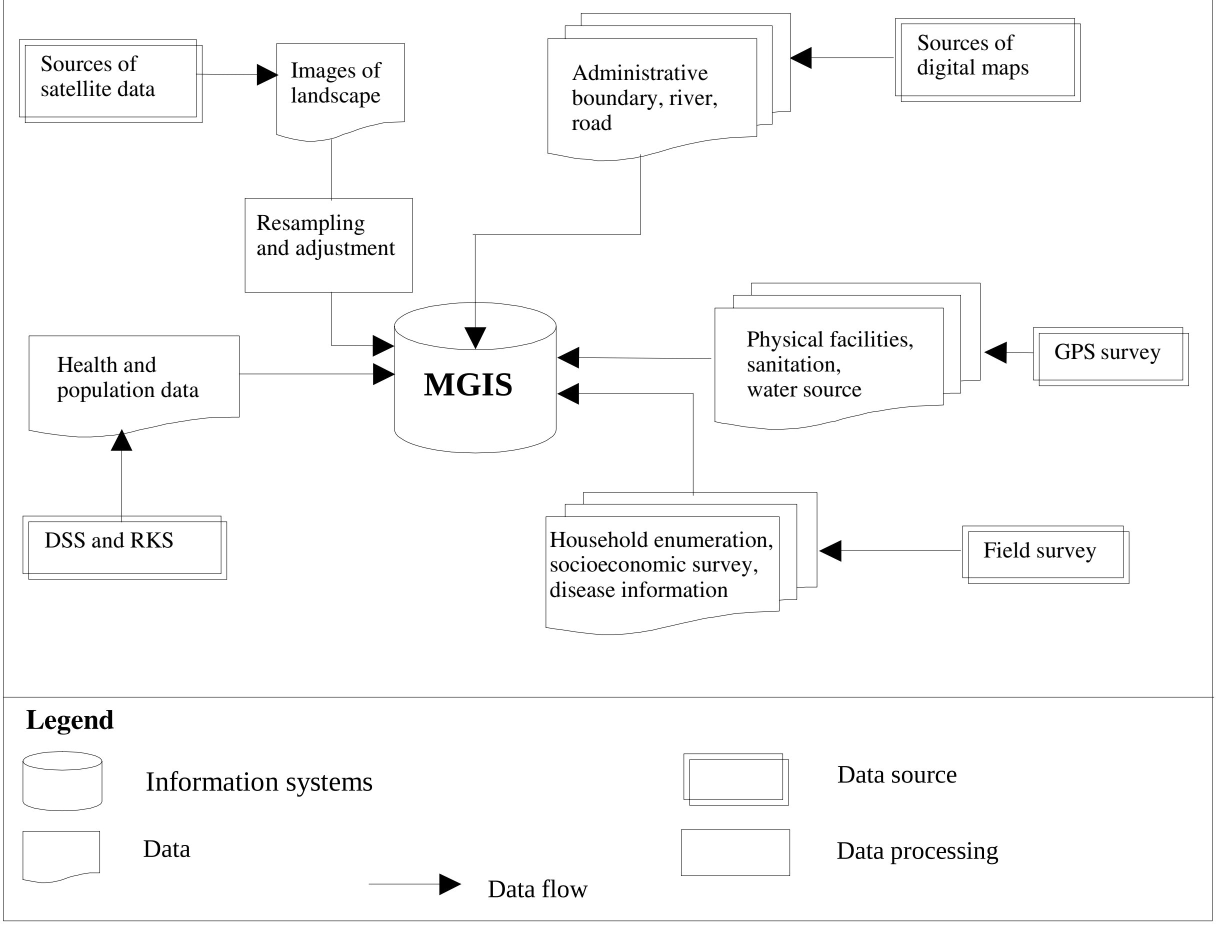
The MGIS design followed a GIS design method introduced by Pantazis and Donnay (21). Fig. 2 shows the entity-attribute relationships of the MGIS design. The locations of the geographic objects are described in real world coordinates, and each object has a logical attribute which is its identification number. Several geographic objects of the same type form an entity called a layer, and there are three types of layers, points, lines, and polygons. In this vector GIS design, a spatial object is described either by points, lines, or polygons. Each layer in the vector GIS has one or more object(s) of the same type of entity (class). The entities are expressed by their common names, such as village, household, or treatment centre. Each entity models the spatial distribution of the phenomena according to the object type of the entity. For instance, the village-level data are modelled as polygons; the health facilities and household settlements (*baris*) are modelled as points; and the rivers, canals, and embankment are modelled as lines.

The topological relationships between geographic objects and/or layers of the MGIS design are also shown in Fig. 2. The following notations are used for describing the topological relationships: adjacent (A) and superimposition (S). S is further distinguished by total (t) or partial (p). The plus sign (+) indicates presence, and the minus sign (-) indicates absence of a relationship. Logical relationships are indicated by lines, and the type of logical relationship is written next to the lines within parentheses. If all objects of a class link with at least one object of another class, the notation ‘1’ is used. ‘N’ indicates that multiple objects of a class may link to one or more object(s) of the other class(es). If an object of a class does not link to any object of the other class(es), a ‘0’ is assigned for the type of relationship.

Spatial database

Fig. 3 graphically shows the geographic data within the MGIS, which were created from 1:10,000 scale air-

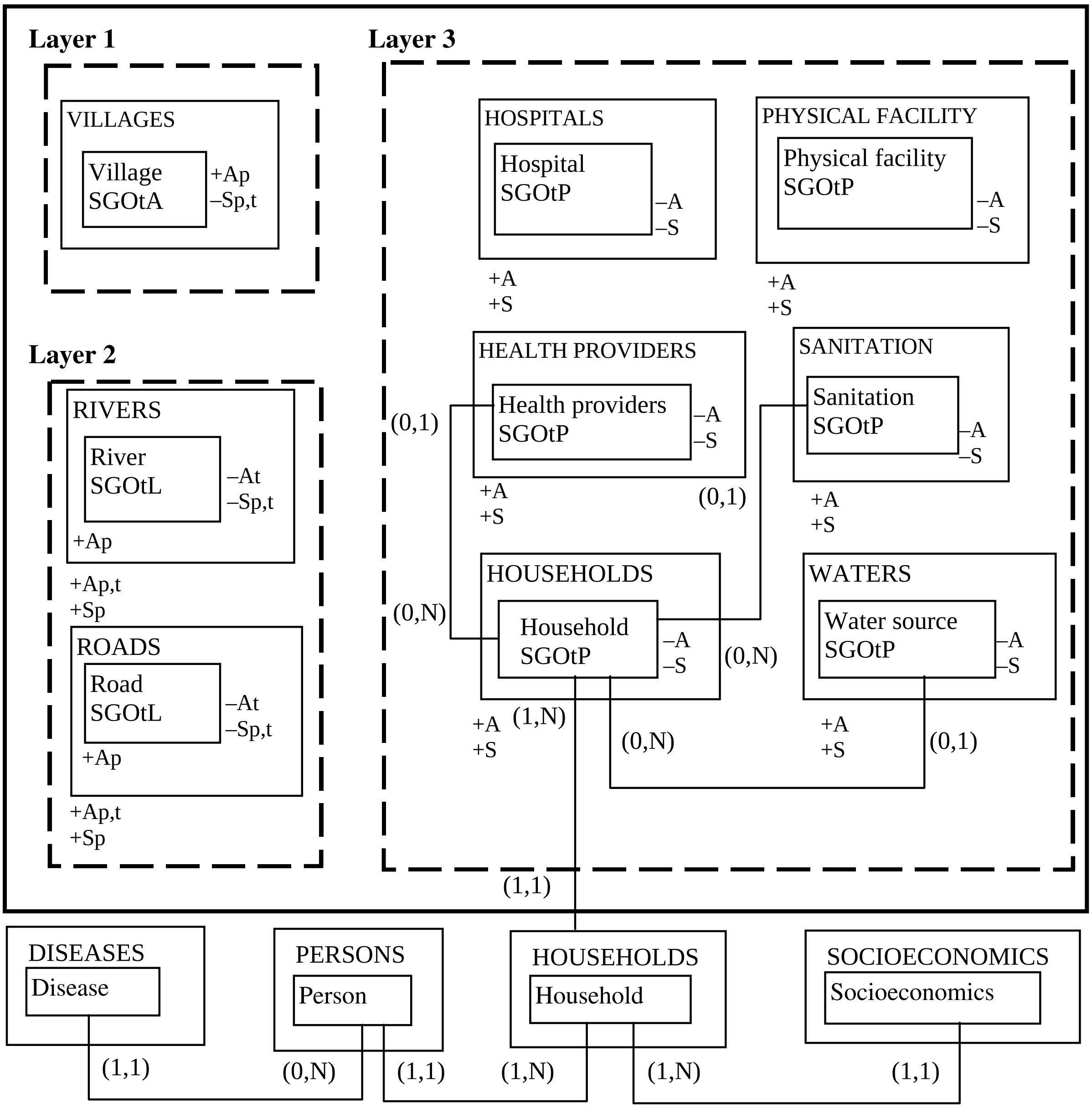
Fig. 1. Flow of data of Matlab MGIS



photos and extensive fieldwork (15). The maps were digitized and edited using ARC/INFO (22). The spatial database includes village boundaries, rivers, canals, a flood-control embankment, religious buildings, schools, roads, and *baris* (households). Brief descriptions of the spatial datasets are provided in Table 1. A ground survey was conducted to assign identification codes to the *baris* according to a demographic surveillance system of the area. An accuracy assessment of the digital map data was conducted. Several prominent features from road intersections and hospitals were digitized from hard copy of SPOT panchromatic satellite images. The same features were digitized from the base maps, and their locations were compared. The results of the analysis suggested that the sample of features on the base maps was accurate enough to pursue building a *bari*-level spatial database. Later, a differential global positioning system (GPS) survey was conducted to examine the locational accuracy of the *baris*. The results of the assessment suggest that the accuracy of the *baris* is an average of 10 metres, which is within the acceptable range for conducting spatial data analysis at the local level.

The spatial database is managed using vector GIS software where the geographic objects are encoded in coordinate pairs in the latitude/longitude-referencing system. Because of the limitations of vector-based GIS software, the attributes of features are stored in the traditional database-management software. The spatial database is also projected in a derivation of the Universal Transverse Mercator referencing system called Bangladesh Transverse Mercator (BTM). BTM uses a Transverse Mercator projection which is a conformal projection, with the line of zero distortion as the

Fig. 2. Conceptual entity relationship of the MGIS design



SGOtA=Simple geographic object, type Area
SGOtL=Simple geographic object, type Line
SGOtP=Simple geographic object, type Point

meridian. Table 2 shows the parameters of BTM. BTM was chosen as the planar coordinate system not only because of its cartographic characteristics but also because several datasets within Bangladesh are created using BTM, and thus, these datasets can easily be integrated with the Matlab MGIS.

Attribute database

The attribute data for the spatially-referenced datasets are derived from the health and demographic surveillance systems of the area. The data are managed by a relational database-management system. Since the

Table 1. Description of spatial databases of Matlab MGIS

Spatial object	Object type	No. of objects
Villages	Polygon	142
Main river	Line	129
Main river (within study area)	Line	120
Embankment	Line	17
Embankment (within study area)	Line	14
River and canals (within study area)	Line	1,247
Concrete roads	Line	21
Non-concrete roads	Line	686
Baris	Point	8,342
Physical structures	Point	Mosque=342 Bazaar=36 Primary school=97 Secondary school=27 College=2
ICDDR,B hospital	Point	1
ICDDR,B treatment centres	Point	2
ICDDR,B subcentres	Point	4

Table 2. Bangladesh Transverse Mercator referencing system

Projection	Transverse Mercator
Datum	Everest
Unit	Metre
Scale reduction factor	0.996
Central meridian	90º
Origin latitude	0º
False easting	500,000
False northing	–2,000,000

Table 3. Raster referencing metadata

Parameter	Value
Number of columns	632
Number of rows	745
Minimum X	562967
Maximum X	581927
Minimum Y	575763
Maximum Y	598113
Reference system	BTM
Reference unit	Metre

surveillance systems collect individual-level data, the data are aggregated according to the spatially-referenced units, such as villages, *baris*, and intervention/comparison areas, depending on the requirement of the analysis. The aggregated data comprise a series of tables according to the spatial units which are used for analyzing health and environmental phenomena and in producing thematic maps.

Rasterization of vector MGIS

The vector spatial data are also transformed into a raster data structure within the MGIS, so that the spatial analytical capabilities of raster GIS software can be exploited. The raster model represents space from a locational perspective in which space is divided into discrete units called pixels (23). Each pixel within the raster system is given a numeric value which represents a feature identifier, a qualitative attribute code, or a quantitative attribute value. The spatial resolution of the raster GIS database is 30 metres, which allows each *bari* to be represented by a single pixel. All pixels in the database do not represent *baris*. The pixels that do not represent *baris* are assigned an attribute value of 'zero.' Table 3 shows the raster MGIS referencing metadata within the BTM referencing system.

As shown in Table 1, the vector GIS database has 8,342 points that represent *baris*, and they are heterogeneously distributed in the study area. When *baris* were very close together during the rasterization process, these were merged into a single pixel resulting in 7,691 pixels that represent single or multiple *bari(s)*. The raster GIS includes several images that represent different features. These images include rasterized

Fig. 3. Vector GIS data of Matlab research area in MGIS

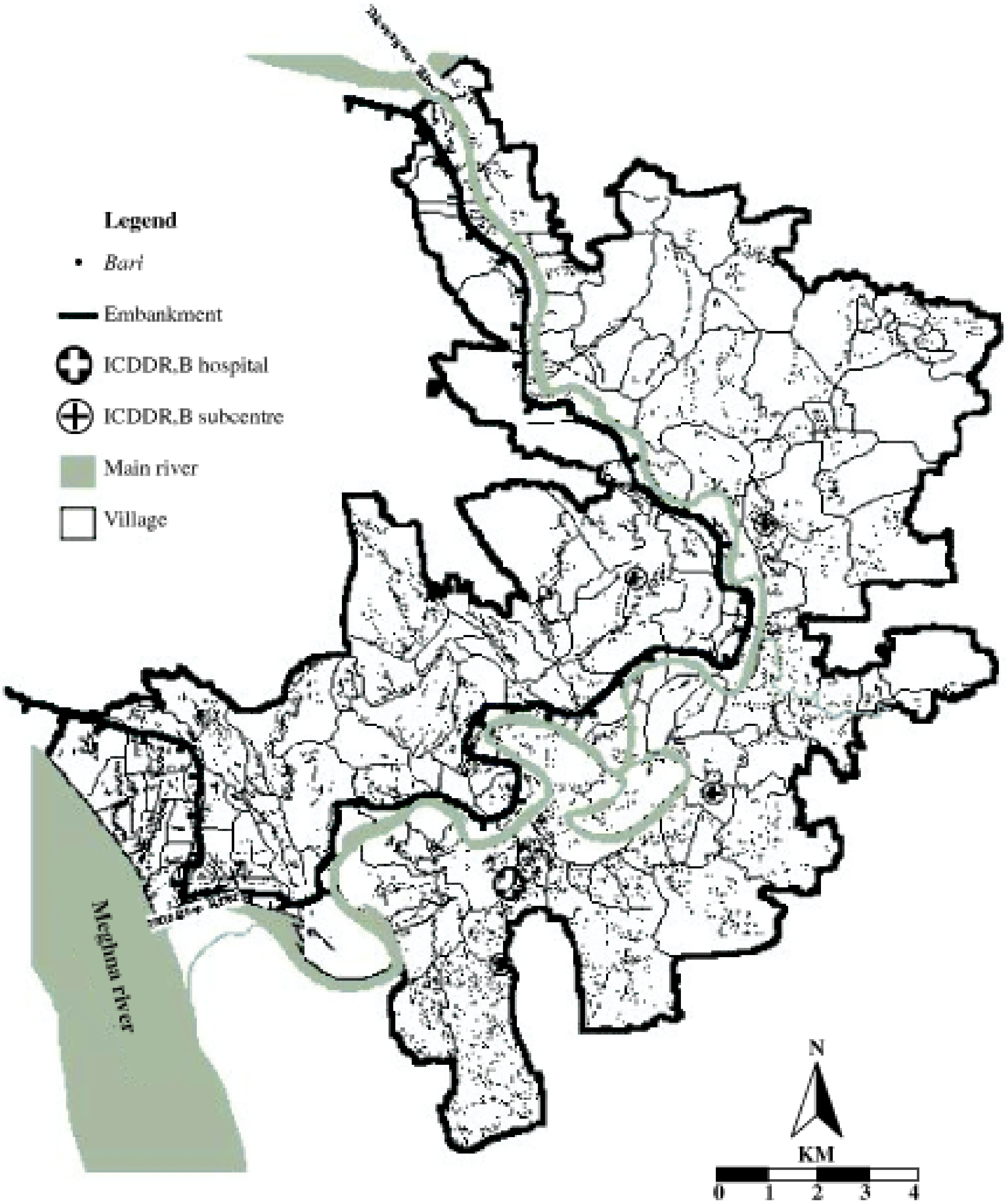


Fig. 4. Biophysical conditions of the research area in the dry season

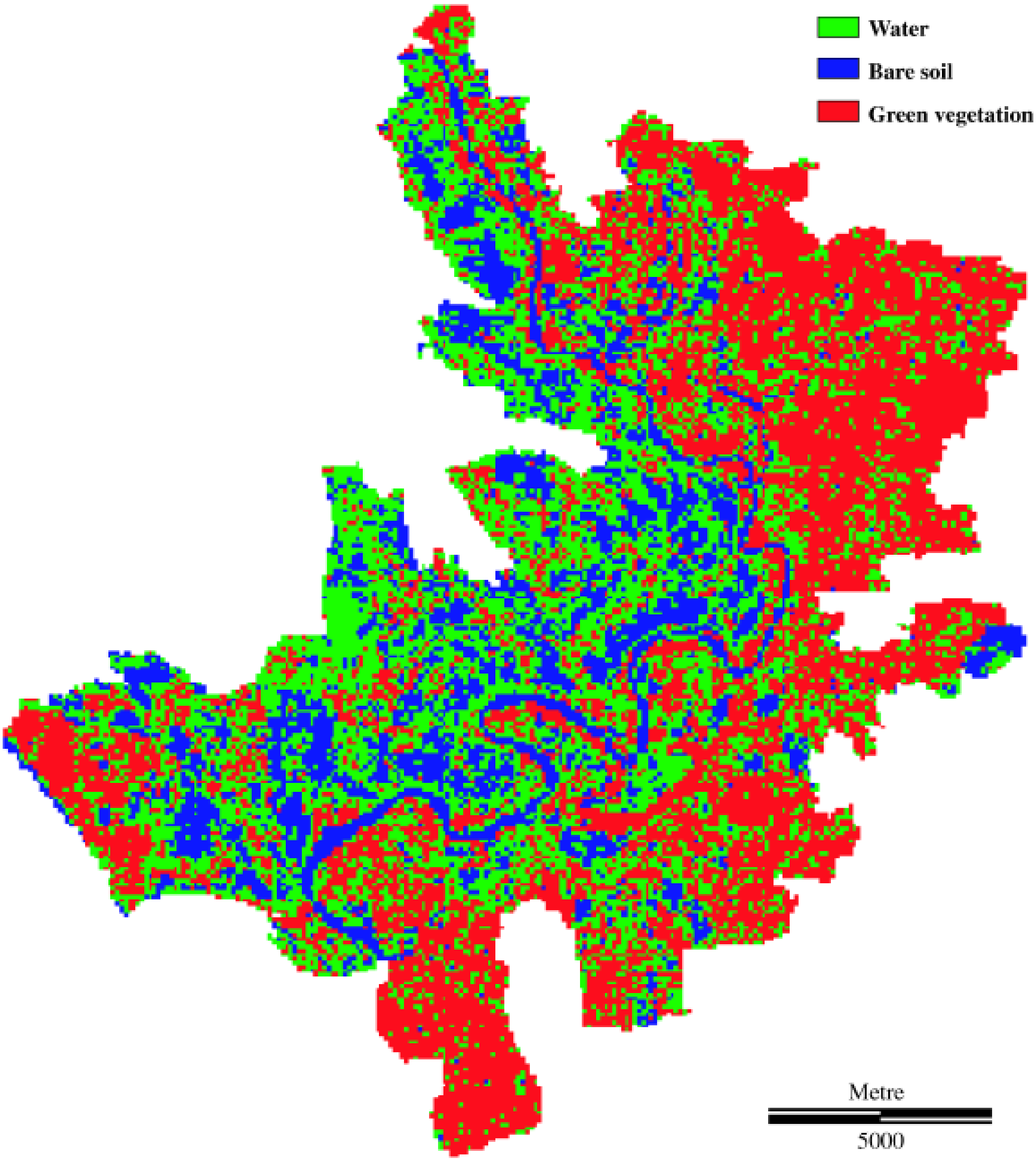
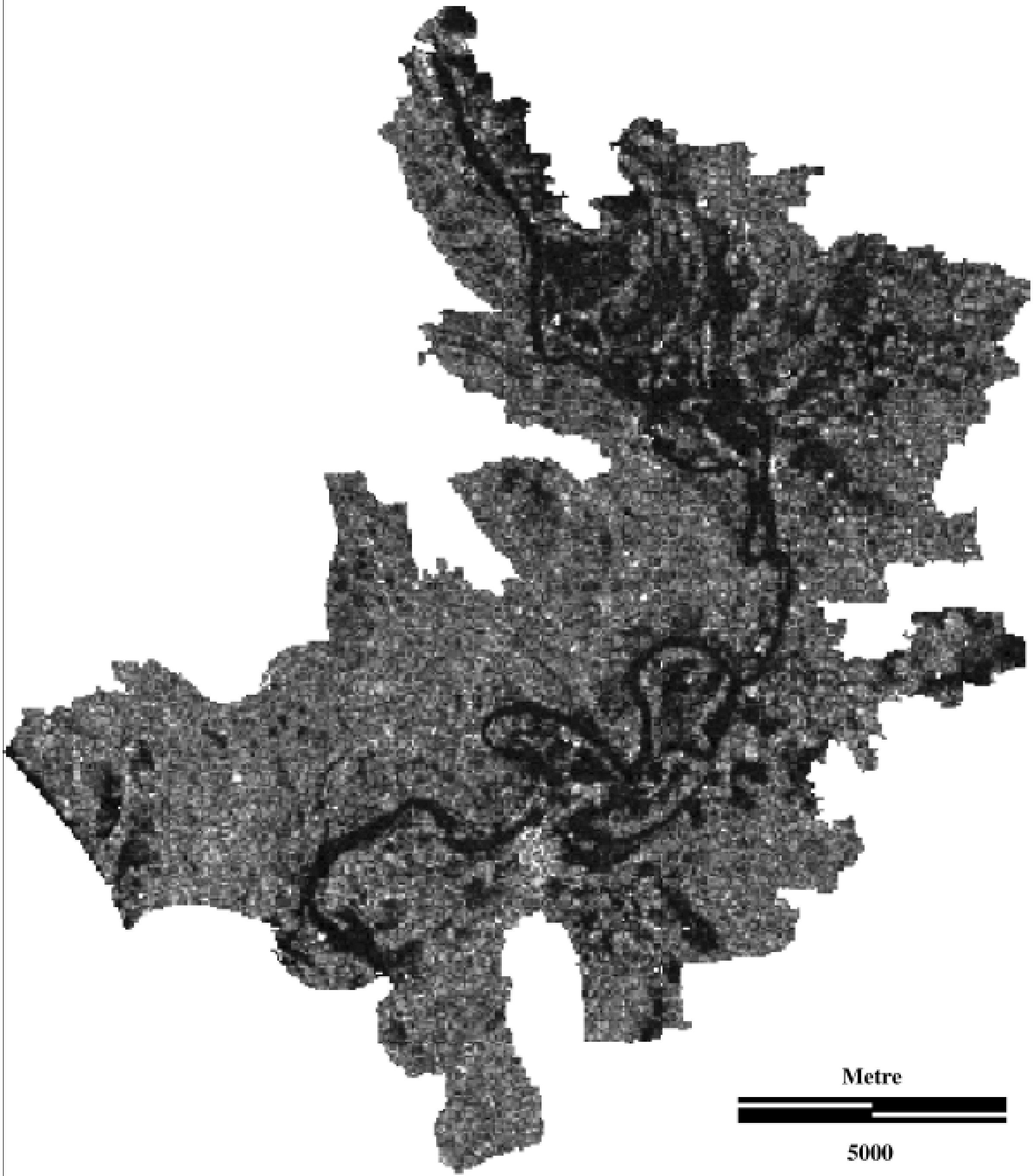


Fig. 5. Radar satellite image of the research area in the wet season



village polygons, *bari* points, and road and river network lines. The *bari* pixels are given a unique identification that allows health and population databases to be modelled as the raster system. Each dataset, such as mortality, population, sanitation conditions, and educational status, becomes a separate image in the raster system, and the data become the attributes of the pixels. The complete implementation of data in the raster system creates a holistic view of the health environment of the study area.

Satellite imagery

Satellite data have been integrated into the MGIS to incorporate environmental characteristics of the research area. A multi-spectral image of the study area was collected on 26 January 1997 (dry season) using the Landsat Thematic Mapper 5 satellite sensor. The spatial resolution of Landsat imagery is 30 metres, which allows integration of the image data with the raster spatial database without resampling. The data allowed dry season biophysical conditions of the study area to be classified (Fig. 4). A Radarsat microwave image was acquired in September 1996, which was a wet season. Fig. 5 shows that the flood-affected areas (dark) are clearly distinguishable in the Radarsat image. Microwave imagery, such as Radarsat, is essential for wet season imaging, because the signal can penetrate atmospheric barriers, such as clouds, whereas the signals used in collecting optical imagery, such as Landsat, cannot.

RESULTS

Uses of Matlab MGIS

The Matlab MGIS has been used for several health and population research projects, including studies that focus on spatial analysis of disease distributions, linking health and environment and health-services research. In one study, the differences between the spatio-temporal patterns of cholera and non-cholera watery diarrhoeas were analyzed using the MGIS (24). Several characteristics were observed in the spatial distribution of 1,273 cholera cases and 4,984 non-cholera watery diarrhoea cases, revealing differences between the spatial patterns of the two disease categories. There were many small, highly-dispersed high-risk areas for cholera. In contrast, the high-risk areas for non-cholera diarrhoeal diseases were clustered in only a few areas. These findings are consistent with a theory that cholera is a disease for which the spatial distribution is partly controlled by environmental parameters, whereas non-cholera disease transmission is controlled by other non-environmental parameters (24).

Another study that used the MGIS as a research tool defined high-risk areas of cholera, based on environmental risk factors of the disease in Matlab (Ali M *et* al. Unpublished). The risk factors include proximity to surface water, high population density, and low educational status. Data on cholera were analyzed by *bari* for two periods: 1983-1987 and 1992-1996. These periods were chosen because of the prevalence of two different dominant cholera agents. From 1983 to 1987, classical *Vibrio cholerae* was dominant, and from 1992 to 1996, *V. cholerae* El Tor was dominant. By defining high-risk areas based on risk factors, a spatial risk model was created for cholera. The model was then evaluated based on the locations of observed cholera cases. Another study used spatial analytical methods to identify spatial clusters of watery diarrhoea and related these clusters to environmental variables (16). A methodological study described spatial filtering techniques that can be used for measuring spatially continuous health and environmental variables, which are superior to individual-level variables, because they model neighbourhood phenomena and reduce error (Ali M *et* al. Unpublished).

In a health-services study, the Matlab MGIS was used for evaluating the effects of healthcare provision on mortality due to acute lower respiratory infection (ALRI) in very young children (14). Since 1988, an ALRI control programme has been in operation in Matlab aiming at decreasing morbidity and mortality of children suffering from ALRI. ALRI-specific mortality data for children aged less than two years were obtained from the health surveillance system of the area from 1988 to 1993. The ALRI mortality data were aggregated by *baris*. To avoid bias in the population size of *baris*, spatial moving averages of ALRI-specific death rates were calculated. The relationships between the ALRI death rates and several environmental and health service-provision variables were measured using regression analysis. The results showed that the ALRI mortality rate was 54% lower in the community-based ALRI control programme area than in a comparison area where there was no intervention. Greater access to allopathic practitioners was related to the lower ALRI mortality rates, while access to indigenous practitioners was related to higher mortality.

DISCUSSION

The examples described above suggest that an MGIS can be used for various types of public-health research. Studying environment in relation to health is a spatial problem (25), and the MGIS is an effective tool for addressing spatial problems in health research. An MGIS can also facilitate investigations of spatial processes of diseases and environmental phenomena. It can be used for mapping disease distributions, helping identify intermediate hosts of diseases, managing control efforts in endemic situations, and developing intervention strategies in epidemic situations.

Spatial demand and supply for healthcare resources can also be analyzed using an MGIS. The Matlab MGIS can be viewed as a model research tool that can be replicated in other settings. It offers data and tools to address the links between the environment and human health and to identify the factors of pathogenesis of diseases. It can support iterative development of health systems research with data- and computation-intensive applications. Integrating other spatial databases with the Matlab MGIS, such as elevation, soil condition, and land cover variables derived from multitemporal satellite data, can indeed facilitate many different types of multidisciplinary research.

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