GIS in Geoscience: The recent trends

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Geological features or factors vary in space and time. This fundamental characteristic is responsible for making it a most genuine application field of Geographical Information Systems, where the strength lies in defining the two dimension (X,Y extent), third dimension (Z component) and the fourth dimension (time) of spatial information. In the beginning, due to the geological variability in space and time, various attempts were made to solve complicated geological problems using multivariate and geostatistical methods. In fact these two fields were developed in a way for addressing various geological applications starting from simple data interpolation/ extrapolation to mineral exploration. These two methods almost laid the foundation of the geological application of spatial information system. In the initial years, such spatial techniques were developed and were used for data analysis of late techniques have been developed for 3-D visualisation of geological data, which eventually resulted in the development of specialised mining packages in the late 70s and 80s, having many features similar to present day advanced GIS packages. However, as it was meant to be used for commercial purposes such as mineral and oil exploration and exploitation, the cost of the packages were prohibitive and general geological community had to be content with cheaper multivariate/geostatistical packages or such package available in public domain. Some statistical packages like Statgraf, Statistica and SPSS contain useful modules on multivariate statistics, which were exploited for many geological applications.

In the initial years of GIS, the systems was visualised as a little more than a graphic tool with very limited spatial analysis capabilities. It was essentially addressing the needs of the geographical community. Therefore, the traditional geological community was skeptical about its usage in solving serious geological problems and it still preferred specialised mining software or geostatistical packages for their applications. However, the GIS developers soon realised the need for incorporating multivariate, geostatistical modules and powerful 3-D analysis and these components work often considered as advanced components and became the selling point of GIS packages. Another advantage was the low cost of the GIS packages as compared to the expence on specialised mining packages. Now it is understood that many of the geological applications can be conducted without such specialised packages. This resulted in the popularity of GIS in geological community.

Geological mapping

One of the most fundamental applications in the field of geology is the geological mapping. In geological mapping it is often required to bring on to one scale various existing geological maps often in different scales. Traditionally, it was done through graph sheet or reflecting projector, which is extremely time consuming as it needs re-tracing of the map itself in the required scale often compromising a lot on quality. With the help of GIS, maps of any scale can be scanned, georeferenced and reproduced in any desired scale thereby bringing all old maps to one scale, at which more information can be collected either by field investigation or by remote sensing techniques to prepare a final updated geological map. In one such attempt at IIRS, the published geological maps on 1:250,000 and 1:50,000 from different sources were brought on to one scale of 1:25,000. Then all maps could be compared and the final map was prepared on 1:25,000 scale, which was later updated using merged IRS-LISS-III and PAN imagery on 1:25,000 scale and supported by ground investigation.

Ground water

GIS can be used for a multiplicity of applications related to occurrence and movement of groundwater. One of the main benefits of using GIS with groundwater modelling programs is that simulation results can be displayed geo-referenced, allowing further analysis and display of topological relationship between the model and other spatial features.

In recent years various hydrological modeling options have become available in commercial GIS packages. Additionally, some hydrological packages have a live link with GIS packages and to perform specific hydrological operations. The most notable amongst them are:

- ModelGIS – pre-processor for the MODFLOW (USGS software for GW modelling) groundwater code that allows model input and output to be created, stored and displayed within ARC/INFO GIS on UNIX workstations.

- SiteGIS – Windows based software package for analysing and presenting environmental data for soil and groundwater remedial investigations. SiteGIS is an application for a desktop mapping package MapInfo.
- Visual MODFLOW- is a commercial program developed by Waterloo Hydrogeologic. Its main advantage over MODFLOW is that it allows the user to design the finite difference grid and input the boundary conditions of the model in a graphical environment. Coupling Visual MODFLOW with ArcView, the most popular GIS software, promises increased accuracy in data input and opportunity to further process modelling output in GIS environment, as well as visually appealing presentation of results.

GIS can be used for almost all application related to groundwater management such as hydrogeological database management, groundwater targeting, resource estimation, groundwater recharge estimation, evaluation of ground water exploitation impact on environment (runoff, soil moisture, vegetation growth conditions etc.), evaluation and re-evaluation of groundwater resources for urban and rural fresh water supplies. Groundwater risk assessment can also be carried out using GIS such as studies related to removal, localisation and remediation of contaminant plumes (including oil and radioactive pollution), ground water vulnerability assessment, environmental impact evaluation for civil engineering and human activity affecting ground water etc. Attempts have been made to develop Groundwater GIS using ArcView and ARC/INFO software in South Australia. This GIS contributes significantly to the assessment, development and management of the groundwater resources.

(http://www.pir.sa.gov.au/pages/sus_res/wat_man/groundwater/gis.htm).

In one novel attempt at IIRS, groundwater prospect maps were produced for entire National Capital Region of India covering around 67 topo-sheets on 1:50,000 scale. Geological, geomorphological and groundwater quality data were integrated and results were produced on 1:50,000 scale using ARC/INFO GIS software. Similar efforts are going on at the national level under Rajeev Gandhi National Drinking Water Mission to prepare ground water prospect maps on 1:50,000 scale in most drought prone districts of India.

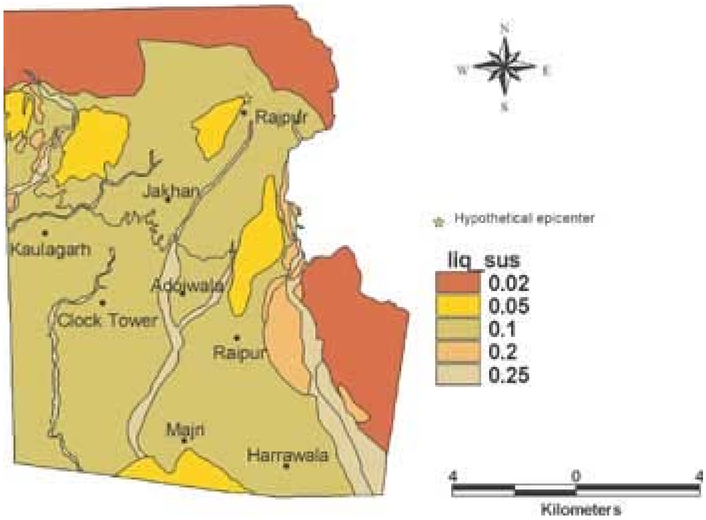

Fig. 1: Liquefaction susceptibility in parts of Doon valley
(Source: G. Dole and B. K. Srivastava, IIRS)

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Mining and mineral exploration

The use of GIS in mineral exploration is now widespread, allowing the integration of disparate digital datasets into a single, unified database. The recommended approach is to compile all of the available geoscientific data within the GIS in the context of an exploration model in order to produce a mineral potential map. Careful consideration must be given in developing the model so that all of the relevant, important aspects of the deposit being sought are represented. The model is also very important in deciding what weightages to apply to each of these aspects. In the final analysis, these weightages may be arbitrarily applied by a geologist, with an intimate knowledge of the model and the deposit. He also decides which factors related to the deposit are most important, ranging down to those of least importance (a knowledge based approach). Another approach, which is not applicable in all situations, is to use a statistical method in order to decide upon weightages. The final result is a combination of all of the weighted values, producing a map which ranks the study area by degrees of perceived prospects. One of the widely used statistical data integration technique is the Weights of Evidence Method suggested by Bonham-Carter et al. (1989) and Bonham-Carter (1994) in which the quantitative relationships between data sets representing the deposit recognition criteria and known mineral occurrences is analysed using Bayesian weights of evidence probability analysis. In this method the predictor maps are used as input maps and the end product is an output map showing the probability of occurrence and the associated uncertainty of the probability estimates of mineral deposits. In ample number of case examples, this approach has been applied using various GIS packages.

GIS is increasingly important in customising and integrating a broad range of exploration data consisting of information on drill holes with summary stratigraphic logs, rock sample and drill hole sample geochemistry, mineral occurrences, magnetic and gravity images, digital geology, current and historic exploration details, roads and railways, localities, parks and reserve forests, restricted areas and integrated bibliography. IIRS has attempted to develop such a system i.e. Mineral Resource Information System, which is a database on mineral deposits, mainly iron and manganese ore deposits of the Iron Ore belt of Keonjhar and Singhbhum regions of Orissa and Jharkhand, India (see box). Similar type of database also exits with much more capabilities and information content like CBMap which is a two-part GIS database that assembles and displays information related to mineral exploration in Central America and the Caribbean Basin. Part 1, The Prospect Database locates and describes over 1000 base and precious metal mines and prospects and the second Part 2, The Land Status Database locates and describes over 2000 mineral concessions, national parks, forest reserves, reservations, and other areas of restricted mineral entry. The data from both the Prospect and the Land Status Databases can be overlaid on a series of detailed base maps including geology, geography, and shaded relief. (www.cbmap.net)

3-D and 4-D GIS

The progress of GIS into three dimensions is a revolutionary change for the utility of the technology in oil and gas exploration and production – because depth is such a fundamental consideration. One example can be cited where Earth Science Association (ESA) has exploited ESRI's extensions to ArcView - Spatial Analyst and 3-D Analyst – to put all of the fields of the Gulf of Mexico in their proper 3-D perspective. By clicking on a field or well in a 2-D map one can see the field or well in 3-D with variables for sands, and wells correctly rendered in 3-D. Also the relevant data can be visualised in 4-D, which can represent series of maps made on a variable that changes over time. For example, it is possible to see monthly or annual maps for oil, gas or water production from a reservoir draped over the 3-D polygon for the reservoir. This is not a simple animation tool – one can still pan and zoom within the viewer and use the ESA Hot Link tool to access Reports, Charts, make Notes or export chosen data to Excel. This technology has great power in quickly examining reservoir performance, identification of permeability barriers and reservoir compartmentalisation.

Landslide Hazard Zonation

Landslide Hazard Zonation (LHZ) refers to "the division of a land surface into homogeneous areas or domains and their ranking according to degrees of actual / potential hazard caused by mass-movement" (Varnes, 1984). In the recent past various methods and techniques have been proposed to analyse causative factors and produce maps portraying the probability of occurrences of similar phenomena in future. They are as direct and indirect methods. The direct method consists of geomorphological mapping in which past and present landslides are identified and assumptions are made on the factors leading to instability, after which a zonation is made of those sites where failures are most likely to occur. The indirect method includes two different approaches, namely the heuristic (knowledge driven) and statistical (data driven) techniques. In the heuristic approach, landslide-influencing factors such as slope, rock type, landform and land-use are ranked and weighted according to their assumed or expected importance in causing mass movements. In the statistical approach, the role of each factor is determined based on the relationship with the past/present landslide distribution. With the advancement of computing technology, it has become feasible to apply various statistical methods to analyse landslide phenomena and derive at reproducible hazard zonation maps. This is further facilitated by the rapid progress in the field of remote sensing, which provides most authentic information on earth surface features and processes involved. Moreover, information from remotely sensed data can be digitally processed and integrated with other ancillary information using GIS.

Recently IIRS has contributed towards a national mission launched at the behest of Cabinet Secretary for landslide hazard mitigation in most critical areas of H.P. and Uttaranchal Himalayas, subsequent to Malpa and Okhimath landslides killing over 300 people in 1998. This project was a joint effort of 11 government departments coordinated by NRSA. The database was generated on 1:25,000 using IRS-LISS-III and PAN merged data products and data integration was carried out in ARC/INFO GIS using customised add-on software modules on Analytical Hierarchy Process (AHP). The hazard degree can be expressed by the Safety Factor, which is the ratio between the forces that make the slope fail and those that prevent the slope from failing. Using one of the simplest models, the so-called infinite slope mode Factor of Safety can be calculated on a pixel basis. For example, the following formula can be easily implemented in any raster based GIS.

$$F = \frac{C' + (\gamma - m\gamma_w)Z\cos^2\beta\tan\phi'}{\gamma z \sin\beta\cos\beta}$$

in which:
C' = effective cohesion (Pa = N/m^2).
g = unit weight of soil (N/m^3).
m = Z_w/Z (dimensionless).
g_w= unit weight of water (N/m^3).
Z = depth of failure surface below the surface (m).
Z_w = height of watertable above failure surface (m).
b = slope surface inclination (°).
f' = effective angle of shearing resistance (°).

Some parameters here can be taken from laboratory analysis as constants and the depth of failure surface can be taken as the thickness of the sliding material. The depth of the water table can be used to build up different scenarios such as slope stability in completely dry or saturated condition. We can also include the effect of seismic acceleration in the infinite slope model.

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Earthquake studies

Potential earth science hazards due to earthquakes include ground motion, ground failure (i.e., liquefaction, landslide and surface fault rupture) and tsunamis. Ground motion is characterised by: (1) spectral response, based on a standard spectrum shape, (2) peak ground acceleration and (3) peak ground velocity. The spatial distribution of ground motion can be determined using one of the following methods such as, deterministic ground motion analysis (methodology calculation), probabilistic ground motion maps and other probabilistic or deterministic ground motion user-supplied maps. Deterministic seismic ground motion demands are calculated for user-specified scenario earthquakes. For a given event magnitude, attenuation relationships are used to calculate ground shaking demand for rock sites which is then amplified by factors based on local soil conditions when a soil map is supplied by the user. IIRS has done such studies for Bhuj with respect to recent earthquake and for Dehradun region with respect to a hypothetical event using ARCVIEW. Peak ground acceleration, liquefaction probability and lateral spreading are calculated and cross-checked with actual liquefaction in Bhuj region. For Dehradun region, different scenarios were built for assessing seismic hazard. Although these studies are very much generalised with respect to data variability, at least one point is highlighted that the role of GIS is obvious in creating such maps. Such maps can be used for calculating intensity and damage in different scenarios using damage assessment methodology such as RADIUS in GIS environment.

Seismicity induced landslides can also be assessed in GIS using parameters such as Intensity; slope steep-ness; strength and engineering properties of geologic materials; water saturation existing landslide areas; and vegetative cover. Various integration techniques for seismic induced landslides like the one given in HAZUS methodology, can be implemented using simple matrix overlay in any GIS package.

Concluding remarks

In recent years, there has been explosion of GIS applications in geosciences, a simple search command in MSN shows 36,000 items for groundwater and GIS, 52,000 items for mining and GIS, 20,000 items for earthquake and GIS. However, the case studies from Indian region are limited to only a few academic departments and research organisations. The single most important reason being late realisation of the role of GIS in geoscience in India. As a result most of the professional departments either have just started or have yet to institutionalise GIS. Any useful Geoscience GIS needs enormous amount of data which lies only with professional departments, therefore, it is highly essential that such departments take a lead in implementing GIS. The need of the hour is that GIS must be seen as a part of the ERP solution in mineral related industry. Apart from the visualisation, simulation and modeling, GIS based Spatial Decision Support Systems must be explored for geological applications.

Mineral Resource Information System

An attempt has been made to develop a prototype of a “Mineral Resource Information System” to provide all basic information related to mineral deposits of a region in a most cost effective manner. In the present study, Singhbhum-

Keonjhar region of Orissa and Jharkhand has been selected, as it is one of the most important iron and manganese-producing belt of India. This area is under mineral exploration since last century and quite a large amount of data is generated.

The concept

The MRIS concept is derived from basic GIS concept and the concept of MERIGOLD, a database on gold deposits of Australia. It aims to provide spatial and non-spatial information on iron and manganese deposits and geological set up of the region. Most importantly, the non-spatial data can be edited and saved with latest information.

Information content

The information content of the MRIS is divided into three parts: spatial, non-spatial and contextual. The spatial information consists of remotely sensed data and thematic information layers. The remotely sensed data consists of raw and processed data products from various sensors such as IRS-LISS-II, Landsat 5-TM, and ERS-1-SAR (Fig. 1). The thematic information layers consists of lithology, lineaments, mine location, road network, drainage network, DEM, slope, aspect and location map. All such information and data layers are organised using GIS and image processing packages such as ERDAS Imagine 8.4 and ARC GIS 8.1. The non-spatial database is stored in a MS Access file and the contextual information is stored in hyper linked MS Word file. The non-spatial database consists of basic information on deposits, year wise, grade wise production, chemical analysis and mining environment.

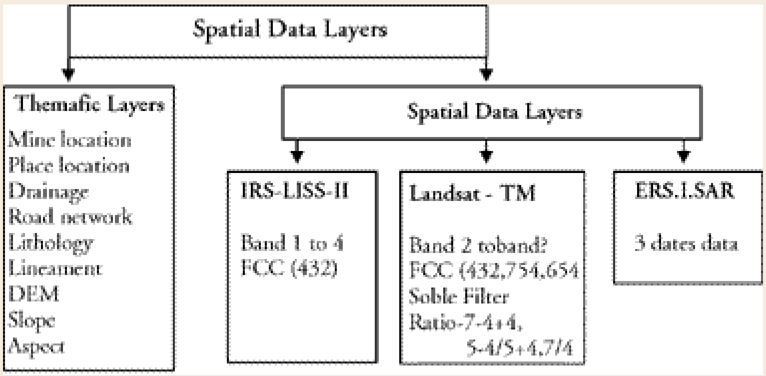

Fig. 1: Organisation of spatial data

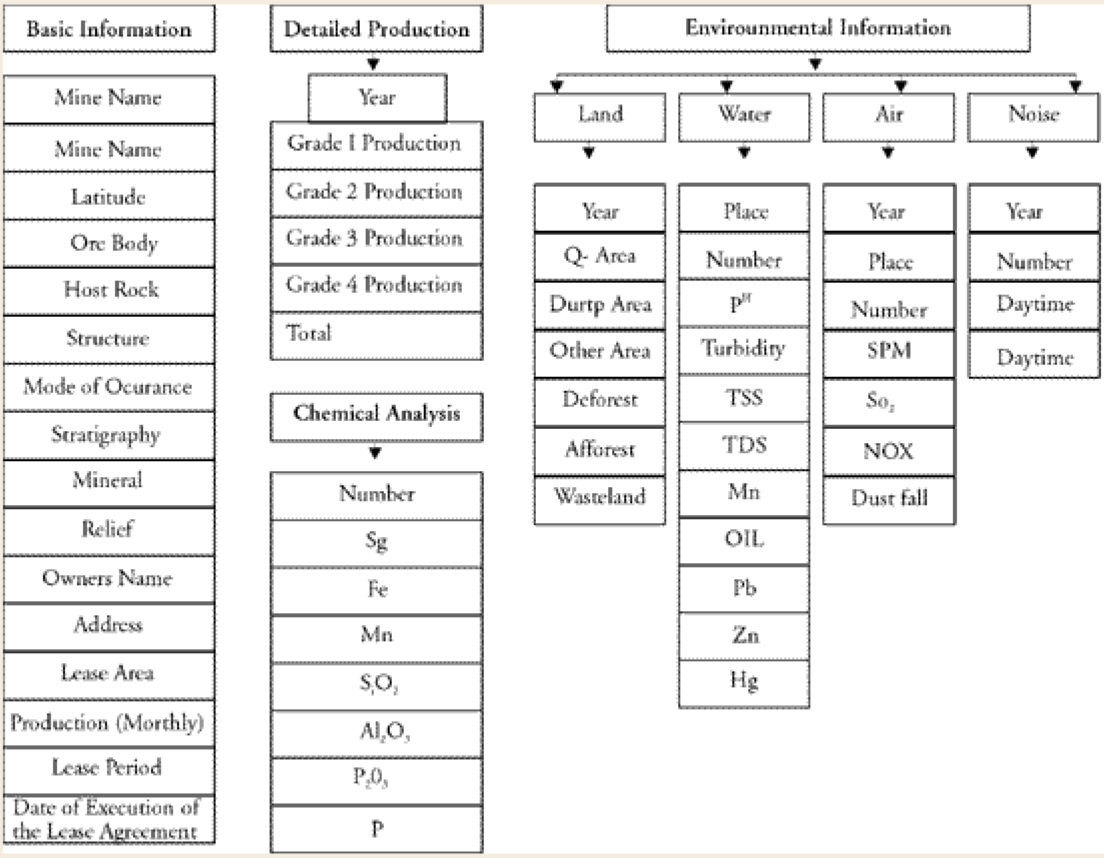

Fig. 2: Organisation of non spatial data

Software design and implementation

The MRIS is designed in such a way that its concept can be used for other related fields, where input data is spatial or non spatial or both. The information regarding a mine can be obtained through graphics by clicking on the appropriate location or selecting from the adjacent scroll bar, where all mine names are kept in order. Following are the information content and salient features of the prototype MRIS v 1.0 (Fig. 3 and 4).

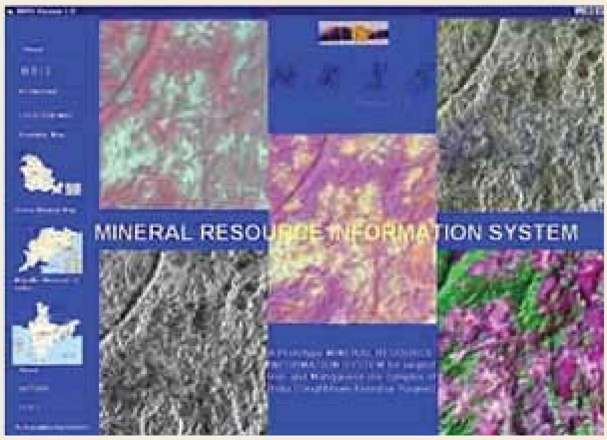

Fig. 3: Front Page of MRIS v 1.0

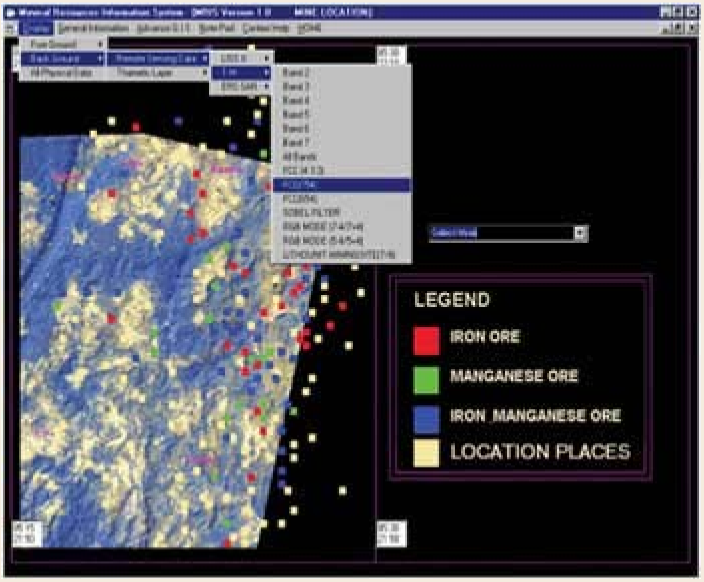

Fig. 4: Different options for displaying mining locations and satellite

- It provides information on geology, mining, production, chemical analysis of ore and rock sample's, and environmental data (air, water and land).
- User friendly information available on point click or through pull down menu.
- Commercial GIS software independent, however, it can be linked to ARC GIS 8.1 if available.
- Produces report various types of line graphs, bar graphs, etc.
- Database updating possible with password option.
- Context help file contains complete geological information in report form, which can be updated in MS WORD with additional information.
- Software uses mostly Microsoft resources (Access and Word)
- MRIS is developed using Visual Basic 6.0
- System used: P-III and Windows NT
- A software package named as "MRIS version 1.0" is developed with all components including database.
- This can be installed in any Windows NT machine and the full capabilities of the software can be utilised.
- System requirement: 133 MB of disk space with 87 MB space for samples, thus total software installation requires 220 MB for full functionality

Application potentials and limitations

The MRIS as visualised can be used for various purposes such as for easy accessibility of geological information, for sharing of geochemical data, in mineral exploration, revenue collection, environmental assessment and management, for mineral customer support, and for research and education purposes. In developmental stage as in the present form, MRIS has various limitations. The database is not complete in many respects due to non-availability of information from mining authorities. The satellite data provided also does not cover completely the study area.

Conclusion

The present attempt has demonstrated that an information system with spatial and non-spatial information can be developed and can be used by clients without expensive commercial GIS packages. In the present case only for preparing spatial data layers, GIS and DIP packages were used, For data access, display, query and updating of non-spatial data, MRIS can be used. The system can be packaged and given to users who can update the database and use it as per their needs. Most importantly, it has highlighted that in the era of software customisation, it is essential that some basic component of any information system should be independent of any GIS package, then there should be gradual entry into the GIS system through customised menu system, and finally most experienced users can be exposed to the GIS system as it is, thereby allowing gradual learning of the spatial information system. Secondly, for most of the basic usage of any information system, investment in terms of GIS infrastructure and GIS training is not mandatory. Thus in every attempt to develop spatial information system, particularly targeting different user groups, it is worthwhile to consider this MRIS philosophy.