Geographic Resources Decision Support System – an Open Source GIS

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Abstract

Fully structured and matured open source spatial and temporal analysis technology seems to be the official carrier of the future for planning of the natural resources especially in the developing nations. This technology has gained enormous momentum because of technical superiority, affordability and ability to join expertise from all sections of the society. Sustainable development of a region depends on the integrated planning approaches adopted in decision making which requires timely and accurate spatial data. With the increased developmental programmes, the need for appropriate decision support system has increased in order to analyse and visualise the decisions associated with spatial and temporal aspects of natural resources. In this regard Geographic Information System (GIS) along with remote sensing data support the applications that involve spatial and temporal analysis on digital thematic maps and the remotely sensed images. Open source GIS would help in wide scale applications involving decisions at various hierarchical levels (for example from village panchayat to planning commission) on economic viability, social acceptance apart from technical feasibility. GRASS (Geographic Resources Analysis Support System, http://wgbis.ces.iisc.ernet.in/grass) is an open source GIS that works on Linux platform (freeware), but most of the applications are in command line argument, necessitating a user friendly and cost effective graphical user interface (GUI).

Keeping these aspects in mind, Geographic Resources Decision Support System (GRDSS) has been developed with functionality such as raster, topological vector, image processing, statistical analysis, geographical analysis, graphics production, etc. This operates through a GUI developed in Tcltk (Tool command language / Tool kit) under Linux as well as with a shell in X-Windows. GRDSS include options such as Import /Export of different data formats, Display, Digital Image processing, Map editing, Raster Analysis, Vector Analysis, Point Analysis, Spatial Query, which are required for regional planning such as watershed Analysis, Landscape Analysis etc. This is customised to Indian context with an option to extract individual band from the IRS (Indian Remote Sensing Satellites) data, which is in BIL (Band Interleaved by Lines) format. The integration of PostgreSQL (a freeware) in GRDSS aids as an efficient database management system.

Introduction

GIS (Geographic Information System) is a system of hardware, software and procedures to facilitate the management, manipulation and analyses of spatial-temporal data. Its application is wide ranging from micro level to macro level planning. However this boundless capabilities are limited by ones ability to visualise its implications. It has become an important component in regional planning with a pivotal role in major decisions related to earth resources. This includes urban sprawl analysis involving growth and migration of population, location of industries, employment activities, basic infrastructure (water, electricity, etc.), transportation (railway and road networks), drainage system (river basin quality, etc.), town planning, etc.

With the growing incidence of ecological and environmental impacts, GIS has been used to analyse the impact of human activities on the ecosystems. This is possible due to the options to display and analyse changes in the geo-referenced temporal and spatial data. This helps to solve complex problems regarding planning and management of resources and also biophysical modeling. The data input includes spatial, statistical and thematic data derived from a combination of existing maps, aerial photographs, interpretation of remotely sensed images and secondary data from the government agencies (census data, land use data, etc.). Digital image processing technique aids in restoration and rectification of data, segmentation of data and also in visualisation. The integration of spatial and temporal technology help in addressing challenges faced by the environment. The integration of GIS with remote sensing data offers enhanced capability for inventorying, mapping, monitoring and modeling to understand many environmental processes. This integration also helps in using remotely sensed image to update the GIS and also maps. The GIS thematic data and attributes are used to guide image classification. GRASS, a GIS based open source software distributed under the GNU GPL (General Public License) integrates these two technologies resulting in numerous advantages.

GRASS was originally developed by the U.S. Army Construction Engineering Research Laboratories, a branch of the US Army Corp of Engineers, as a tool for land management and environmental planning by the military. GRASS is a raster/vector GIS, image processing system, and graphics production system (http://wgbis.ces.iisc.ernet.in/grass). GRASS contains over 350 programs and tools to render maps and images on monitor and paper; manipulate raster, vector, and sites data; process multi spectral image data; and create, manage, and store spatial data. GRASS has the options to interface with printers, plotters, digitizers, and databases to develop new data as well as manage existing data. GRASS uses both intuitive windows interface as well as command line syntax for ease of operations and is supported by developers and users worldwide. Numerous sub modules existed in GRASS but most of them are in command line arguments. The command line syntax for GRASS was cumbersome and time consuming for individuals, who were not exposed to computer programming and did not possess any programming skills. In order to overcome this difficulty, it was the necessity for an economically viable, technically superior and a more flexible spatial and temporal analyses tools that led to the development of a user friendly graphical user interface (GRDSS) for GRASS GIS along with the database component as depicted in figure 1.

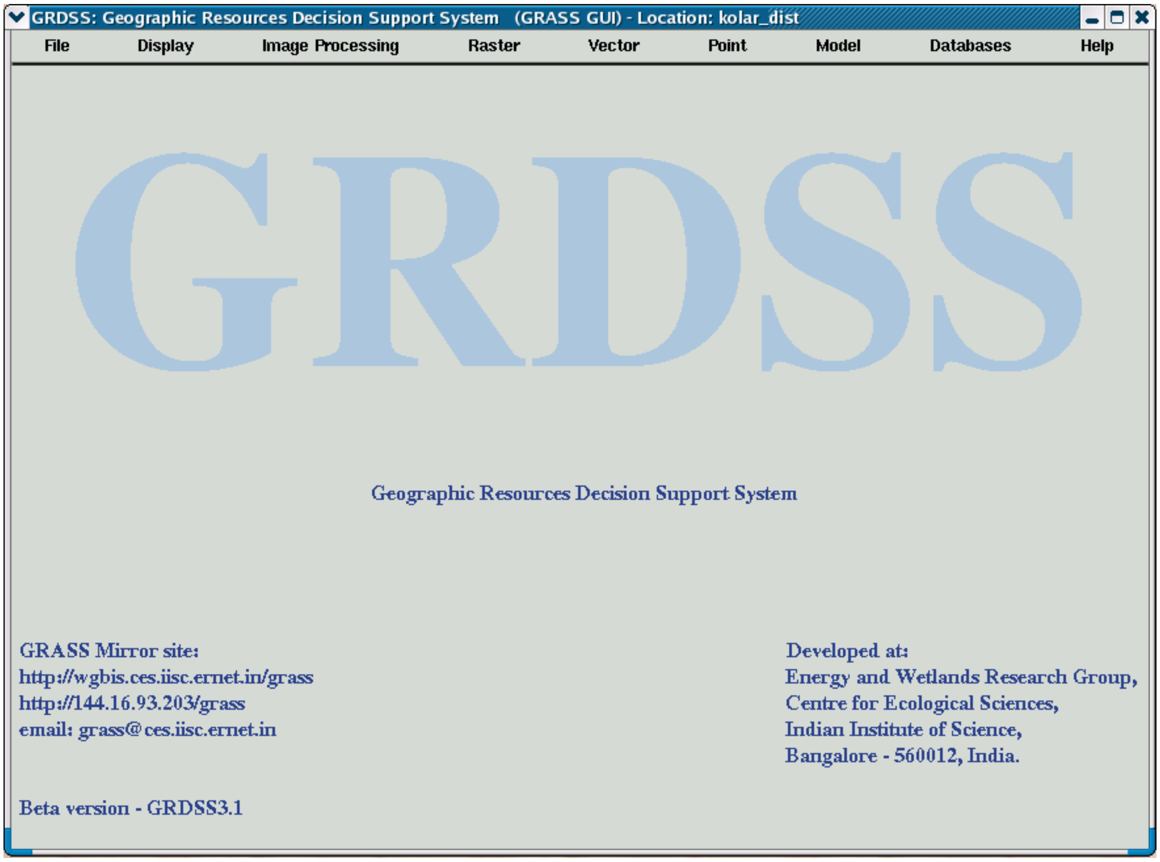

Figure 1: **GRDSS**

The process of developing the GUI also involved undertaking the task of identifying the commands and implementation of the interfacing code. The layout of the interface had to be altered to suit the end user's perspective. Figure 2 shows the structural diagram of the GRDSS graphical user interface.

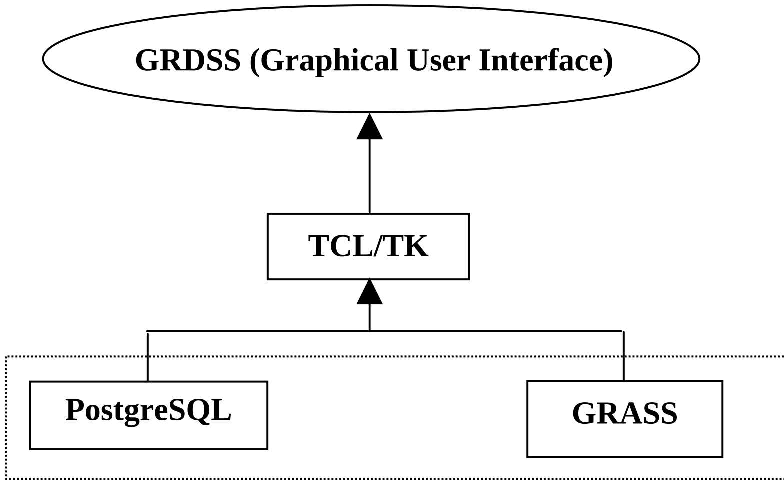

Figure 2**: GRDSS - GUI structural diagram**

Methodology

The current development in GRDSS in the allied technologies of remote sensing and GIS is to build an integrated spatial decision support system (SDSS). Recent advances in the development of graphical user interface based programming have enabled rapid prototyping, testing, and application development. Various GIS packages such as MapInfo (http://mapinfo.com), Idrisi (http://www.idrisi.clarku.edu), Geomedia (http:// w ww.intergraph.com) etc were comparatively studied as per the set criteria listed in table 1.

Sl. No.	Characteristics	MAPINFO	IDRISI	GEOMEDIA	GRDSS
1.	Menus and user interface	Y	Y	Y	Y
2.	Command line syntax	N	N	N	Y
3.	Data Import/Export	Y	Y	Y	Y
4.	IRS LISS–MSS Data extraction (Data in BIL and BSQ format to individual spectral bands)	N	Y	N	Y
5.	Map Registration & projection	Y	Y	Y	Y
6.	Digitization (vector data)	Y	Y	Y	Y
7.	Coordinate transformation	N	Y	Y	Y
8.	Buffer generation	Y	Y	Y	Y
9.	Digital Image analysis	N	Y	Y	Y
10.	Map Algebra	N	Y	Y	Y
11.	Terrain Modelling (DTM)	Y	Y	Y	Y
12.	Distance calculation	Y	Y	Y	Y
13.	Database support	Y	Y	Y	Y
14.	Error Explanation	Y	Y	Y	Y
15.	Help	Y	Y	Y	Y
16.	Online manuals and tutorials	Y	Y	Y	Y

17.	Proprietary software	Y	Y	Y	N
18.	Open source	N	N	N	Y
19.	Free software	N	N	N	Y
20.	Mailing List	N	N	Y	Y
21.	Digital Elevation Model (DEM)	Y	Y	Y	Y
22.	Fly through and animation	N	Y	Y	Y
23.	Fusion	N	N	N	Y

Note: IRS: Indian Remote Sensing Satellite, LISS: Linear imaging self scanner, MSS: Multi Spectral Scanner, BIL: Band interleaved by line, BSQ: Band Sequential Format.

Y = features present
N = features not present

Table 1: **Comparative analyses of GIS softwares**

The limitations of the commercial GIS softwares were also considered while implementing the GRDSS to offer optimal performance. The following feature characterises GRDSS development.

i). System requirements - The GRDSS GUI sources can be compiled on all PC's running LINUX. It is a full system with X Window graphical user interface. Minimum PC can be 486 (or better), with "LINUX". The Linux- system with a three-button mouse, 32 MB RAM (64 MB recommended) and a hard disk space of 250MB (beside DOS/Windows partition). GRDSS binaries require only 45-50 MB and to compile additional 150 MB disk space is required (to store the sources). The GRDSS source code can be compiled using a GNU "C" compiler.

ii). User friendly interface and menu organisation - The user interface is designed to suit to the users in India and those who are not much exposed to programming. The interface is customized and simplified comparable to proprietary softwares in the market. The menu is organised sequentially in a user-friendly environment that satisfies both specific and common users.

iii). Functional capabilities - GRDSS is equipped with the functional capabilities such as data import/export in different formats (including the IRS data format), map analysis, data modeling, buffer generation, spatial and non spatial statistical calculation, digital image processing (spatial, spectral and temporal data analysis), raster, vector and point analysis and query, map calculator, terrain modeling, erosion modeling, report generation and can also handle spatial and non-spatial database (both spatial data and attribute information), etc.

iv). Help facilities – GRDSS extends all the help facilities present in GRASS. All the commands with their functions and options are present in help to get started with the GRDSS. There is a mailing list and mailing list archive where users can post their doubts and can discuss through e-mails worldwide. The help facilities and the documents available on the GRASS official website provide enough information to start with the software.

v). Error explanation and manual support - GRDSS is equipped with error explanation, which automatically renders error messages through the mail facility in Linux. Beside many sample data sets are available on the GRASS official website, including online tutorials and manuals.

Figure 3 shows the design and conceptual diagram of GRDSS.

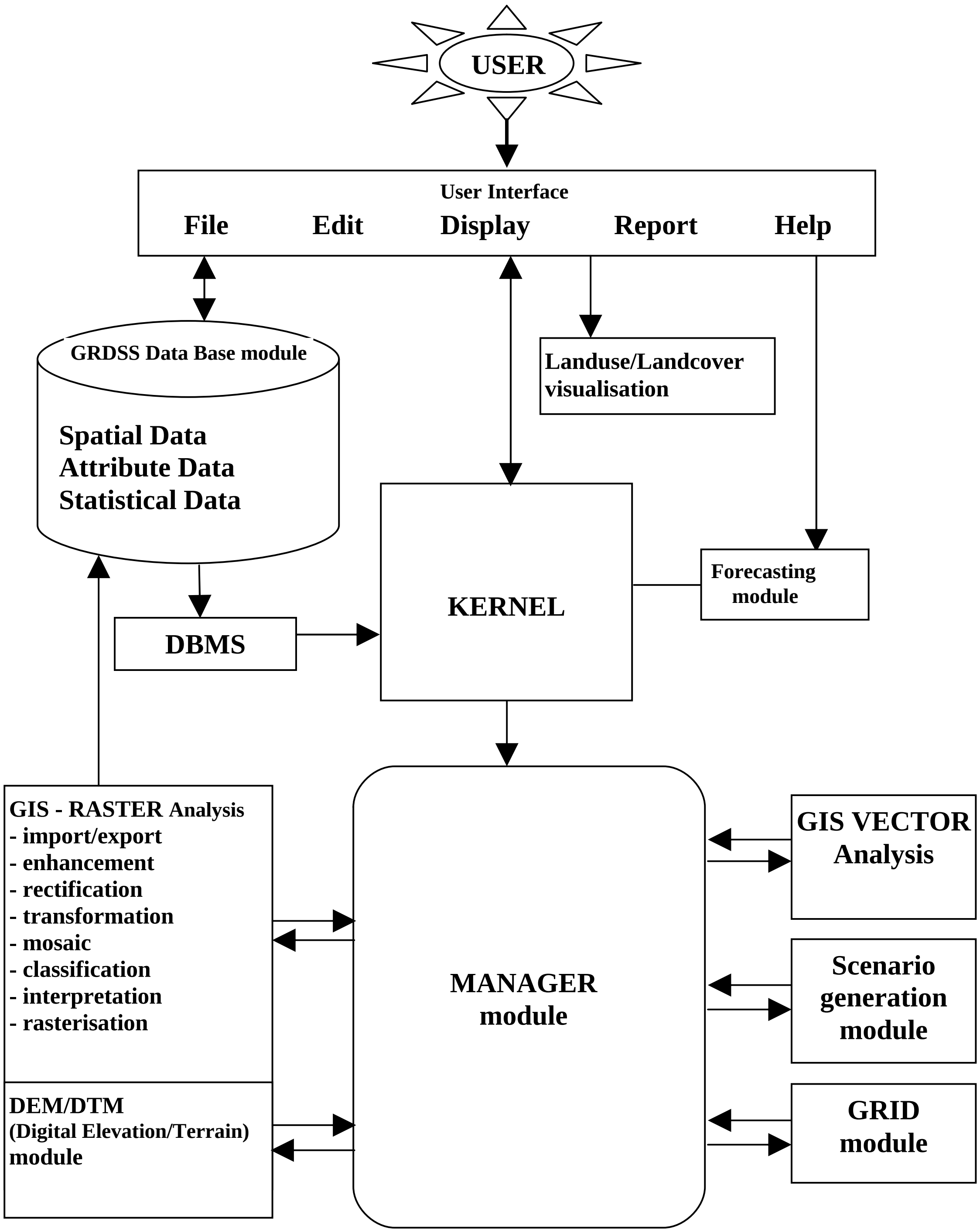

Figure 3: **The GRDSS design and conceptual diagram.**

Overview and description of GRDSS

GRDSS supports all basic features required by any GIS package.

i). It supports a wide range of data Import/Export that are also supported by other standard GIS including IRS (LISS3 and PAN) data extraction and DTEM/DTED (Digital Terrain Elevation Model / Digital Terrain Elevation Data) extraction.
ii). It has capabilities for displaying the raster/vector images. GRDSS can further interact with commercial plotters and printers and is capable of color management.
iii). GRDSS has the image processing capabilities (rectification, enhancement, transformation, classification, data analysis, etc.).
iv). GRDSS has the capability of manipulating raster, vector and point data. This includes digitization, topology creation, map overlay, arithmetic operations, DEM generation, decision support, distance, area and statistical report, etc.
v). It can perform wetland analysis, terrain modeling with slope, aspect, relief, profile, cost between two locations to analyze terrain data, runoff-modeling, etc.
vi). Thematic data preparation, histogram generation, and charts of different formats.
vii). Database (PostgreSQL) management system.
viii). Online tutorials with help manuals and sample datasets. Figure 4 depicts the GRDSS hierarchical menu arrangement.

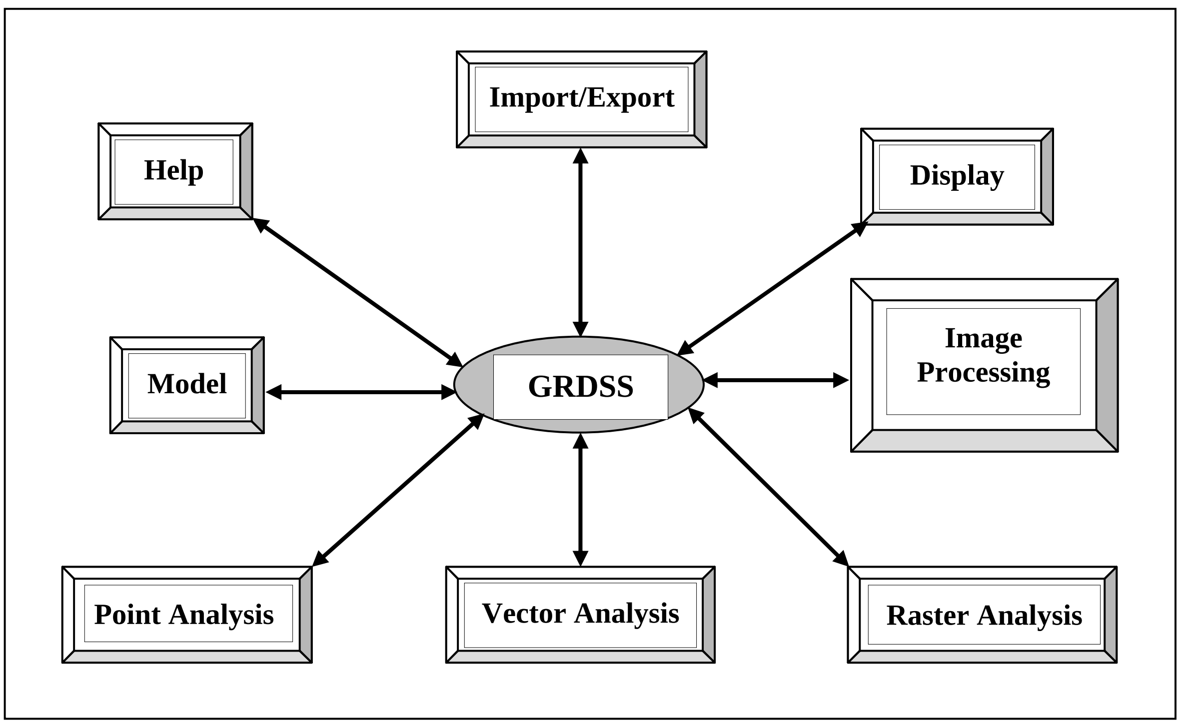

Figure 4: **GRDSS hierarchical menu arrangement.**

Table 2: Functions of GRDSS modules

<table>
<tr>
<td rowspan="3">Import/Export (supported data formats)
• Raster formats –
IRS Data format (.bil – band interleaved by lines),
Binary,
Bsq (band sequential format),
tiff (Tagged Image File Format),
geotiff,
img (image file),
jpeg (joint photographic expert group),
ppm (Portable Pixel Map),
png (Portable Network Graphics),
pbm (Portable Bit Map),
pgm (Portable Gray Map),
utm (Universal Transverse Mercator)
sunraster, arcinfo, Esri, Erdas, ascii, tang, gridatb, Landsat tape formats, Idrisi etc.
Vector formats –
Autocad (dxf-Drawing eXchange Format),
Atlas,
shp (shape file),
ascii,
Esri,
Arcinfo (dlg-Digital Line Graphs),
Mapinfo (mif-MapInfo Interchange File),
Sdts (Spatia Data Transfer Standard),
Moss, xyz etc.
• Site formats –
Ascii,
Shp (shape file),
Dbf (data base file),
Esri, etc.
• DEM/DTED extraction module.</td>
<td>Point (site) data formats
• Basic information attributes.
• Quadrat counts, univariate statistics.
• Buffer generation
• Reprojection
• Triangulation
• Interpolation
• Rainfall data preparation
• Conversion tools – point to raster, vector, grid 3d etc.</td>
</tr>
<tr>
<td>Image Processing
• Segmentation
• Rectification and restoration
• Georegistration (geocorrection)
• Transformation
• Image enhancement
• False color composite
• Signature development
• Clustering
• Classification (land use analysis)
• Vegetation indices (land cover analysis)</td>
</tr>
<tr>
<td>Models
• Wetland
• Watershed
• Landscape
• Wildfire
• Erosion tools</td>
</tr>
</table>

<table>
<tr>
<td>Vector format
Digitize
Basic information about layers attributes, statistical calculation.
Report
Distance operators
Length, Perimeter, areas etc.
Reprojection
Grid generation
Conversion tool – vector to raster, vector to point, areas to line etc.</td>
<td>Database (PostgreSQL)
Import /Export attribute data from different formats.
Select database/select table
Display table
Modify (add/delete) values
Query table
List table, list columns
Query raster, vector, sites data
Display raster, vector, sites data</td>
</tr>
<tr>
<td>Raster Analysis
Image information, report, area, category range, and statistical calculations.
Map algebra, regression analyses.
Distance operators, buffer creation.
Coordinate conversion tools
Topographic variables
Digital elevation model
Decision support
Grid generation, reclass, rescale, recode, color management.
Subimage extraction
Change resolution
Digitise
Conversion tools raster to vector lines, vector areas, point etc.
Cropping
Mosaic</td>
<td>Display
Display raster, vector, sites, 3d map.
Color management.
Display HIS, RGB, north arrow, frame, legend, map title.
Generate 3d view.
Animation.
Fly through.
Draping multiple raster, vector, site data.
Zoom, pan.
Generate histogram, pie chart, bar chart.
Select font size, symbols, appearance, style, width, and orientation.
Colors, line and polygon fill.
Placing text strings, map title, labels on raster, vector and point data.</td>
</tr>
</table>

Figure 5 depicts the GRDSS data flow diagram.

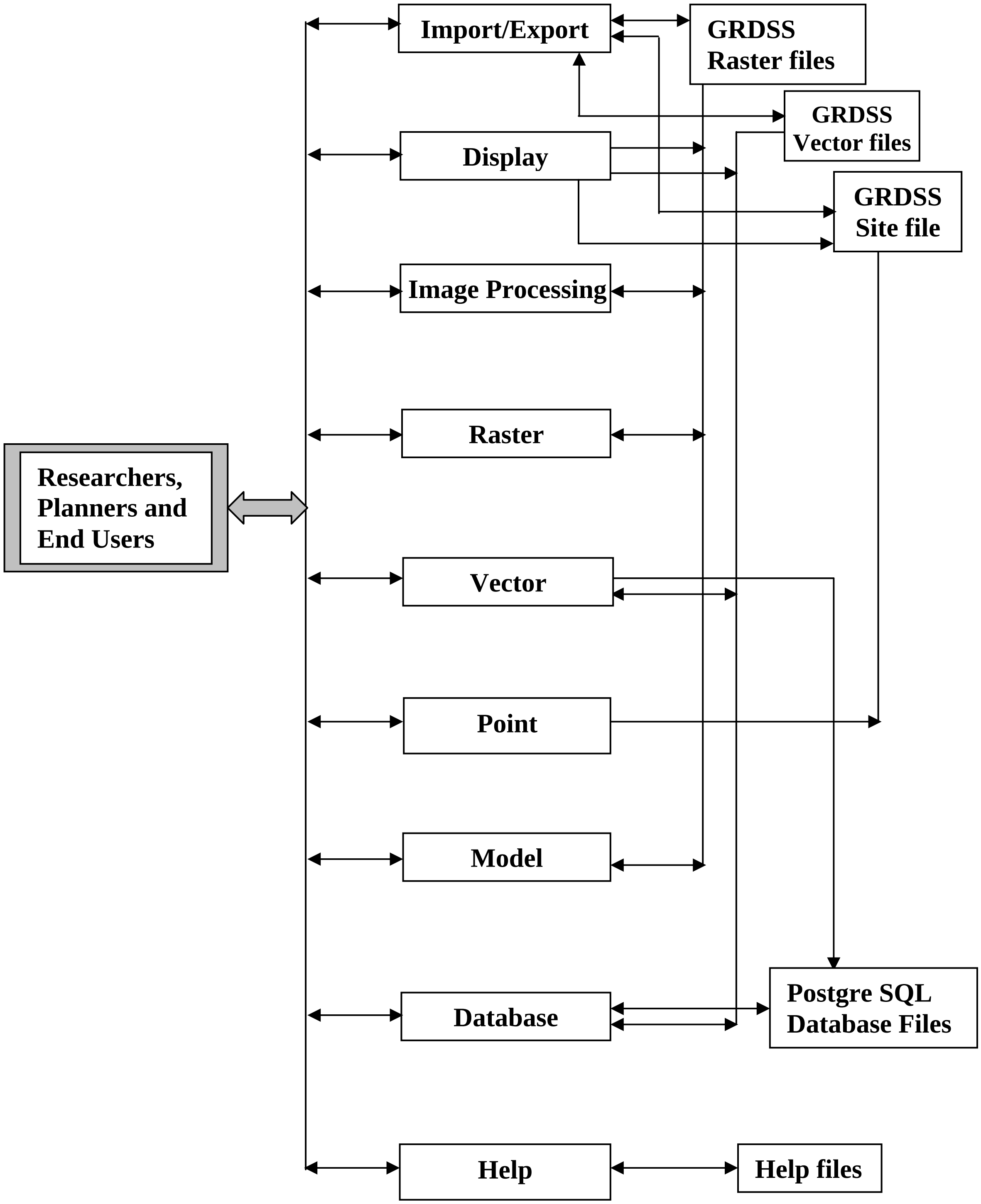

Figure 5: **GRDSS data flow diagram.**

Database connectivity

GRDSS uses PostgreSQL (a freeware) as a database for data storage, data retrieval, query and manipulation of both spatial and attribute information. It is the most advanced open source database server used primarily for data storage and retrieval, and complex data analysis. PostgreSQL is a sophisticated object-relational database management system (ORDBMS). An ORDBMS is an extension of the more traditional relational database management systems (RDBMS). For the advanced developer, PostgreSQL even supports extensibility of its data types and procedural languages.

PostgreSQL has comprehensive SQL support, referential integrity, MVCC or Multi-Version Concurrency Control to avoid unnecessary locking that increases the reliability of the database by logging changes before they are written to the database.

Applications

GRDSS provide a support for spatial data as well as attribute data by integrating GIS, image processing, GPS (global positioning system) and other techniques.

Land cover analysis: This has been done by computing both slope based and distance based vegetation indices as the district had varying extent of vegetation covers. The result of land cover analysis is listed in table 3.

		Area in hectares		**Area in percentage**	
Kolar	**Cutoff point**	**Non-vegetation**	**Vegetation**	**Non-vegetation**	**Vegetation**
RATIO	1	444659	379184	53.98	46.03
NDVI	0	418783	401654	51.05	48.96
RVI	1	82824.8	68955.7	54.56	45.43
NRVI	0.99	401647	369692	52.08	47.93
TVI	0.71	444099	379183.2	53.94	46.06
CTVI	0.707	418203	379183.2	52.46	47.55
TTVI	0.73	364415.1	305628	54.39	45.61
PVI	26.00	446960	376808	54.26	45.74
PVI1	7.00	453558	369512	55.10	44.89
PVI2	104	435853	387416	52.95	47.05
PVI3	3850	448812	375025	54.47	45.53
DVI	45	452326	371438	54.91	45.09
AVI	1	468967	354879	56.92	43.08
SAVI	0.02	72405.7	55919.4	56.42	43.58
TSAVI1	0.0199	409483	390422	51.19	48.81
TSAVI2	0.024	453360	370482	55.03	44.97
MSAVI1	0.17	451548	372294	54.81	45.19
MSAVI2	0	444626	355103	55.60	44.41
WDVI	42.01	450160	373627	54.65	45.35

Table 3: **Vegetation Indices**

Land use analysis: GRDSS through its capability of analyzing the statistical, raster and vector data with options for map overly, map algebra and other operators aid in analyzing the landuse pattern. Both supervised and unsupervised classification approaches were tried to identify landuse categories in the district using Gaussian maximum likelihood classifier (GMLC). The level of accuracy in GMLC was 94.67% compared to unsupervised classifier (78.07%). The composition of land use categories (agriculture, forest, plantation, built-up and wasteland) are listed in the table 4.

	Supervised		**Unsupervised**	
Categories	Area (in ha)	**Area (%)**	Area (in ha)	**Area (%)**
Agriculture	233519	28.34	222416	27.00
Builtup	131468	15.96	70970	8.62
Forest	68300	8.29	85295	10.35
Plantation	70276	8.53	84716	10.28
Waste land	320284	38.88	360450	43.75

Table 4: **Land use details of Kolar district**

Accuracy Estimation

Accuracy estimation in terms of producer's accuracy, user's accuracy, overall accuracy and κ Kappa coefficient were calculated after generating confusion matrix for supervised classification (table 5) and unsupervised classification (table 6).

Classification data	Agriculture	Builtup	Forest	Plantation	Waste land	**Row Total**
Agriculture	42	1	0	0	0	43
Built up	0	16	0	0	0	16
Forest	0	0	20	3	0	23
Plantation	0	0	2	34	0	36
Waste land	2	0	0	0	30	32
Column Total	44	17	22	37	30	150

Table 5: **Error Matrix Resulting from Classifying Training Set Pixels.**

Classification data	Agriculture	Builtup	Forest	Plantation	Waste land	**Row Total**
Agriculture	33	0	0	0	1	34
Built up	0	17	0	0	4	21
Forest	0	0	38	13	0	51
Plantation	0	0	0	28	0	28
Waste land	8	8	5	2	30	53
Column Total	41	25	43	43	35	187

Table 6: **Error Matrix for Unsupervised Classification.**

The producer's accuracy, user's accuracy corresponding to the various categories and overall accuracy results obtained are summarized in table 7.

	Supervised Classification			**Unsupervised Classification**		
Category	**Producer's Accuracy**	**User's accuracy (%)**	**Overall accuracy (%)**	**Producer's accuracy (%)**	**User's accuracy (%)**	**Overall accuracy (%)**
Agriculture	95.45	97.67	94.67	80.49	97.06	78.07
Builtup	94.11	100.00		68.00	80.95	
Forest	90.90	86.96		88.37	74.51	
Plantation	91.89	94.44		65.16	100.00	
Waste land	100.00	93.75		85.71	56.60	

Table 7: Producer's accuracy, user's accuracy and overall accuracy.

A $\hat{k}$ value was computed (0.931577) which is as an indication that an observed classification is 93 percent better than one resulting from a chance.

GRDSS was also used to study the watershed status in Kolar district along with land use and land cover analyses. The digital elevation model generated for the district is depicted in figure 6. Draping a land use data on the DEM enabled to assess the status of the catchment of major water bodies. The temporal analysis of Kolar district provided a picture of land use changes. The analysis indicates the unplanned developmental activities without proper planning have lead to the conversion of large scale productive land to waste land (43.75%).

Watershed mismanagement and conversion of waterbodies for various anthropogenic activities (agriculture, buildings, etc.) were the prime reasons for the depletion of the water table along with increasing ecological problems such as salinization, runoff, etc.

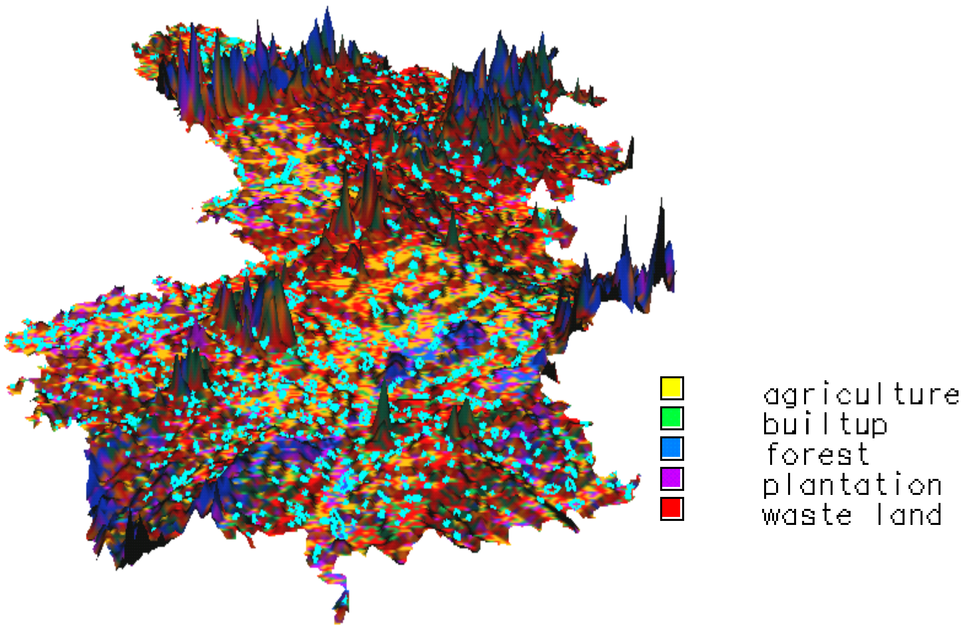

Figure 6: **3d-view of the Kolar district with landuse map draped on the image.**

The land cover and land use analyses showed NRVI, CTVI, PVI1 results are comparable to GMLC in terms of percentage area. The assessment of the watershed and holistic approaches in landuse planning considering the actual ground condition could help in ensuring the sustainable development.

Summary

GRDSS a open source GIS with capabilities such as raster analysis, vector analysis, image processing, map algebra and other functionalities is comparable to any commercial software available in the market for various applications including natural resource management. An economical (free ware) with user friendly GUI's, GRDSS is hoped to penetrate in all sections of decision making and contribute to the sustainable development of India.

References:

1) GRASS official website: http://grass.itc.it
2) GRASS mirror site in India: http://wgbis.ces.iisc.ernet.in/grass/welcome.html
3) GRASS mailing list and mailing list archive: http://wgbis.ces.iisc.ernet.in/grass/support.html
4) GRASS software download page: http://wgbis.ces.iisc.ernet.in/grass/download.html
5) Requirements to compile GRASS GIS: http://wgbis.ces.iisc.ernet.in/grass/grass5/source/REQUIREMENTS.html
6) Mapinfo: http://www.mapinfo.com/location/integration
7) Idrisi: http://www.idrisi.clarku.edu
8) Geomedia: http://www.intergraph.com/dynamicdefault.asp