

## **Guidance Note on Usage of Remote Sensing Data**

### **and Geographic Information System for effective audits**

#### **I. Introduction**

*In its endeavour to improve Governance through proper Public Sector auditing, CAG of India needs to tune its audit methodology to the changing times. As a part of this, pursuit for advanced tools which could improve the efficiency of Audit in a significant manner has always been given a high priority. It is in this context that GIS and Remote sensing become important tools in the repertoire of Audit techniques.*

*The application of Geographic Information Systems (GIS) and Remote sensing in various fields has gained substantial momentum over the past few years. Analysing developments in their spatial context and identifying potential aspects and impacts is useful in predicting the potential risks upfront. Use of GIS and Remote Sensing in Audit could organize and present spatial data in a way that allows effective management of Audit Planning and other Audit Processes.*

*A guideline has been framed to encourage Offices to make use of such scientific methods for effective planning and execution of Audit.*

#### **II. Objective of the Guidance Note**

*The basic objective of this guidance note is to introduce some important concepts and tools of RS, GIS and GPS. In a nutshell, these have been detailed in the diagram on next page. To know more about GPS read here....*



- a) Key concepts of Remote Sensing to enable selection of remote sensing imageries for the purposes for audit*
- b) Key analytical tools used to interpret remotely sensed data for audit*
- c) Concepts and techniques of GIS and their usage in audit*
- d) Key concepts in using GPS Satellite System and their usage in audit*

e) *Integration of the tools of Remote Sensing, GIS and GPS for meaningful audit analysis*



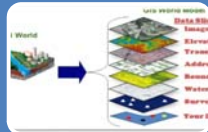
#### Concepts in Remote Sensing

- Types of Sensors
- Different types of Resolutions
- Basis for selection of Satellite Imageries

#### Digital Image Processing

#### Techniques in Digital Image Processing

- Elements of Image Interpretation
- Image enhancement, cloud and noise reduction
- Image Classification, Ground-truthing and audit analysis



#### Geographic Information System

- Raster and Vector Data Structure
- Tools for analysis of vector and raster data
- Spatial analytical tool for audit analysis



#### Concepts in Global Positioning System (GPS)

- Determination of location using GPS device
- Using GPS for the purposes of selection of target-areas and field verification for audit

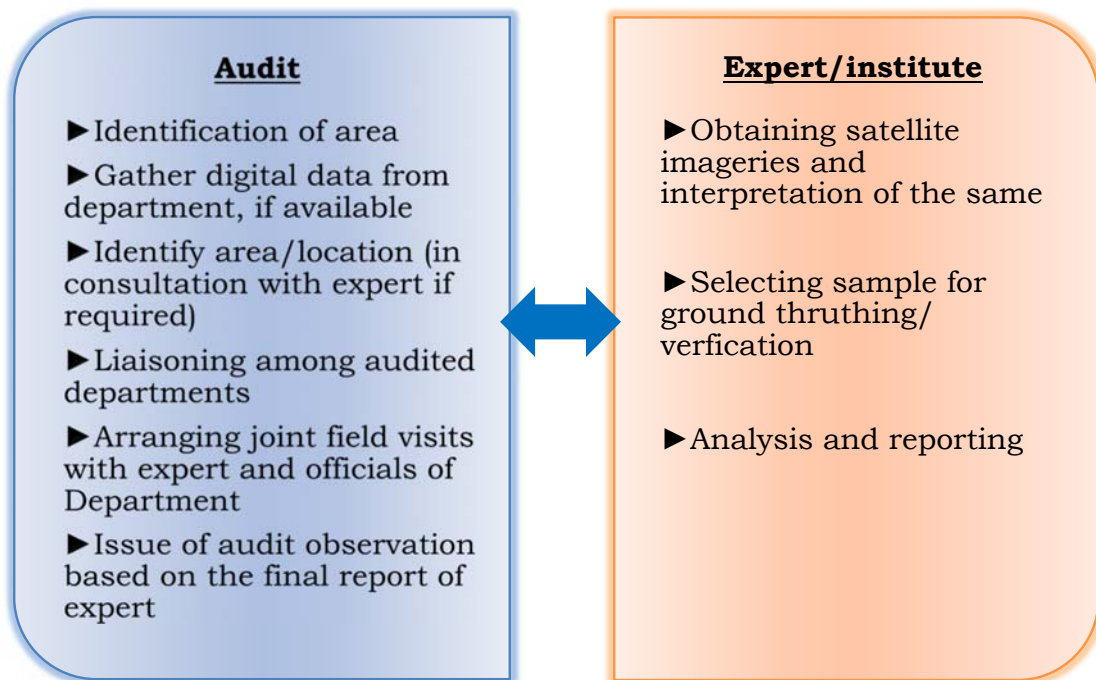


#### Integration of Remote Sensing and GIS

- Conversion of Raster Data to Vector Data
- Spatial Modelling using Remote Sensing and GIS Data

### III. Role of Audit

*Use of GIS/RSD in audits involves a lot of technical expertise which needs to be outsourced to an expert/institute. However, there are certain responsibilities which the audit office needs to address to get the desired objectives of using GIS/RSD which are discussed as under. If required and if in-house resources are available, the Audit party may also be involved in the digitisation of data under the guidance of experts.*



#### IV. What is RSD and GIS

##### **Remote Sensing Data (RSD)**

*As the name itself suggests, it is sensing without touching. Remote sensing is the science of obtaining information from a distance wherein it can be used to assess certain features of the Earth, which, one cannot visualize by physically being there. The three most common remote sensing methods are by **airplane, satellite** and **drone**.*

*There are several platforms for obtaining remotely sensed data, as detailed below:*

- a) Handheld devices like camera, spectrometer, transmissometer etc.,*
- b) Airborne devices like Aircraft, Drones etc.,*
- c) Seaborne devices like dedicated ships for SONAR,*
- d) Satellite-based Sensors like India's LISS-3 on-board IRS satellites, Microwave sensors on-board INSAT satellites.*



Know more

## **Selection of types of Satellite Imagery for Audit**

*Before sunlight illuminates any object on the earth, it passes through the atmosphere and attenuates due to absorption in the atmosphere and the object itself. It also gets scattered, and refracted. Finally, a portion of the light is absorbed by the object and part of it is reflected by the object to the remote sensing sensor. The part of the electromagnetic spectrum, which allows the reflection from an object back to the sensor without absorption, is called 'atmospheric window'.*

*It is this 'window' which allows reflected energy back to the sensor making remote sensing possible and hence, knowing the correct wavelength window for different objects are crucial for selecting the correct band for audit analysis. The reflection from different objects as recorded by the sensor is called 'spectral reflectance' or 'spectral signature'. To know more about spectral signature read here.....*



*A single satellite imagery covers certain portions of the study area. Imageries covering larger area in a single frame are said to be of coarser resolution than imageries covering smaller areas and capturing finer details. This in Remote Sensing terminology is called 'Spatial Resolution'. Spatial resolution of present day remote sensing sensor may vary between few centimetres to several kilometres. For example, spatial resolution of Indian Remote Sensing (IRS) Cartosat 2E satellite, launched in 2017, is two metre in the visible spectrum, whereas French satellite SPOT 6, launched in 2012, captures six meter in a single pixel.*

*Season or time is an important factor in remote sensing analysis. Usually, an area on earth is covered by the same satellite at an interval of 10-26 days depending on its orbital height and angle. This is called 'Temporal Resolution' or 'periodicity' of the Satellite. During rainy season or winter season in Northern India and Tamil Nadu, there can be extensive cloud cover (due to western disturbance in Northern India and North-east monsoon in Tamil Nadu) in the imageries, hindering audit analysis. Hence, while selecting multiple imageries for comparison among different years, the periodicity factor along-with the seasonal factor has to be kept in mind.*

## **Techniques for interpretation of Remote Sensing Imageries**

*For making the analysis of remotely sensed data meaningful, for example, to study how has the land usage changed over a period of time or the forest cover has disappeared, identification of the location, size, shape, tone/color, texture, pattern, height, depth and site/situation/association in a satellite imagery is crucial. These are called ‘elements of image interpretation’.*



## **Geographical Information System (GIS)**

*A Geographic Information System (GIS) is a computer-based tool for mapping and analyzing feature events on Earth. GIS manages location-based information and provides tools for display and analysis of various statistics. GIS allows to link databases and maps to create dynamic displays. It analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insights into data – such as patterns, relationships and situations – which helps in decision making.*



## **V. Concepts in GPS**

*Global Positioning Systems (GPS) satellites, part of constellation of 24 satellites and placed at about an altitude of around 20,000 KM, provide satellite-based radio-navigation system to provide real-time location of any device, capable of receiving the signal and calculate accordingly. NAVSTAR GPS is the primary satellite constellation owned by the US Government. Subsequently, Russian GLONASS, European Galileo and Chinese Beidou have been providing alternative services in this field. Despite these recent development, US GPS satellites form the basis of satellite-based navigation till date. Indian system of GPS-Aided GEO Augmented Navigation (GAGAN), is a system to improve the accuracy of location by providing reference signals with the help of US GPS.*

*GPS constitutes of three segments, namely space, ground and user segment. ‘Space segment’ consist of the 24 to 32 satellites orbiting in the space. These satellites carry atomic clocks which are precise to even microsecond (millionth part of a second) of time. These atomic clocks in*

satellite are synchronized with the atomic clocks in the 'ground segment', controlled by the US military. The 'user segment' is composed of thousands of military as well as civilian users. Thus, a handheld GPS device, generally used by the civilian Govt. organizations and audit party, for that matter, is part of the user segment. When the device is active, it receives signals from three different satellites, the receiver calculates the latitude and longitude of its location. A minimum of four satellite would give information on altitude as well.

GPS devices can be used by the audit parties for verification of information already obtained from analysis of remotely sensed data. The inputs obtained in the field can be fed into the GPS device and can be directly imported into the system and overlapped with the primary analysis done using RS and GIS for value addition.

### **GPS Device**

For the purpose of field audit and verification of remotely sensed data, procuring good-quality handheld GPS devices is very important. Garmin. Trimble and TomTom Go are some of the standard GPS devices available in the market for purchase.

## **VI. Sources of GIS/RS data**

Satellite and aerial imagery provides answers for many questions on environmental change, weather forecasting, disaster management, food security etc. These imageries are available online, where in some of them are free and available as open source. Other sources, which are sources of expertise, provide services on chargeable basis, based on the quality and the purpose we need the imageries for.

**Source of Remote Sensing Data and GIS software:** Geospatial data are available from a large number of sources including commercial suppliers, government agencies and open source data available freely online.

Some of the free sources are as below:

### **i. USGS Earth Explore or GLOVIS Data**

<https://gisgeography.com/usgs-earth-explorer-download-free-landsat-imagery/>

USGS is without any doubt one of the best free satellite data providers. It provides access to Landsat satellite data, which is the only satellite program with 40-years of history of our Earth with consistent spectral

bands. It also provides NASA's ASTER and Shuttle Radar Topography Missions Global Digital Elevation Models. It provides full access to NASA's Land Data Products and Services including Hyperion's hyperspectral data, MODIS & AVHRR land surface reflectance and Dispersed Radar data.

The GLOVIS website provides satellite data of different dates for almost all parts of the globe. Some of the data are free to download while the others can be downloaded on payment. To download data, one has to register at this site once and then download data. The data is downloaded as separate zipped folder which has to be unzipped for further use.

## **ii. Google Earth**

<https://google-earth-pro.en.softonic.com/download>

Google Earth (GE) is a computer program that renders a 3D representation of the Earth based on satellite imagery. The program maps the Earth by superimposing satellite images, aerial photography, and GIS data onto a 3D globe, allowing users to see cities and landscapes from various angles. Google Earth is able to show various kinds of images overlaid on the surface of the Earth and is also a Web Map Service client. In version 5.0, Google introduced Historical Imagery, allowing users to view earlier imagery. Clicking the clock icon in the toolbar opens a time slider, which marks the time of available imagery from the past. This feature allows for observation of an area's changes over time.

Google Earth with its high resolution images is very helpful as it can be used in projects like cadastral/parcel mapping, pipeline/electrical layout planning, city/town management, etc. The terrain information in GE can be used for land use studies. Historical images of GE help in change (natural and human induced) detection studies. Geoinformatics tools like QGIS give functionalities to export the project data into KML. With this feature one can validate GIS data by embedding them on GE. The Google layers plugin of QGIS allows one to download the Google images into local computer. With this feature one can have high resolution images for executing a geoinformatics project.

Sources which are available on a chargeable basis:

### **i. The National Remote Sensing Centre (NRSC)**

<https://www.isro.gov.in/about-isro/national-remote-sensing-centre-nrsc>



*The National Remote Sensing Centre (NRSC) in Hyderabad is devoted to the acquisition, processing, and dissemination of remote sensing data. Data is acquired primarily via India's own satellites, as well as satellites belonging to other countries, including USA's Landsat.*

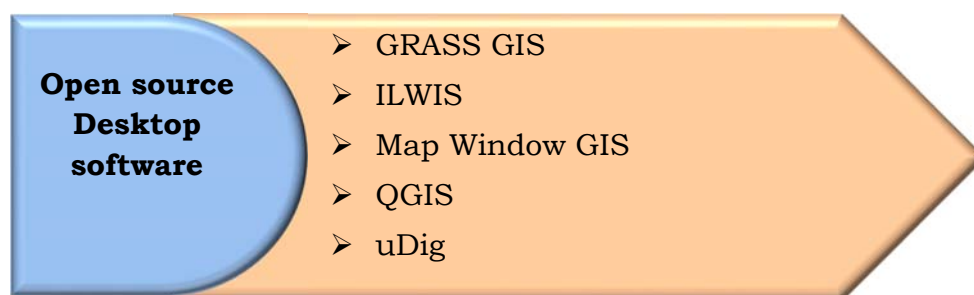
*The cost of data normally depends on the quality of resolution sought and source of procurement (national or international satellite). Normally, low resolution data acquired through National Satellites are free and are provided based on specific requests under MOUs signed with user Departments. High resolution data especially acquired from International satellites are provided on payment basis at predetermined costs. The price varies from case to case depending on the number of imageries indented and their resolution levels. However, the indicative costs are in the range of USD 5 to 45 per square kilometer imagery with minimum 25 Sq. Km. per order. With regard to satellite data generated for Indian User Departments/Ministries, the permission of the respective Departments/Ministries would be required for making such data available to audit.*

## **ii. Geoportal of ISRO – Bhuvan platform**

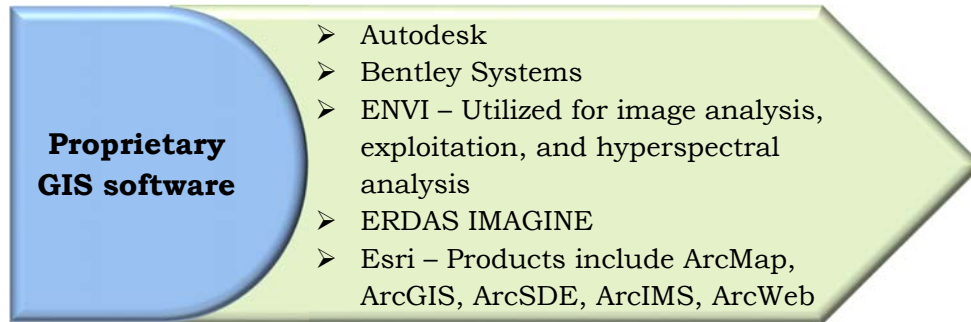
*Bhuvan is a Geoportal of Indian Space Research Organisation (ISRO), hosted through the URL <http://bhuvan.nrsc.gov.in>. Bhuvan started in 2009 with a simple display of satellite images with medium resolution (5m) satellite data and basic GIS functionality with many thematic maps on display functions. Presently, satellite image data for more than 350 cities are hosted at 1 m spatial resolution that could help in various plans for town/ city development schemes of the Government.*

## **GIS Software**

*GIS Software is designed to store, retrieve, manage, display, and analyze all types of geographic and spatial data. GIS software lets users produce maps and other graphic displays of geographic information for analysis and presentation. Important GIS software available are:*







*QGIS, among the open source and ArcGIS, among the proprietary software are very popular among GIS users. QGIS has no initial fee and no recurring fee as it is an absolutely free software. It has been constantly developing as more functionalities are being added very frequently. Extensive help and documentation are available along with free tutorials. It can be installed on MacOS, Windows and Linux. It has a large repository of plugins capable of doing large number of tasks.*

## **VII. Where to use GIS/RSD**

*GIS and RSD are technologies which can be used independently or jointly as per the requirement of the study under consideration.*

*GIS can be used to map different socio-economic parameters to locations and analyze, query and find patterns related to locations and arrive at conclusions. On the other hand, RSD is the physical data (image) of a location and can be used in areas where audit wants to study the physical changes over a period of time. RSD is also a data source for GIS.*

*The important analysis, which can be done using RSD and GIS, include:*

- *Spatio-Temporal Analysis (Land use: what has changed over the last twenty years in an urban location, near a factory, garbage dump, etc. and why?)*
- *Resources inventory (what is available and where?)*
- *Network Analysis (How to get to a place in the shortest amount of time?)*
- *Location Analysis (Where is the best place to locate a garbage dump, industry, warehouse, etc.?)*

- *Terrain Analysis (Which areas are most vulnerable to natural disaster such as flood? Or Where to locate a cyclone shelter?)*
- *Calculation of areas, distances, route lengths.*
- *Proximity Analysis (finding out area surrounding a place or an event for decision making)*

*Some of the core areas where this technology could be used are listed in the subsequent pages.*

## Part-A: Use of Remote Sensing Data

### Forest And Environment Audit

1. Encroachment
2. Land Use Land Change (fragmentation, built up areas and forest open areas)
3. Land facet corridor analysis (Analysis of corridor linkages)
4. Patrolling roads and jeep roads (widening of these paths which can in fact affect the tree cover)
5. Water bodies (Current and earlier; also, desilting can be linked to amount spent)
6. Linear intrusions (Roads, Railways, Pipelines etc.)
7. Mining/quarry (Old/New) close to forest boundaries and within, if any and their impact
8. Afforestation/reclamation (Mining/Quarry areas)
9. Weed Spread areas (Lantana/Eupatorium)
10. Forest fires
11. Commercial activities adjacent to forest boundaries (Impact on forest)
12. Social forestry/urban forestry
13. Coast line erosion

### Water in our cities

1. Lakes and tanks (Status)
2. Recent Encroachments
3. Conversion to landfills/others
4. Catchment areas (Status)
5. Storm water drains/canals
6. Sewage inlet into Lakes/Tanks
7. Classification of Lakes based on pollution content
8. Industries/flats/commercial activities around Lakes and their effect on Lakes
9. Ground water status
10. Bore-wells
11. Sewerage system

### Minor Irrigation

1. Areas which come under Minor Irrigation
2. Schemes and utility
3. Lift irrigations
4. Registration/desilting of water bodies
5. Source of water for the schemes and long term impacts

## **Land-use Planning**

1. Risk analysis
  - i. Roads and vehicles
  - ii. Buildings/High-rise
  - iii. Underground utilities
2. Land fills
3. Water distribution
4. Green belts
5. Land acquisition
6. Urban planning
7. Regional Planning

## **Agriculture**

1. Land Use Land Cover (LULC) Agriculture to Horticulture – irrigated & rain-fed and others
2. Crop grown and use of fertilizer
3. Changes in crop pattern (going for more commercial crops in place of paddy and pulses)
4. Drought areas
5. Conversion of Agricultural and Horticultural lands

## **Disaster Manage- ment**

1. Preparedness
  - i. Flood plains
  - ii. Hilly terrain
  - iii. Coastal areas (tsunamis, cyclones, tides etc.)
2. Secured areas

## **Climate Change**

1. Industrial growth
2. Deforestation and Desertification
3. Air Pollution (Industries, Vehicular, Agricultural burning and Byproducts)
4. Water pollution and its effects on rivers

## Part-B: Use of GIS (only a few examples are given here to just highlight the difference between RSD and GIS)

### Social Sector

1. Education
  - i. Schools in given area
  - ii. Census of children
  - iii. Actual enrollment of Children and required staff
2. Health
  - i. Primary Health Centres (PHC)
  - ii. Trauma centers
  - iii. District Hospitals
  - iv. Ambulance
3. Schemes

### Agriculture And Horticulture

1. Agro map
2. Crop productivity
3. Revenue
4. Storage godowns (Cold storage)
5. Agriculture Produce Marketing Committees (APMC)

## VIII. Impact of use of RS & GIS on Audit

*There are multiple ways by which use of GIS can enhance our efficiency and effectiveness. The first and foremost benefit is that we as an institution can drive its widespread usage in government by advocacy through our reports. Apart from this, using geospatial information can provide added value to all stages of an audit: assessing relevant risks, designing the audit, conducting the audit, analysing audit results and communicating audit results.*

### Risk analysis

*GIS makes it possible to analyse various data attributes or layers in a geographical context, which would be difficult or complicated if using only spread sheets. GIS can analyse, for example, the geographical spread of infrastructural projects behind schedule, the use of certain contractors in various regions, the geographical spread of funds allocated, demographic information, etc. Remote sensing data can be used to verify information*

*in administrative databases with information from the field (can infrastructural projects registered as finished actually be seen on satellite or airborne imagery?).*

*When information is available on which areas are protected, combining satellite imagery with administrative data on forestry management can indicate risk areas (for instance deforestation takes place in a protected area), which we should look into.*

### **Audit design**

*When information is available on risks, geospatial information can assist in designing the audit by deciding on the audit objectives, focus and scope. First of all, using geospatial information and GIS can assist in managing the complexity of a topic for which risks have been assessed. This complexity can consist of the variety of data that needs to be considered, but it can also consist of the geographical area that has to be considered: A forest can be vast and sometimes barely accessible. Conventional methods cannot be used by us when dealing with land on this scale and remoteness. The same argument goes for auditing the aid to a wide disaster area. Geospatial information can for example provide insight into the number and geographical spread of housing projects on or behind schedule. It is easier and faster to determine which housing projects are on schedule from a map than from a table with numbers. When the realization of projects versus their planning is mapped, it becomes visually clear which projects should be audited in case a relevant number of projects is behind schedule. It can then be decided to focus on auditing procurement of contractors and managing contracts including supervision. When projects seem to be on schedule it can be decided to audit the quality of houses, occupation rates, infrastructure including water, sanitation and electricity. Furthermore, geospatial information and GIS can be used to select sample sites and the routing of the audit teams. It can also assist in establishing an optimal mix between the various sources of information needed: field visits and for instance remote sensing data of locations where houses have been constructed (to which locations does a team need to be sent to and for which locations can be relied on remote sensing data like satellite imagery?).*

### **Gathering and analysing audit findings**

*The design of the audit determines what kind of data should be gathered from which sources. As stated before, we should be aware of the amount of geospatial information that is already publicly available and of the potential geospatial information that is available in the administration of*

public entities. “Potential” meaning that geospatial information can be created by linking data to certain locations (e.g. census data). Another way in which auditors can create geospatial information is to link their own field observations by geotagging these observations. When an audit team uses GPS-devices and satellite-based maps to link audit field data to their geographical location, it can analyse field data not only at a later stage but immediately when coordinates are uploaded to GPS software and combined with maps. Field data are directly and visibly mapped in a geographical context and could – on the spot – directly lead to more in depth questions with regard to the field observation. For example, when field observations indicate that housing projects are not constructed at the right location the audit team can ask more in-depth questions on the spot about the reasons behind this.

As stated before, using geospatial information and a GIS make it possible to analyse complex information by making use of its geographical location. When auditors – for instance – want to know if schools have been built in areas where children need schools. One of the spatial queries that a GIS can execute is a buffer analysis: which features fall inside a given buffer and which features fall outside. This type of analysis can be used for hazard mapping or for policy measures that are directed at a certain area.

### **Visualising and communicating audit results**

Visualisation of audit results – like visualising geospatial information on a map - enables a strong and clear message to the audience of an audit in comparison to solely written words. With the power of visualisation also comes the responsibility for using that power wisely. For instance, the use of symbols and colours in a map has a strong influence on how the map will be perceived and interpreted by users: when using red as a colour one should be aware that this will have a negative connotation for the user of the map and thus can stimulate that findings are perceived more negatively.

With geospatial information different kinds of visualisations can be made. The simplest form is a standard two-dimensional map that will be used in audit reports. Most GIS software packages can publish different file types, like jpg, png, svg and pdf. Besides two-dimensional maps, GIS software packages also have the possibility to produce three-dimensional models. These models are used for mapping elevation (Digital Elevation Model, Digital Terrain Model) of a certain area or the underground structure of an area for mining purposes or for urban planning purposes. The use of three dimensions in a GIS (for analytical and visualisation



*purposes) has been a recent development that will lead to a number of new possibilities for using GIS, also for us.*

*Next to static maps, GIS software packages also make it possible to establish and publish interactive maps: maps where the user of the map can create its own visualisations by selecting and analysing data layers.*

## **IX. Constraints of GIS/RSD**

*GIS/RSD have their own constraints and drawbacks. Some of the issues which Audit may encounter while using these tools are listed below:*

- 1. Resolution of the camera is an important criterion in accurately determining the attributes of an image. Further, in order to ensure uniformity and to bring out accurate comparisons, Remote sensing maps have to be from the same satellite while comparing over a time period. In case the resolutions and satellites are not uniform, the interpretation of the images may vary and the output would not be accurate;*
- 2. If the datasets are acquired during different seasons it will affect visual interpretation capability (in case of time period analysis);*
- 3. Remote sensing requires special skill sets and training to analyze the images which have to be updated regularly.*
- 4. Requirement for hardware, software commensurate with the volume of data to be handled needs to be assessed regularly, fulfilled and updated.*

## **X. SoP for use of GIS/RSD**

*A standard operating procedure needs to be followed in use of RSD and GIS in audit which is briefed as under.*

### **Activity 1**

- Obtain information from the Department concerned about the usage of GIS and mapping details available with it (Most of the Departments have GIS inventorised their assets and functions which are available with the State Remote Sensing Authority).
- Identify area of audit outcome for which GIS/RSD to be used.
- Identify the location (taluks, districts) for which the study is to be conducted.

### **Activity 2**

- Identify the Expert/Institution tentatively to be finalised for outsourcing the job.
- Obtain details of satellite and image resolution (both for image of starting point and latest current image available) which will be used to analyse the outcome over a period of time in the audit and the source for the data (whether free or chargeable).
- Obtain proforma invoice from Expert/Institution to frame proposal to CAG's office for approval.
- Send detailed justification for administrative and financial approvals.
- Enter into clear written unambiguous agreement (including presentation/ discussion of the technical details with the Audited Department representatives, if necessary) with the Expert/Institution regarding the work entrusted and timeline for completion so that the Bond Copy dates are adhered to.
- An exclusivity clause needs to be incorporated in the agreement with the technical consultant, so that if he/she wants to use this or quote this work elsewhere, he needs to take prior permission of Audit department.

### **Activity 3**

- Inform the Department of the satellite and image resolution and area being covered through GIS/RSD either in the Entry Conference or through another meeting convened after finalisation of the details.
- Make all efforts to obtain written concurrence of the Department for the satellite and image resolution which will be used for starting point and ending point images for audit analysis. Otherwise signed minutes of the meeting would serve as the concurrence.
- Audit team should also closely interact and understand the basic layers of GIS mapping used by the Expert/Institute to arrive at meaningful audit conclusions and convey the gist of work done to the Audited Department during Exit Conference.

### **Activity 4**

- Ensure that the GIS mapping done by the Expert/Institution is shared with the Department well before the Exit Conference giving the Department time to offer remarks and replies.
- The audit findings, conclusions and recommendations based on GIS and RSD should be specifically discussed in the Exit Conference and minuted.

## **XI. External Consultants**

*For interpreting GIS/RSD data people who have expertise in that field are required. From audit perspective, it is important to engage such experts who can give an authoritative output and also help audit to broaden the scope of analysing these data and use it more effectively in finalizing an Audit Report.*

*However, the charges of these consultants may vary from subject to subject and as per the requirements of the study to be undertaken. Generally, the charges could be taken up as a whole package or can be arrived at depending on these three broad heads.*

- 1. Collection of satellite data images(Cost varies with resolutions);*
- 2. Professional charges;*
- 3. Field visit charges.*

*Few IA&AD offices have already engaged external consultants to interpret satellite imageries to arrive at Audit conclusions. For instance, in the Office of AG (E&RSA) Karnataka, the expertise of IISc, Bengaluru was utilised in the Performance Audit to assess the encroachment and land-use change in the Protected Areas of Karnataka. There are similar instances where some other offices have already made use of such consultants (Annexure-I). All the states have their own state remote sensing institutions (Annexure-II) which can be consulted for using RS & GIS in audit. As selection of consultants is a dynamic process which depends on their availability as well as the subject selected for audit by a particular field office, the database of consultants for use and interpretation of RSD and GIS may be updated periodically.*

## **XII. Training of Audit staff**

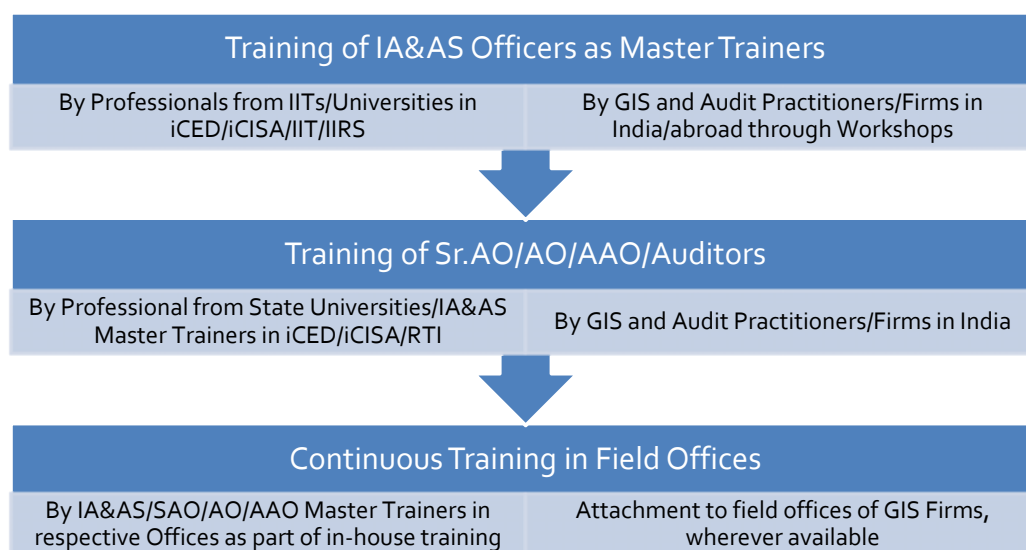
*Audit staff can be trained in using the GIS tools and Google maps to plot certain defined data (Ex: data of schools, children and staff strength) which are already available. They could also be trained in interpreting the maps in collaboration with external institutions/experts. However, in-house analyses and interpretations may be refuted by the auditee or Legislatures or even the public, citing lack of professional expertise in the field. Further, ‘Ground truthing’<sup>1</sup>, which involves a scientific approach and a lot of time in the field, is one of the crucial aspects of using RSD/ GIS data and its interpretation.*

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<sup>1</sup> Verification of the actual field conditions in sample cases to corroborate the results obtained through satellite images.

*Keeping these things in mind it is better to have selective training sessions for dedicated audit staff who could form a special cell or unit in each office to work on some of these issues. In other words, interpretation of RSD data would be safer through experts in the field with certification from an authorized institution, while our audit staff could improve expertise in locating the areas where RSD/GIS data can be used and deducing relevant audit observations from the data so analysed.*

*Training of Human Resources of the organization can be done through a three-pronged approach, as detailed in the diagram below:*



*A group of Master trainers from the IA&AS Officers, Sr. AO, AO and AAO need to be developed. These master trainers need to impart training continuously in RTIs and as well as in respective offices as part of the in-house IT training program. Besides, consultation with experts at the time of audit planning including sampling and field visits would be crucial.*

*'Training Tool on Environmental Data: Resources Option for Supreme Audit Institutions' developed by INTOSAI Working Group on Environmental Auditing (WGEA) may also be referred for training the audit staff. The training tool can accessed at this link <https://www.environmental-auditing.org/publication/>*

### **XIII. Conclusion**

*Embracing new technologies as Audit tools will always add a new dimension to Auditing. **Geographical Information System, Remote Sensing Data** and **Global Positioning System** can radically alter our audit paradigm and will keep the Audit up with the times, which is inevitable in an ever-evolving technology-driven environment. Such*

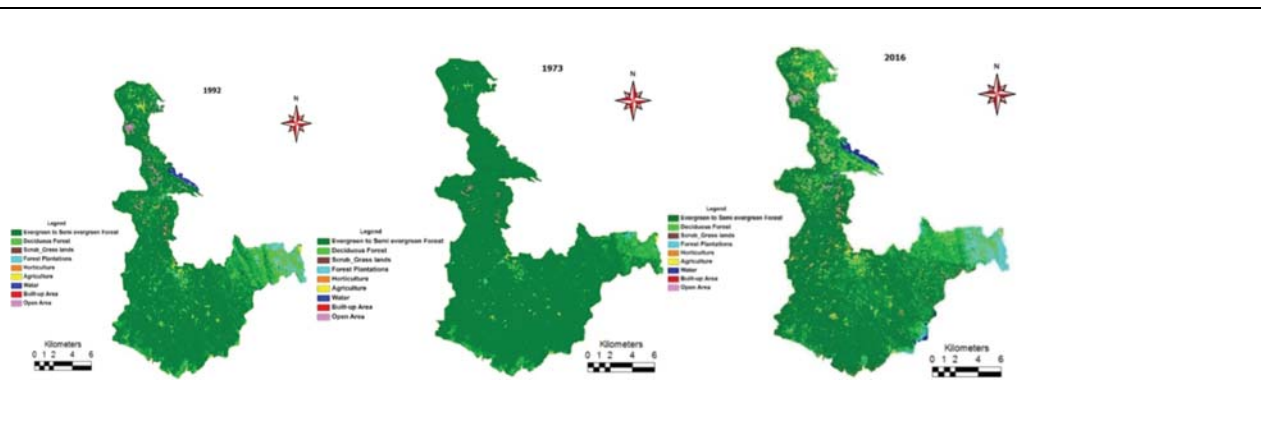
*technologies will open up new horizons of evidence-gathering which could handhold Audit in analyzing areas which were hitherto outside the scope of Audit. However, caution may be exercised in employing such techniques due to their inherent disadvantages and over-reliance on expertise from the relevant fields.*

## Annexure-I

Illustrations showing the use of GIS/RD in our Department **Report No 06 (2017): Performance Audit on Administration of National Parks & Wildlife Sanctuaries in Karnataka**

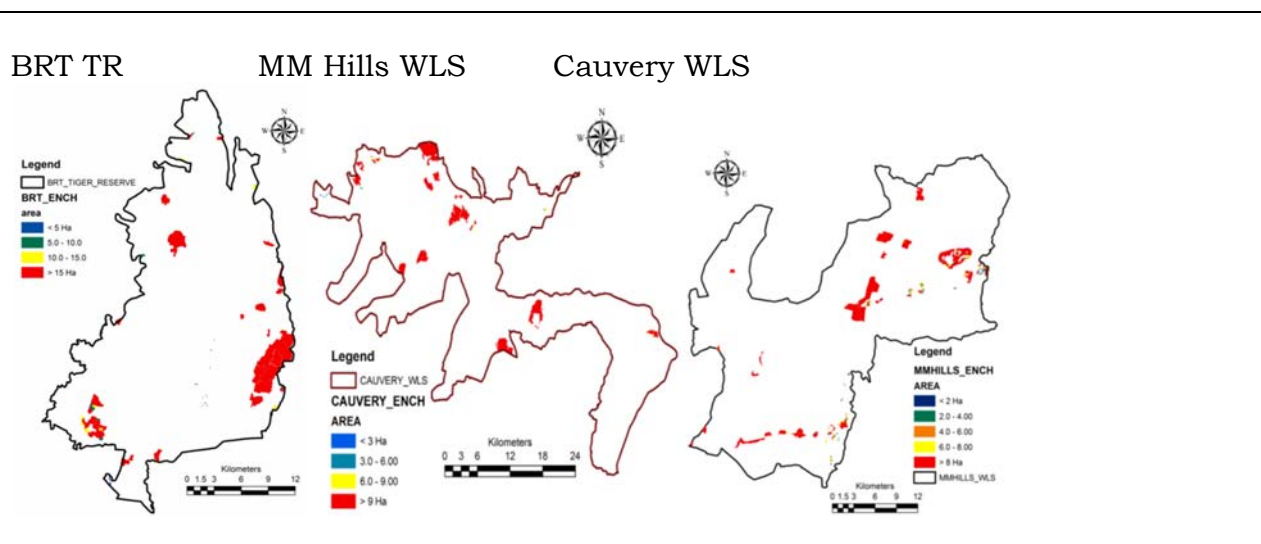
**Land use land change:** An analysis of LULC using remote sensing data in and around (10 km radius) in 13 Protected Areas was done by the Indian Institute of Science (IISc) at the instance of Audit involving three period time interval to assess the LULC dynamics.

**Impact:** The study revealed large scale drop in forest cover and increase in area under plantations in all the Protected Areas.



**Encroachment:** At the instance of Audit IISc analysed the encroachment data in 13 Protected Areas selected for PA.

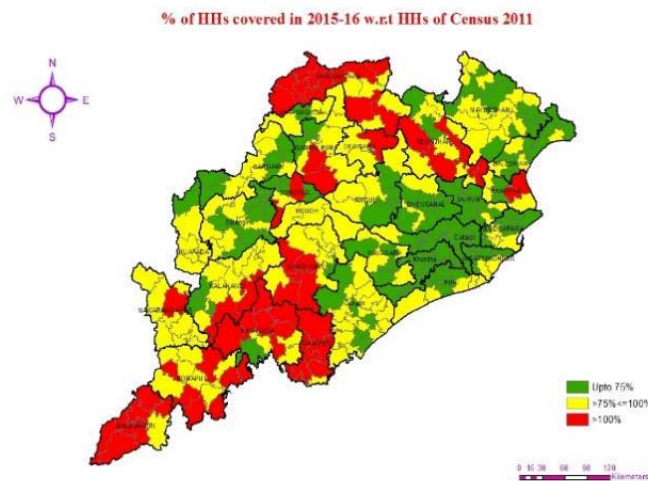
**Impact:** The encroachments as per Forest Department were 5002 acre, grossly varied as against 31,677 acre as per the analysis by IISc.





### Performance Audit of MGNREGA by AG (G&SSA), Odisha

GIS was used for trend analysis and selection of districts, blocks and GPs in more transparent and perceptible manner. Various MGNREGA parameters were plotted (upto block level granularity) on GIS Maps to know the spatial distribution of the issues. For instance, households issued with Job Cards under MGNREGA as a percentage of population across different blocks within the state is represented below. The red color represents the high risk areas where the number of Households (HH) issued with the Job Cards (JC) is more than the number of HHs in Census-2011.



### PA on Management of Storm Water Drains in Bengaluru

Initially, the cadastral maps (early 1900s) were used for creating database on lakes and natural drainage network and subsequently, time series maps were generated for 1965, 2008 and 2016-time frame using satellite and ancillary data.

**Impact:** Total length of drains/streams as per cadastral maps was 113.24 km which reduced to 86.36 km as per satellite imagery of 1965. In 2008, the total length of the drains as visible on the satellite data was 62.32 km which marginally increased to 62.84 km in 2016 due to remodeling.

### Realignment and modeling of drainage network near Bellandur Lake





## **Annexure II**

### **Link of State Remote Sensing Institutions**

<b>Sl No</b>	<b>State</b>	<b>Link</b>
1	Karnataka	<a href="http://kgis.ksrsac.in/kgis/">http://kgis.ksrsac.in/kgis/</a>
2	Kerala	<a href="http://ksrec.kerala.gov.in/">http://ksrec.kerala.gov.in/</a>
3	Tamil Nadu	<a href="https://it.tn.gov.in/en/TNEGA/TNGIS">https://it.tn.gov.in/en/TNEGA/TNGIS</a> <a href="https://www.annauniv.edu/RemoteSensing/">https://www.annauniv.edu/RemoteSensing/</a>
4	Andhra Pradesh	<a href="https://apsac.ap.gov.in/">https://apsac.ap.gov.in/</a>
5	Telangana	<a href="http://www.trac.telangana.gov.in/trac/">http://www.trac.telangana.gov.in/trac/</a>
6	Arunachal Pradesh	<a href="http://ardst.arunachal.gov.in/state-remote-sensing-application-center/">http://ardst.arunachal.gov.in/state-remote-sensing-application-center/</a>
7	Assam	<a href="http://www.astec.gov.in/">http://www.astec.gov.in/</a>
8	Bihar	<a href="http://www.dst.bih.nic.in/BIRSAC.aspx">http://www.dst.bih.nic.in/BIRSAC.aspx</a>
9	Chhattisgarh	<a href="http://cgcost.nic.in/chhattisgarh-space-applications-centre">http://cgcost.nic.in/chhattisgarh-space-applications-centre</a>
10	Goa	<a href="https://www.unigoa.ac.in/facilities/remote-sensing-laboratory.html">https://www.unigoa.ac.in/facilities/remote-sensing-laboratory.html</a>
11	Maharashtra	<a href="https://mrsac.gov.in/MRSAC/flipbook/project/desertification-and-land-degradation-status-mapping-in-maharashtra-and-go-a-state">https://mrsac.gov.in/MRSAC/flipbook/project/desertification-and-land-degradation-status-mapping-in-maharashtra-and-go-a-state</a>
12	Gujarat	<a href="http://www.bisag.gujarat.gov.in/">http://www.bisag.gujarat.gov.in/</a> <a href="https://bisag.gujarat.gov.in/">https://bisag.gujarat.gov.in/</a>
13	Haryana	<a href="http://www.harsac.org/">http://www.harsac.org/</a>
14	Himachal Pradesh	<a href="http://himcoste.hp.gov.in/Council%20websites/REMOTE%20SENSING/Contact_Us.aspx">http://himcoste.hp.gov.in/Council%20websites/REMOTE%20SENSING/Contact_Us.aspx</a> <a href="http://agisac.gov.in/">http://agisac.gov.in/</a>
15	Jammu and Kashmir	<a href="http://www.jkdears.com/eers/files/remote.asp">http://www.jkdears.com/eers/files/remote.asp</a> <a href="http://jammuuniversity.in/mscgis/index.html">http://jammuuniversity.in/mscgis/index.html</a>
16	Jharkhand	<a href="http://jsac.jharkhand.gov.in/">http://jsac.jharkhand.gov.in/</a>
17	Madhya Pradesh	<a href="http://www.mpcost.gov.in/center/remote-sensing-application-centre">http://www.mpcost.gov.in/center/remote-sensing-application-centre</a>
18	Manipur	<a href="https://www.nesdr.gov.in/Manipur/">https://www.nesdr.gov.in/Manipur/</a>
19	Meghalaya	<a href="https://nesac.gov.in/remote-sensing-and-gis/">https://nesac.gov.in/remote-sensing-and-gis/</a>
20	Mizoram	<a href="https://mirsac.mizoram.gov.in/">https://mirsac.mizoram.gov.in/</a>
21	Nagaland	<a href="http://nagalandgis.in/">http://nagalandgis.in/</a> <a href="http://dst.nagaland.gov.in/nastec/centres/remote-sensing.html">http://dst.nagaland.gov.in/nastec/centres/remote-sensing.html</a>
22	Odisha	<a href="https://www.orsac.gov.in/">https://www.orsac.gov.in/</a>
23	Punjab	<a href="http://prsc.gov.in/?AspxAutoDetectCookieSupport=1">http://prsc.gov.in/?AspxAutoDetectCookieSupport=1</a>
24	Rajasthan	<a href="http://jodhpur.rajasthan.gov.in/content/raj/jodhpur/en/TelephoneDirectory/department/srsac---state-remote-sensing-application-centre.html">http://jodhpur.rajasthan.gov.in/content/raj/jodhpur/en/TelephoneDirectory/department/srsac---state-remote-sensing-application-centre.html</a>
25	Sikkim	<a href="http://dstsikkim.gov.in/RemoteSensing.html">http://dstsikkim.gov.in/RemoteSensing.html</a>
26	Tripura	<a href="http://www.tscst.nic.in/manpower-TSAC">http://www.tscst.nic.in/manpower-TSAC</a>
27	Uttar Pradesh	<a href="http://rsacup.org.in/">http://rsacup.org.in/</a>
28	Uttarakhand	<a href="https://www.u-sac.in/">https://www.u-sac.in/</a>
29	West Bengal	<a href="https://www.nrsc.gov.in/aboutus_campus_nrsrc/rsrc_east">https://www.nrsc.gov.in/aboutus_campus_nrsrc/rsrc_east</a>

## **Regional Remote Sensing Centres**

### **Regional Remote Sensing Centre – West**

NRSC, ISRO,  
CAZRI Campus,  
Jodhpur – 342 003  
Rajasthan

### **Regional Remote Sensing Centre – East**

NRSC, ISRO,  
BG-2, AA-1B, Jyoti Basu Nagar,  
Kolkata – 700 156  
West Bengal

### **Regional Remote Sensing Centre – North** *(Previously in Dehradun – Now moved to Delhi)*

Plot no 7, Planning Center Area,  
Sadiq Nagar, New Delhi – 110049

### **Regional Remote Sensing Centre – South**

NRSC, ISRO  
[Department of Space](#) / Government of India  
ISITE Campus, Marathahalli, Outer Ring Road,  
Bangalore – 560 037  
Karnataka

### **Regional Remote Sensing Centre – Central**

NRSC, ISRO,  
NBSS & LUP Campus,  
Amravati Road,  
Nagpur – 440 010  
Maharashtra

### Annexure – III

#### Interpretation of Satellite Imagery

##### Interpretation of Satellite Imageries

Interpretation is the process of extraction of qualitative and quantitative information of objects from satellite images. To derive useful spatial information from images is the task of image interpretation. It includes:

**Detection and Identification:** recognition of certain target. A simple example is to identify vegetation types, soil types, rock types and water bodies. The higher the spatial / spectral resolution of an image, the more detail we can derive from the image.

**Delineation:** to outline the recognized target for mapping purposes. Identification and delineation combined together are used to map certain subjects. If the whole image is to be processed by these two procedures, we call it image classification.

**Enumeration:** to count certain phenomena from the image. This is done based on detection and identification. For example, we can count the number of various residential units.

**Mensuration:** to measure the area, the volume, the amount, and the length of certain target from an image. This often involves all the procedures mentioned above. Simple examples include measuring the length of a river and the acreage of a specific land-cover class. More complicated examples include an estimation of timber volume, river discharge, crop productivity, river basin radiation and evapotranspiration.

##### Elements of interpretation

The interpretation of satellite imagery involves the study of various basic characters of an object with reference to spectral bands, which is useful in visual analysis. The basic elements are shape, size, pattern, tone, texture, shadows, location, association and resolution.

**Shape:** The external form, outline or configuration of the object. This includes natural features (e.g. Amazon River) or Man Made feature (e.g. Eiffel Tower).

**Size:** This property depends on the scale and resolution of the image / photo. Smaller feature will be easily indented in large-scale image / photo.

**Pattern:** Spatial arrangement of an object into distinctive recurring forms: This can be easily explained through the pattern of a road and railway line. Even though both looks linear, major roads associated with steep curves and much intersection with minor road.

**Shadow:** Indicates the outline of an object and its length, which is useful in measuring the height of an object. Taller features cast larger shadows than shorter features.

**Tone:** Refers to the colour or relative brightness of an object. The tonal variation is due to the reflection, emittance, transmission or absorption character of objects.

This may vary from one object to another and changes with reference to different bands. In General smooth surface tends to have high reflectance, rougher surface less reflectance.

**Infrared imagery:** Healthy vegetation reflects Infrared radiation much stronger and appears very bright in the image. A simple example is the appearance of light tone by vegetation species and dark tone by water.

**Texture:** The frequency of tonal change. It creates a visual impression of surface roughness or smoothness of objects. This property depends upon the size, shape, pattern and shadow.



**Location Site:** The relationship of feature to the surrounding features provides clues towards its identity. Example: certain tree species are associated with high altitude areas.

**Resolution:** It depends upon the photographic / imaging device namely cameras or sensors. This includes of spectral and spatial resolutions. The spectral resolution helps in identifying the feature in specific spectral bands. The high spatial resolutions imagery/photographs is useful in identifying small objects.

**Association:** Occurrence of features in relation to others.

Hence, careful examination has to be done to identify the features in the imagery combined with field information. The most intuitive way to extract information from satellite images is by visual image interpretation. It is based on our ability to relate patterns and colours in an image to real world features. To visually interpret digital data such as satellite images, individual spectral bands must be displayed simultaneously in the form of a colour composite. When the blue, green and red parts of the electromagnetic spectrum are superimposed, the resulting image strongly resembles what our eyes would see from the sensor's vantage point. Two terms 'true colour' and 'false colour' are used for images. True colour image means that the picture shows objects in the same colours that your eyes would normally see. False colour image means that the colours have been assigned to three different image bands which have been acquired in the wavelengths that your eyes might not normally see.

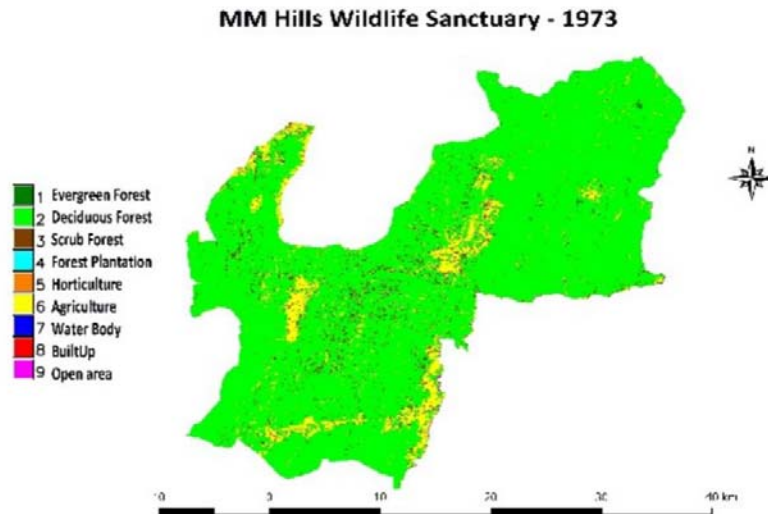


**True Colour and False Colour Images**

Remote sensing data in digital mode is easy to store and distribute. Computer assisted image interpretation approach mimics the visual image interpretation approach to a certain level. Manual image analysis uses most of the elements of image interpretation such as tone, colour, size, shape, texture, pattern, height, shadow, site and association whereas computer assisted image interpretation involves the use of only a few of the basic elements of image interpretation. In fact, majority of all digital image analysis appears to be dependent primarily on just the tone or colour of image feature.

### **Classification System**

Our ultimate aim of interpretation is to produce a land use/land cover map. Land cover refers to the type of features present on the surface of the land. It refers to a physical property or resources e.g., water, snow, grassland, deciduous forest, sand, sugarcane crop, etc. The term Land use relates to the human activity or economic function for a specific area e.g., urban use, industrial use, recreation area or protected area. It is of prime importance in overcoming problems such as unplanned development, deteriorating environmental quality, loss of agricultural lands, destruction of wetlands and loss of fish and wildlife habitat. Land use data are required in the understanding environmental processes and problems. Land use changes through time can also be interpreted from land cover change maps. These maps are an important tool in the planning process. Such data is increasingly used in tax assessments, natural resource inventories, water-resource inventory, flood control, water-supply planning and waste-water treatment. This data is also required for assessment of environmental impact resulting from development and management of energy and natural resources. This data is also helpful to make national summaries of land use patterns and changes for national policy formulation.



There have been several classification systems developed across the globe. Important one include classification by U.S. Geological Survey, Anderson and others, 1976, Indian (NRSC), etc.

In addition to satellite or aerial imagery, other data can be used to increase the accuracy of the classification. Some possible ancillary data are digital elevation models (DEMs) and their derived datasets (slope and aspect), climate data such as rainfall and temperature, and vector overlays such as roads, rivers and populated places.

All image based mapping processes require field observations. Field observations can be used to gather local knowledge beforehand to guide the interpretation. “Ground Truthing” is the term which is used for data collected ‘on site’. Ground truth data are complementary to the remote sensing data as it helps to link the image data to the ground reality.

When dealing with a new area, some of the features observed on the images will not be understood and field observations will help in interpreting these features. Field observations are also used to validate the interpretation made. Ground truth is a term used in a range of remote sensing techniques. It generally refers to the

The quality of the result of an image interpretation depends on a number of factors such as the interpreter, image data used and the guidelines provided.

### **Processing and Classification of Remotely Sensed Images**

**Classification** is the process of assigning spectral classes into information classes. Spectral classes are groups of pixels that are uniform with respect to their brightness values in the different spectral channels of data. Information classes are categories of interest that an analyst attempts to identify in the image on the basis of his knowledge and experience about the area. For example, a remote sensing image contains spectral signatures of several features present on the ground in terms of pixels of different values. An interpreter or analyst identifies homogeneous groups of pixels having similar values and labels the groups as information classes such as water, agriculture, forest, etc. while generating a



thematic map. When this thematic information is extracted with the help of software, it is known as digital image classification. It is important to note that there could be many spectral classes within an information class depending upon the nature of features the image represents or the purpose of the classification. In other words, different spectral classes may be grouped under one information class. There are two general approaches to image classification:

- **Supervised Classification:** It is the process of identification of classes within a remote sensing data with inputs from and as directed by the user in the form of training data, and
- **Unsupervised Classification:** It is the process of automatic identification of natural groups or structures within a remote sensing data.

Both these methods can be combined together to come up with a '**hybrid**' approach of image classification.

The image classification process consists of following three stages i.e. **training, signature evaluation and decision-making**.

**Training** is the process of generating spectral signature of each class. For example, a forest class may be defined by minimum and maximum pixel values in different image bands, thus defining a spectral envelope for it. This simple statistical description of the spectral envelope is known as signature. Either training can be carried out by an image analyst with guidance from his experience or knowledge (i.e. supervised training) or by some statistical clustering techniques requiring little input from image analysts (i.e. unsupervised training).

**Signature Evaluation** is the checking of spectral signatures for their representativeness of the class they attempt to describe and to ensure a minimum of spectral overlap between signatures of different classes.

**Decision Making** is the process of assigning all the image pixels into thematic classes using evaluated signatures. It is achieved using algorithms, which are known as decision rules. The decision rules set certain criteria. When signature of a candidate pixel passes the criteria set for a particular class, it is assigned to that class. Pixels failing to satisfy any criteria remain unclassified.

**Accuracy assessment** is the final step in the analysis of remote sensing data which help us to verify how accurate our results are. It is carried out once the interpretation/classification has been completed. Here, we are interested in assessing accuracy of thematic maps or classified images, which is known as thematic, or classification accuracy. The accuracy is concerned with the correspondence between class label and 'true' class. A 'true' class is defined as what is observed on the ground during field surveys. For example, a class labeled as water on a classified image/map is actually water on the ground.

All remote sensing images are susceptible to a variety of distortions. These distortions occur due to data recording procedure, shape and rotation of the Earth and environmental conditions prevailing at the time of data acquisition. Therefore, they cannot be used directly and require **image correction**. The primary aim of image correction operations is to correct distorted image data to create a more accurate representation of the original scene. Image corrections, also known as a



preprocessing, is a preparatory phase that improves quality of images and serves as a basis for further image analysis.

### **Limitations of Remote Sensing**

Though Remote Sensing is a powerful tool, it has some limitations. Some of these limitations are listed below:

1. It is expensive method of analysis and requires a special training to analyze the images.
2. There is scope for human error in analysis.
3. The instruments used in remote sensing may sometimes be un-calibrated which may lead to un-calibrated remote sensing data.
4. Different features being analyzed may look the same during measurement which may lead to classification error.
5. The image being analyzed may sometimes be interfered by other phenomena that are not being measured and this should also be accounted for during analysis.
6. Remote sensing technology is not a panacea that will provide all the solution and information for conducting physical, biological or scientific study.
7. Sometimes large scale engineering maps cannot be prepared from satellite data.

## **Annexure-IV**

### **Remote Sensing Data access protocol**

*(Issued vide CDMA U.O. No. 193/39/CDMA/MOU for accessing Remote Sensing Data/NRSC dated 17.10.2016)*

National Remote Sensing Centre (NRSC), of the Indian Space Research Organisation (ISRO) under the Department of Space, Government of India, is engaged in acquisition, processing and dissemination of remote sensing data. They are also engaged in developing technologies and applications for Natural Resources Management, Climate & Environment Monitoring, Infrastructure Development & Regional and Local Planning.

Remote sensing data is thus increasingly becoming relevant for audits. It can help in better audit planning and collection of relevant audit evidences during audits. Such data will be useful for application of data analytic techniques in combination with other relevant data sets.

Some offices have made use of remote sensing data in the past and some intend to use the same in ongoing audits. Accordingly, till the time a generic arrangement between IAAD and the NRSC is put in place, a protocol on access of remote sensing data by field audit offices, from NRSC, has been developed.

The protocol addresses the requirements of field audit offices in obtaining remote sensing data from the NRSC and making use of the same in their audits.

#### **THE PROTOCOL:**

1. The need for remote sensing data is identified/ established
  - a. At the audit plan proposal stage
  - b. During development of audit guidelines for a performance or thematic audit.
2. The nature, period of data required is established, if required, by interacting with the NRSC.
3. To establish if the required data is readily available on BHUVAN or will have to be obtained specifically through the NRSC.
  - a. If available on BHUVAN, is intervention of NRSC required to use the data?
  - b. If intervention of NRSC required, is it required for
    - i. Developing a specific application?
    - ii. Handholding during the project
    - iii. Imparting training
4. If the data is readily available with or without intervention of NRSC, use the data when
  - a. Data is available free of cost
  - b. Training/ Handholding can be imparted free of cost

This mode would be the preferred mode of access. As such, the requesting offices should explore all options to establish that the data is available free or at minimum cost.

5. If data is readily available but is not free or the data is not readily available (on BHUVAN) or the intervention of NRSC has cost implications,
  - a. Make a proposal with fund estimates and forward to the headquarters (respective functional wing). The proposal should contain
    - i. Details of data. ii. Period of data.
    - iii. Whether the data is available with NRSC or it will have to be obtained through foreign satellites?
    - iv. Whether intervention of NRSC include
      1. Developing a specific application?
      2. Handholding during the project
      3. Imparting training
    - v. Amount of fund required for access of data and intervention of NRSC.
    - vi. How the data is going to be used for audit?
  - b. If an MoU with NRSC is required, filled in MoU may be forwarded to the respective functional wing in headquarters. An MoU template from NRSC is enclosed. However, latest template may also be obtained from NRSC.
  - c. The functional wing, after vetting the proposal/ MoU with the audit proposal(s) from the office, will forward the proposal/ MoU with recommendation to the CDMA for approval by DAI and provision of requisite funds through AC(N).
6. In case of all India reviews, the comprehensive proposals may be prepared by the nodal office.
7. It will be desirable that the above requests are finalised along with the development of guidelines or audit plan as the case may be, so that the necessary data is obtained from NRSC in time. The time required by NRSC for making data and other requirements available to audit may also be suitably factored in.
8. Complete documentation on the use of the data obtained from the NRSC may be ensured. The same may be shared with CDMA in soft copy.
9. Requisite security and confidentiality of the remote sensing data must be ensured by the field offices.

## Global Positioning System (GPS)

(Source: [https://en.wikipedia.org/wiki/Global\\_Positioning\\_System#Applications](https://en.wikipedia.org/wiki/Global_Positioning_System#Applications))

The Global Positioning System (GPS), originally NAVSTAR GPS is a satellite-based radio navigation system owned by the United States government and operated by the United States Space Force. It is one of the global navigation satellite systems (GNSS) that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. Obstacles such as mountains and buildings block the relatively weak GPS signals.

The GPS does not require the user to transmit any data, and it operates independently of any telephonic or internet reception, though these technologies can enhance the usefulness of the GPS positioning information. The GPS provides critical positioning capabilities to military, civil, and commercial users around the world. The United States government created the system, maintains it, and makes it freely accessible to anyone with a GPS receiver.

Many civilian applications use one or more of GPS's three basic components: absolute location, relative movement, and time transfer.

- Astronomy: both positional and clock synchronization data is used in astrometry and celestial mechanics. GPS is also used in both amateur astronomy with small telescopes as well as by professional observatories for finding extrasolar planets.
- Automated vehicle: applying location and routes for cars and trucks to function without a human driver.
- Cartography: both civilian and military cartographers use GPS extensively.
- Cellular telephony: clock synchronization enables time transfer, which is critical for synchronizing its spreading codes with other base stations to facilitate inter-cell handoff and support hybrid GPS/cellular position detection for mobile emergency calls and other applications. The first handsets with integrated GPS launched in the late 1990s. The U.S. Federal Communications Commission (FCC) mandated the feature in either the handset or in the towers (for use in triangulation) in 2002 so emergency services could locate 911 callers. Third-party software developers later gained access to GPS APIs from Nextel upon launch, followed by Sprint in 2006, and Verizon soon thereafter.
- Clock synchronization: the accuracy of GPS time signals ( $\pm 10$  ns) is second only to the atomic clocks they are based on, and is used in applications such as GPS disciplined oscillators.
- Disaster relief/emergency services: many emergency services depend upon GPS for location and timing capabilities.
- GPS-equipped radiosondes and dropsondes: measure and calculate the atmospheric pressure, wind speed and direction up to 27 km (89,000 ft) from the Earth's surface.
- Radio occultation for weather and atmospheric science applications.
- Fleet tracking: used to identify, locate and maintain contact reports with one or more fleet vehicles in real-time.

- Geofencing: vehicle tracking systems, person tracking systems, and pet tracking systems use GPS to locate devices that are attached to or carried by a person, vehicle, or pet. The application can provide continuous tracking and send notifications if the target leaves a designated (or "fenced-in") area.
- Geotagging: applies location coordinates to digital objects such as photographs (in Exif data) and other documents for purposes such as creating map overlays with devices like Nikon GP-1
- GPS aircraft tracking
- GPS for mining: the use of RTK GPS has significantly improved several mining operations such as drilling, shoveling, vehicle tracking, and surveying. RTK GPS provides centimeter-level positioning accuracy.
- GPS data mining: It is possible to aggregate GPS data from multiple users to understand movement patterns, common trajectories and interesting locations.
- GPS tours: location determines what content to display; for instance, information about an approaching point of interest.
- Navigation: navigators value digitally precise velocity and orientation measurements.
- Phasor measurements: GPS enables highly accurate timestamping of power system measurements, making it possible to compute phasors.
- Recreation: for example, Geocaching, Geodashing, GPS drawing, waymarking, and other kinds of location based mobile games.
- Robotics: self-navigating, autonomous robots using a GPS sensors, which calculate latitude, longitude, time, speed, and heading.
- Sport: used in football and rugby for the control and analysis of the training load.
- Surveying: surveyors use absolute locations to make maps and determine property boundaries.
- Tectonics: GPS enables direct fault motion measurement of earthquakes. Between earthquakes GPS can be used to measure crustal motion and deformation to estimate seismic strain buildup for creating seismic hazard maps.
- Telematics: GPS technology integrated with computers and mobile communications technology in automotive navigation systems.

## Remote Sensing

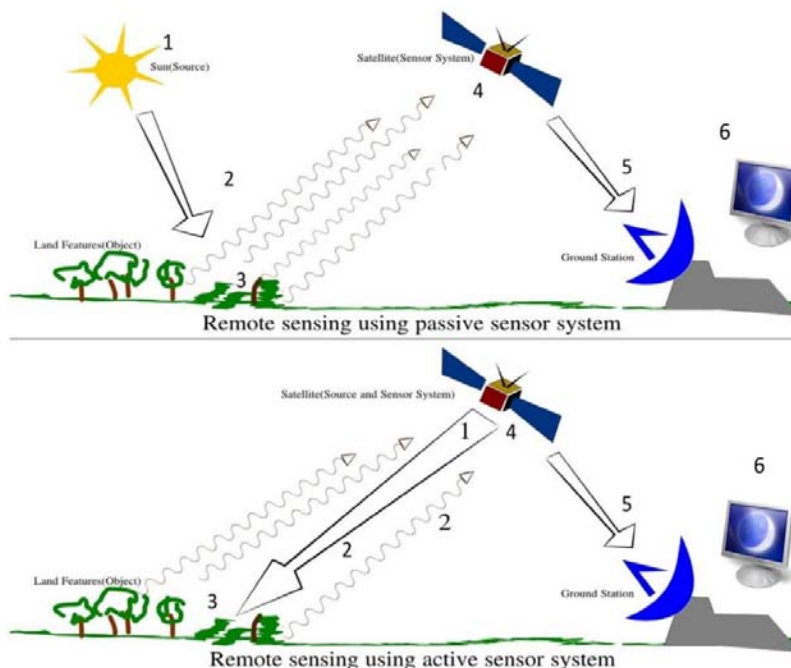
Remote sensing sensors use different wavelength of the electromagnetic spectrum to obtain information about specific object class. While for the purpose of natural resource studies, optical Remote Sensing is mostly used, there are certain branches of Remote Sensing like Thermal Infrared Remote Sensing, Microwave Remote Sensing etc. which are also used widely for different scientific analysis and can be used for the purpose of audit as well.

Among the satellites, there are again three major types- sun-synchronous, geo-stationary and GPS satellites, depending on orbit, height and purpose for what they have been deployed.

### Components of Remote Sensing System

There are several steps in remote sensing system as detailed below:

**Source of Energy (1):** The first and very important requirement for remote sensing is an energy source which provides electromagnetic energy to the Earth. It may be either from natural (e.g. solar radiation) or artificial (e.g. RADAR) sources. Basically, there are two types of sensor systems, i.e. Passive and Active Sensor System as shown below:



**Interaction of energy with the atmosphere (2):** When energy travels from its source to the Earth surface, it comes in contact with the Earth's atmosphere where it interacts with atmospheric constituents. The energy

reflected from Earth's surface is received by remote sensors. In this process the energy once again interacts with atmosphere.

**Interaction with Earth surface features (3):** Energy reaching the Earth surface through the atmosphere interacts with the Earth surface features. The interaction and its outcome depend on the characteristics of the features and the energy.

**Recording of energy by the sensor (4):** After interacting with Earth surface features the reflected and emitted energy travels to the sensor. And, the sensor records the reflected and emitted energy.

**Transmission, reception, and processing of the recorded signals (5):** The energy recorded by the sensor is transmitted in the form of signals to receiving and processing station on the Earth. The signals are in electronic form and are processed and converted into an image.

**Utilization of the data (6):** The processed image is interpreted and analysed to extract information about the object of interest. The above mentioned components comprise the remote sensing system and underline the importance of energy and its interaction with atmosphere and Earth features.

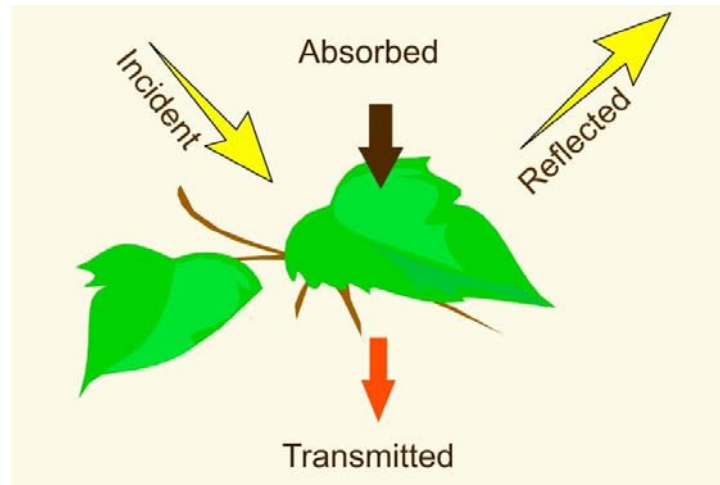
### **Remote Sensing and Electromagnetic Radiation (EMR)**

Electromagnetic Radiation (EMR) is a form of energy exhibiting wave like behaviour as it travels through space. EMR ranges from very high energy radiation such as gamma rays and X rays through ultraviolet light, visible light, infrared radiation and microwaves to radio waves. The range of frequencies of EMR is known as electromagnetic spectrum. This division of the electromagnetic spectrum is for practical use. Human eyes use visible light to see objects. We can feel infrared radiation as heat. We employ microwaves in microwave ovens and radio waves are used for communications. All the types of EMR are wave forms which travel at the speed of light. The radiation can be defined in terms of either their wavelength or frequency. Shorter wavelength radiations (infrared or shorter) are generally described in terms of its wavelength, whereas longer wavelength radiations (microwave, etc.) are generally described in terms of its frequency.

Sensors record energy which has interacted with Earth surface features. This energy serves as the main communication link between the sensor and the object. In remote sensing, mostly visible, infrared and microwave bands are used. By the time EMR is recorded by a sensor, it has already passed through the Earth's atmosphere twice (once while travelling from the Sun to the Earth



and second time while travelling from the Earth to the sensor). When light travels through atmosphere, a gradual reduction in its intensity occurs. This attenuation occurs mainly because of the scattering and absorption of light in atmosphere. Absorption is the process by which radiation (radiant energy) is absorbed and converted into other forms of energy such as heat or chemical energy. Absorption is wavelength-dependent.



To understand it better, let us take an example. Grass appears green because it scatters green light more effectively than red and blue light. Apparently, red and blue light incident on the grass is absorbed. The absorbed energy is converted into some other form, and it is no longer present as red or blue light.

The visible and NIR spectral band from 0.3  $\mu\text{m}$  to 3  $\mu\text{m}$  is known as the reflective region. In this band, the Sun's radiation sensed by the sensor is reflected by the Earth's surface. The band corresponding to the atmospheric window between 8  $\mu\text{m}$  and 14  $\mu\text{m}$  is known as the thermal infrared band. The energy available in this band for remote sensing is due to thermal emission from the Earth's surface. Both reflection and self-emission are important in the intermediate band from 3  $\mu\text{m}$  to 5.5  $\mu\text{m}$ . In the microwave region (1-30 cm) of the spectrum, the sensor is normally a radar, which is an active sensor, as it provides its own source of EMR. The EMR produced by the radar is transmitted to the Earth's surface and the EMR reflected (back-scattered / radar return) from the surface is recorded and analysed. The microwave region can also be monitored with passive sensors, called microwave radiometers, which record the radiation emitted by the Earth's surface and its atmosphere in the microwave region.

### **Remote Sensing Platforms and Sensor systems**

Platforms are commonly called the vehicles or carriers for remote sensing devices. The three most common types of platforms are terrestrial platform, airborne platform, and space borne platform as shown in the figure.

You are familiar with the fact that today man-made or artificial satellites are widely used for a large number of purposes including military and civilian Earth observations, communication, navigation, weather forecasting and research purposes. Hence such satellites are classified into six major types namely, astronomical, communication, weather, earth observation, navigation and reconnaissance satellites based on their uses.

A sensor is a device that gathers electromagnetic radiations, converts it into a signal and presents it in a form suitable for obtaining information about the objects under investigation.

- Sensor systems can be broadly classified as passive or active systems based on the source of EMR. Passive Sensors detect the reflected or emitted EMR from natural sources. The useful wave bands are mostly in the visible and infrared region for passive remote sensing detectors. Active Sensors detect the reflected or emitted radiation from the objects which are irradiated from artificially generated energy sources, such as RADAR and LIDAR. The active sensor detectors are used in the radar and microwave regions.
- Based upon the form of the data output, the sensors are classified into photographic (analogue) and non- photographic (digital) sensors. A photographic sensor (camera) records the images of the objects at an instance of exposure. On the other hand, a non- photographic sensor obtains the images of the objects in bitby bit form. These sensors are known as scanners. In satellite remote sensing, the Multi Spectral Scanners (MSS) are used as sensors. These sensors are designed to obtain images of the objects while sweeping across the field of view. A scanner is usually made up of a reception system consisting of a mirror and detectors. A scanning sensor constructs the scene by recording a series of scan lines. While doing so, the motor device oscillates the scanning mirror through the angular field of view of the sensor, which determines the length of scan lines and is called 'swath'. It is because of such reasons that the mode of collection of images by scanners is referred bit-by-bit.

Each scene is composed of cells that determine the spatial resolution of an image. The oscillation of the scanning mirror across the scene directs the received energy to the detectors, where it is converted into electrical signals.

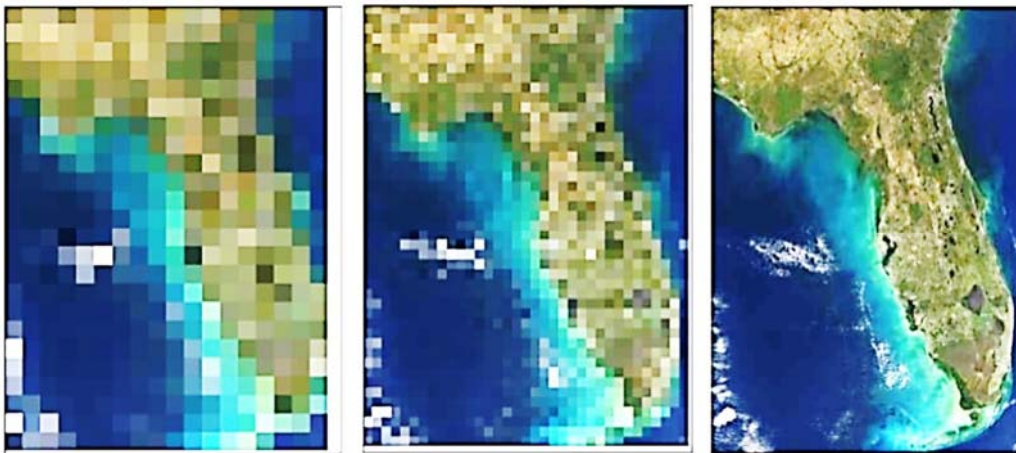
These signals are further converted into numerical values called Digital Number (DN Values) for recording on a magnetic tape.

### **Sensor Resolutions**

Remote sensors are characterised by spatial, spectral and radiometric resolutions that enable the extraction of useful information pertaining to different terrain conditions as detailed below:

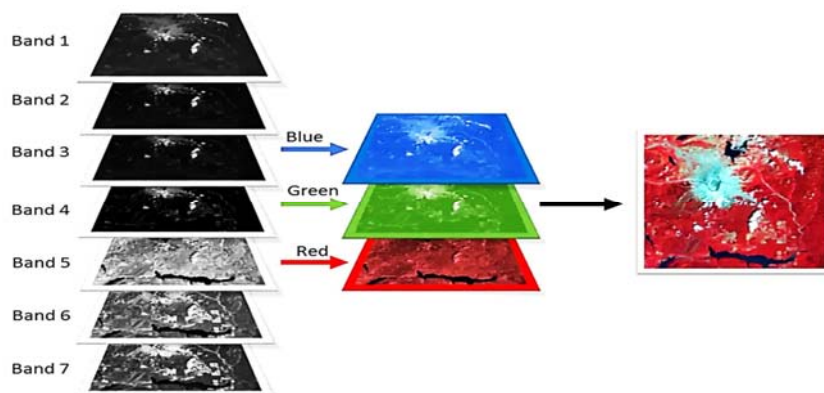
- **Spatial Resolution:** In remote sensing, the spatial resolution of the sensors refers to the capability of the sensor to distinguish two closed spaced object surfaces as two different object surfaces.

As a rule, with an increasing resolution the identification of even smaller object surfaces become possible as shown below:

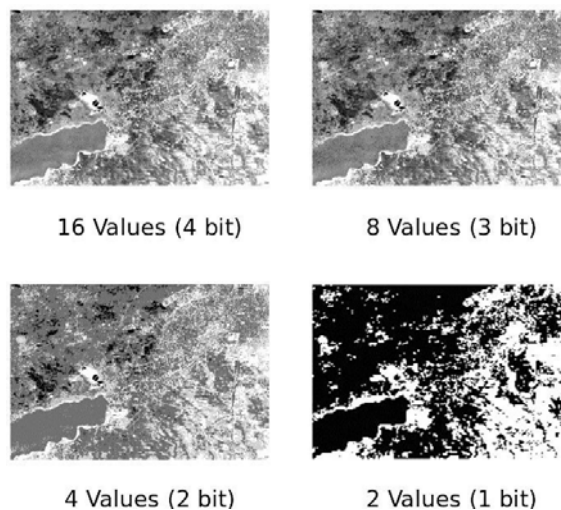


**Spatial Resolution of 17 Km, 9 Km and 1Km**

**Spectral Resolution:** It refers to the sensing and recording power of the sensor in different bands of EMR (Electromagnetic radiation). Multispectral images are acquired by using a device that disperses the radiation received by the sensor and recording it by deploying detectors sensitive to specific spectral ranges. The images obtained in different bands show objects response differently. Figure below illustrates images acquired in different spectral regions:



•  
**Radiometric Resolution:** It is the capability of the sensor to discriminate between two targets. Higher the radiometric resolution, smaller the radiance differences that can be detected between two targets.



The spatial, spectral, and radiometric resolutions of some of the remote sensing satellites of the world are given below:

Satellite / Sensor	Spatial Resolution (in metres)	Number (in Bands)	of Radiometric Range (Number of Grey Level Variations)

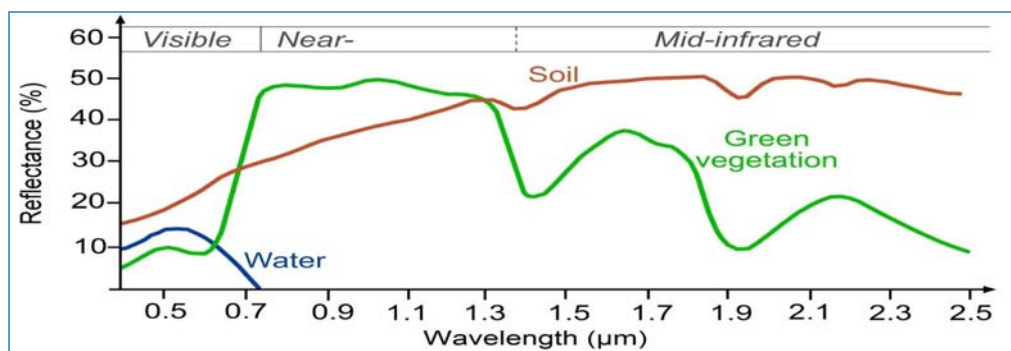
<b>Landsat (USA)</b>	<b>MSS</b>	80.0 x 80.0	4	0 - 64
<b>IRS LISS (India)</b>	<b>- I</b>	72.5 x 72.5	4	0 - 127
<b>Landsat (USA)</b>	<b>TM</b>	30.00 x 30.00	4	0 - 255
<b>IRS (India)</b>	<b>PAN</b>	5.80 x 5.80	1	0 - 127
<b>SPOT HRV - II (France)</b>		10.00 x 10.00	1	0 - 255

## Spectral Signature

Spectral signatures are the combination of reflected, absorbed and transmitted or emitted EMR by objects at varying wavelengths, which can uniquely identify an object. When the amount of EMR (usually intensity of reflected radiation or reflectance in percentage) coming from the material is plotted over a range of wavelengths, the connected points produce a curve which is known as spectral signature of the material or in other words spectral response curve.

To interpret remote sensing images, it is absolutely important to start with a basic understanding of spectral signature, which means how different terrain features such as water, rock, soils, and vegetation, interact with the different wavelengths (bands) of the EMR.

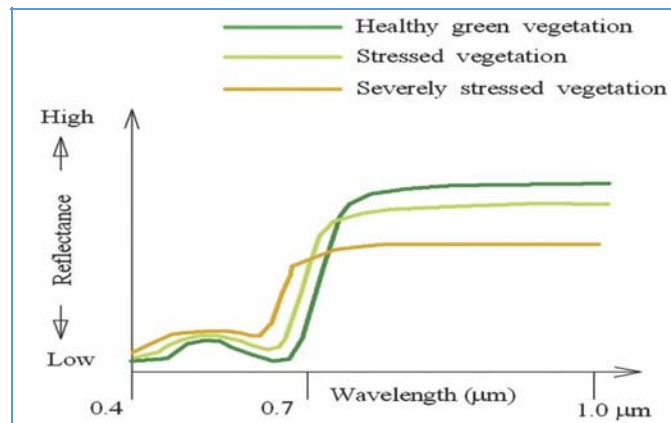
As you see, vegetation appears green. We know that an object appears green when it reflects green light (light in green region within the visible range of the EM spectrum). In case of vegetation, reflection of green light is due to the presence of the chlorophyll pigment in plant leaves. Presence of the chlorophyll pigment results in unique spectral signature of vegetation that enables us to distinguish it easily from other types of land cover (non-living) features in an optical / near-infrared image. The reflectance of vegetation is low in both the blue and red regions of the EM spectrum, due to absorption of blue and red wavelengths by chlorophyll for photosynthesis. It has a peak reflectance at the green region that gives green colour to vegetation. In the near infrared (NIR) region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves. Hence, vegetation can be easily identified in the NIR region of spectrum. Typical spectral signature of green vegetation is shown below:



Reflectance of vegetation changes according to the composition,

maturity and Spectral Signature health of vegetation. The amount of chlorophyll content determines the health of vegetation. Chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear 'greenest' to us when chlorophyll content is at its maximum. In certain seasons, there is less chlorophyll in the leaves; so, there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow (yellow is a combination of red and green wavelengths).

The internal structure of healthy leaves acts as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near infrared, trees would appear extremely bright to us at these wavelengths. In fact, measuring and monitoring the NIR reflectance is one of the ways by which scientists can determine how healthy (or unhealthy) the vegetation is. Spectral signatures of healthy, stressed and severely stressed vegetation are shown below:

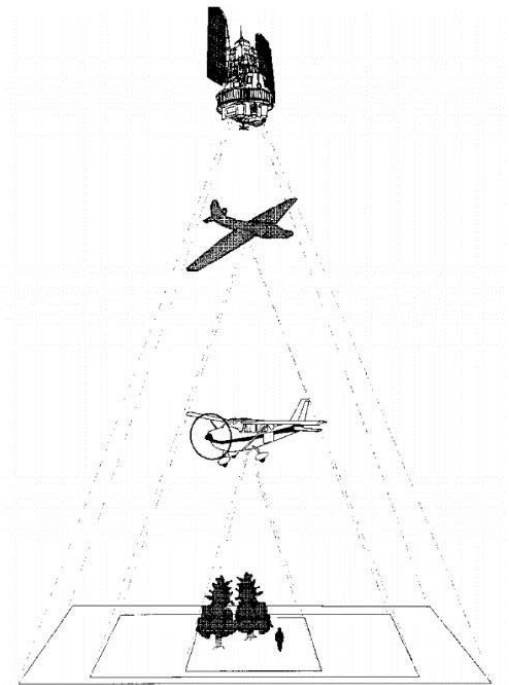


The shape of the reflectance spectrum varies with the type of vegetation. For example, the reflectance spectra of deciduous and coniferous trees can be distinguished based on their reflectance spectrum. Deciduous trees and coniferous trees have almost similar reflectance in the visible region, but they vary in the NIR region, where deciduous trees have higher reflectance than coniferous trees.

In case of soil in general, surfaces appear brown to the human eyes. Brown colouring is a product of green and red EMR such that 'brown' surfaces absorb more of blue wavelength than either green or red.

Furthermore, very little energy is transmitted through soil; the majority of the incident flux is absorbed or reflected. As water is relatively strong absorber of all

wavelengths, particularly those longer than the red part of the visible spectrum. Therefore, as the moisture content of the soil increases, the overall reflectance of that soil tends to decrease. Soil rich in iron oxide reflects proportionally more of the red than other visible wavelengths and therefore appears red (rust colour) to the human Spectral Signature eyes. A sandy soil, on the other hand, tends to appear bright white in imagery because visible wavelengths are more or less equally reflected; when slightly less blue wavelengths are



reflected, it results in a yellow colour. Unlike soils, rock reflectance is less dependent on water content and completely independent of organic matter content, texture or structure. Rock spectral reflectance primarily depends on their mineral composition.

In case of water, the majority of the radiant flux is not reflected but is either absorbed or transmitted. At visible wavelengths of EMR, very little energy is absorbed, a small amount usually under 5% is reflected and the majority is transmitted. If you happen to be standing in water you can see your foot/toes through the water. Water absorbs strongly at NIR wavelengths, leaving little radiation to be either reflected or transmitted.



## Techniques for interpretation of Remote Sensing Imageries

Tone or color is the spectral reflectance pattern of any object and the same needs to be correctly identified for using them as audit evidence. The same may also be established by field verification of selected site. Texture is defined as 'arrangement of repetitions of tone or color in an image'. A grassland or cropped area with no trees would have uniform smoother texture compared to an area with mixed varieties of trees (image below). Moreover, texture is also a function of scale. If the scale becomes smaller, coarser texture would become smooth as larger variations are subsumed in single pixels in the image.



Once familiarity with these elements have been developed, we can classify an area into certain land-use types. Moreover, we can train the Image Processing software to classify areas like grassland, cropland (paddy, pulse, potato and so on), forest areas (healthy, stressed, severely stressed etc.) and other categories based on our given inputs. This is called 'Supervised Classification'. Alternatively, we can ask the software to classify the area into ten probable land-use categories and then identify which classified category resembles to what land-use through ground verification. The latter is called 'unsupervised classification'.

## Introduction to GIS and GIS file formats

### Overview

Geographical Information System (GIS) is a system for capturing, storing, checking, integrating, manipulating, analysing and displaying data, which are spatially referenced to the Earth. This is normally considered to involve a spatially referenced computer database and appropriate applications software. Geographical information is of two types i.e. spatial and non – spatial. The spatial data are characterised by their positional, linear and areal forms of appearances. The most common source of spatial data is topographical or thematic maps in hard copy (paper) or soft copy form (digital). All such maps are characterised by:

- A definite scale which provides relationship between the map and the surface it represents,
- Use of symbols and colours which define attributes of entities mapped, and
- An agreed coordinate system, which defines the location of entities on the Earth's surface.

### Basic Concepts

GIS is a computer-based system to aid in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information. Geographic information is the information about places on the earth's surface i.e. "what is where when". Time is very essential. GIS encompasses end-to-end processing of data including capture, storage, retrieval, analysis/modification, display, etc. It uses explicit location on earth's surface to relate data. The aim of GIS is to support decision making in areas which ranges from Disaster Management, land use planning, urbanisation, agriculture, etc.

### GIS Data Model: Integration of Spatial and non- spatial data

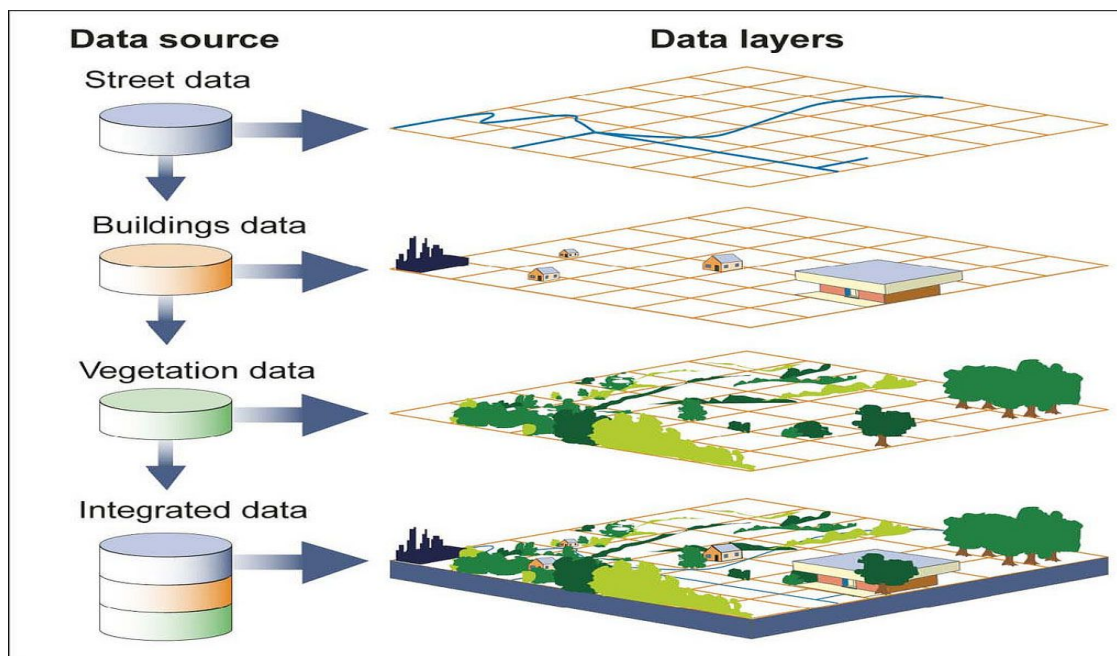
**Spatial Data** represent a geographical space. They are characterised by the points, lines and polygons. The point data represent positional characteristics of some of the geographical features, such as schools, hospitals, wells, tube-wells, etc. Similarly, lines are used to depict linear features, like roads, railway lines, canals, etc. Polygons are made of a number of inter-connected lines, bounding a certain area, and are used to show area features such as administrative units (countries, districts, states, blocks); land use types (cultivated area, forest lands, degraded/waste lands, pastures, etc.)

**Non-spatial Data** or attribute data describes the spatial data. For example, if you have a map showing positional location of your school, you can attach the information, such as the name of the school, subject stream it offers, number of students in each class, schedule of admissions, teaching and examinations, available facilities, like library, labs, equipment, etc. In other words, you will be defining the attributes of the spatial data.

For instance, the polygon representing area of a city with proper geographical coordinates is Spatial data, whereas the name, population, per capita income, etc. are non-spatial or attribute data.

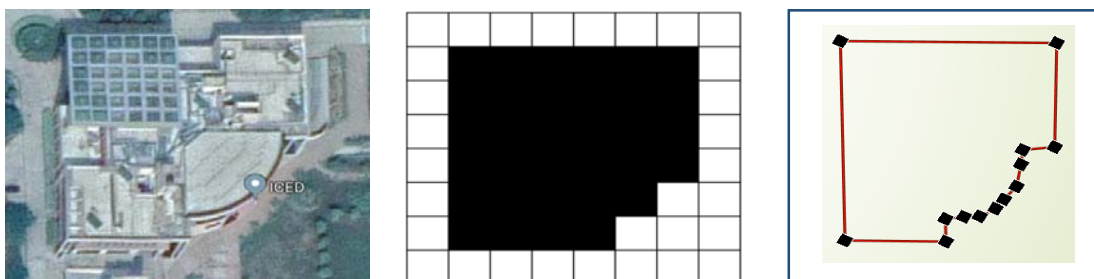
## Data Layers in GIS

A layer represents geographic data, such as a particular theme of data. Examples of map layers include streams and lakes, terrain, roads, political boundaries, parcels, building footprints, utility lines, and orthophoto imagery. Each map layer is used to display and work with a specific GIS dataset. Various layers can be superimposed over each other to create various maps and do spatial analysis as described below:



## Spatial Data formats: Raster and Vector data

Raster data represent a graphic feature as a pattern of grids of squares, whereas vector data represent the object as a set of lines drawn between specific points. Consider one of the blocks of iCED, Jaipur. Its raster and vector data formats are as below:



As seen from above, a raster file would represent this image by sub-dividing the area into a matrix of small rectangles, similar to a sheet of graph paper called cells. Each cell is assigned a position in the data file and given a value based on the attribute at that position. Its row and column coordinates may identify any individual pixel. This data representation allows the user to easily reconstruct or visualise the original image.

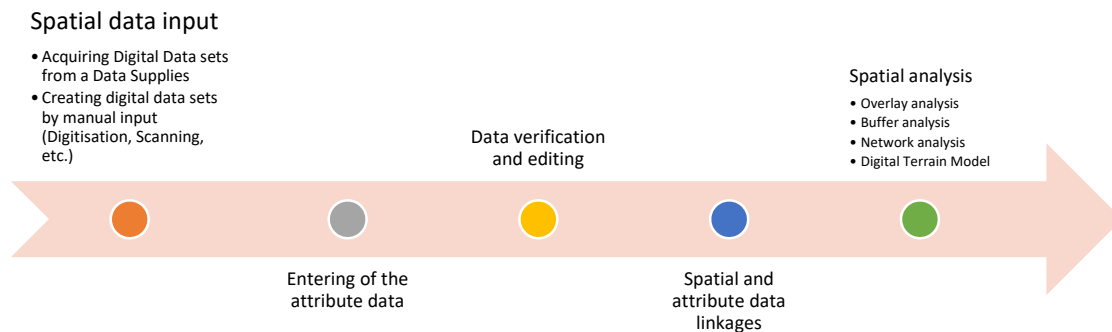
A vector representation of the same image would record the position of the line by simply recording the coordinates of its starting and ending points. Each point would be expressed as two or three numbers (depending on whether the representation was 2D or 3D, often referred to as X,Y or X,Y,Z coordinates) Joining the measured points forms the vector. A vector data model uses points stored by their real (earth) coordinates. Here lines and areas are built from sequences of points in order. Lines have a direction to the ordering of the points. Polygons can be built from points or lines. Vectors can store information about topology. Manual digitising is the best way of vector data input.

The advantages and disadvantages of the two formats is as below:

Raster Model	Vector Model
<ul style="list-style-type: none"> <li>• Simple data structure</li> <li>• Easy and efficient overlaying</li> <li>• Compatible with satellite imagery</li> <li>• High spatial variability is efficiently represented</li> <li>• Simple for own programming</li> <li>• Same grid cells for several attributes</li> <li>• Inefficient use of computer storage</li> <li>• Errors in perimeter and shape</li> <li>• Difficult network analysis</li> <li>• Inefficient projection transformations</li> <li>• Loss of information when using large cells,</li> <li>• Less accurate (although interactive) maps</li> </ul>	<ul style="list-style-type: none"> <li>• Compact data structure</li> <li>• Efficient for network analysis</li> <li>• Efficient projection transformation</li> <li>• Accurate map output</li> <li>• Disadvantages</li> <li>• Complex data structure</li> <li>• Difficult overlay operations</li> <li>• High spatial variability is inefficiently represented</li> <li>• Not compatible with satellite imagery</li> </ul>

## GIS activities

The various activities involved in GIS are spatial and non-spatial data inputs, verification of data, spatial and attribute linkages and finally the analysis as described below:



While importing Spatial Data, users must consider the following characteristics of the data to ensure that they are compatible with the application:

- The scale of the data
- The geo-referencing system used
- The data collection techniques and sampling strategy used
- The quality of data collected
- The data classification and interpolation methods used
- The size and shape of the individual mapping units
- The length of the record

Typical problems encountered during Data Verification are incomplete or double data or spatial data at the wrong scale. While manipulating and analysing data, the same format should be used for all data. When different layers are to be used simultaneously, they should all be in vector or all in raster format. Usually, the conversion is from vector to raster, because the biggest part of the analysis is done in the raster domain. Vector data are transformed to raster data by overlaying a grid with a user-defined cell size

While conducting analysis, in Buffer Operation, buffer of a certain specified distance can be created along any point, line or area feature. It is useful in locating the areas/population benefitted or denied of the facilities and services, such as hospitals, medical stores, post office, asphalt roads, regional parks, etc. Similarly, it can also be used to study the impact of point sources of air, noise or water pollution on human health and the size of the population so affected. This kind of analysis is called proximity analysis. The buffer operation will generate polygon feature types irrespective of geographic features and delineates spatial proximity. For example, numbers of household living within one-kilometre buffer from a chemical industrial unit are affected by industrial waste discharged from the unit.

### **GIS Software**

GIS Software are designed to store, retrieve, manage, display, and analyze all types of geographic and spatial data. QGIS among the open source and ArcGIS among the proprietary software are very popular among GIS users. Comparative analysis of a few GIS software is depicted in the next page:

Software (Column Name)	Functionality (Row Name)	GRASS (Geographic Resources Analysis Support System)	QGIS* (Quantum GIS)	uDig*			MapWindow GIS	ESRI ArcGIS
				uDig	JGrass	DiviGIS		
FOCUS		Full GUI based GIS Spatial analysis and scientific visualization	Viewing, Editing GRASS-Graphical User Interface	Viewing (OGC standards)	Raster Analysis based on GRASS + 3D visualization	Analyze and document potato genotypes	Providing core GIS and GUI functions, developing Decision Support Systems	Full GUI-based GIS Extensive data creation, editing and analysis
Supported Operating Systems		MacOSX	MacOSX	Windows, Linux, MacOSX	Windows, Linux, MacOSX	Windows only	Windows only	Windows only
License		Free software	Free software	Free software	Free software	Free software	Free software	Proprietary
Data Import/Export	Reading - Raster/Images	All GDAL supported formats, also voxel support	All GDAL supported formats	Yes (1.1.0 is limited to memory)	Yes (through GRASS and Geotools)	Yes (Through Geotools)	All GDAL supported formats + BGD, and others.	ECW, MrSID, JPEG, jpg, jp2, TIF, geoTIFF, PNG, GIF, img, bmp, cirs, ers, img, raw, Grid, RST, MrSID, Others
	Reading - Vector	Yes (through OGR)	Yes (through OGR)	Yes	Yes	Yes	At least: SHP, DXF(P), CSV(P), MDB(P)	SHP, DXF, DGN, multiple geodatabases, others
	Reading tabular data	Yes (CSV + many more)	Yes	No			DBF, CSV(P), MDB(P)	
	Reading - Databases	PostGIS, PostgreSQL,	PostGIS	PostGIS, Oracle, DB2,	PostGIS, Oracle, DB2,	PostGIS, Oracle, DB2,	PostGIS(p)	ArcSDE(p), PostGIS,
	Writing - Raster/Images	All GDAL-formats	no	yes	yes	yes	All GDAL supported formats and more	
	Writing - Vector	All OGR-formats	All OGR-formats	Yes (Shape)	Yes (Shape)	Yes (Shape)	At least: SHP	SHP, DXF, DGN, multiple geodatabases, others
	Writing tabular data	CSV	no	no	no	no	copy to Excel table possible	DBF
	Writing - Databases	PostGIS (p, limited)	PostGIS	PostGIS, Oracle, DB2, ArcSDE	PostGIS, Oracle, DB2, ArcSDE	PostGIS, Oracle, DB2, ArcSDE	PostGIS(p), MDB(p)	PostGIS(p), MDB(p)
	Attribute Calculator	yes, via SQL	No	no	no	no	yes	yes
	Q/A: Quality Assurance Tools	yes	No	yes	yes	yes	no	yes
	Join tables	yes	yes (ftools plugin)	no	no	no	no	yes
Printing		yes	yes	yes	yes	yes	Yes	yes
Queries		yes	Yes	limited	yes	no	Attribute queries	Attribute queries, spatial queries
Database Queries (SQL)		yes	yes	no	no	no	no	yes
Styling / Mapping	Point styles	color, size, shape, fill pattern	color, size, shape, fill pattern	Full SLD compliance	Full SLD compliance	Full SLD compliance	Color, size, shape, image	Extensive library plus symbol creation tools
	Line styles	color, width	color, width, pattern	Full SLD compliance	Full SLD compliance	Full SLD compliance	Color, size, line style	Extensive library plus symbol creation tools
	Polygon styles	color, outline, fill	color, outline, fill, pattern	Full SLD compliance	Full SLD compliance	Full SLD compliance	Color, outline, fill patterns.	color, outline, fill patterns, transparency
	Text labeling	Yes (simple labeling)	Yes (simple labeling)	Full SLD compliance	Full SLD compliance	Full SLD compliance	Yes (simple)	
Thematic mapping	Charts	Bar, Pie charts, Graduated Symbol, Ranges	Bar, Pie charts (developed but not included yet)	no	no	no	no	Bar, Pie charts, Graduated Symbol, Ranges
	Classification	equal range, interval, std_deviation, quantiles, custom_breaks	equal range and quantiles	Quantile, equal interval, custom	Quantile, equal interval, custom	no	Equal range, continuous ramps, custom-defined	natural breaks(Jenks) equal range, interval, std_deviation, quantiles, custom_breaks
Vector based Spatial Analysis Tools	Interpolation	IDW, Splines (2D and 3D RST, B-Splines)	GRASS functions via GRASS Plugin	no	GRASS functions	no	Some available through plug-ins	Kriging and co-kriging via add-on
	Spatial Statistics	Link to R-stats	yes (R plugin)	no	GRASS functions	no	Basic raster statistics(p)	Geostatistical analyses
	Buffer	yes	GRASS functions via GRASS Plugin	Yes with Axios plugin	GRASS functions and Axios plugin	no	yes (p)	yes, single and multi-ring, merging
	Join geometries by attributes	yes	no	no	no	no	yes (p)	yes
	aggregate / join attributes spatially	yes	GRASS functions via GRASS Plugin	no	GRASS functions	no	yes (p)	yes
	Spatial Correlation Analysis	yes (via R interface)	no	no	no	no	no	yes, multiple methods
	Other	union (= dissolve), centroid calculation		Union, split, intersect, reproject	Union, split, intersect, reproject	no	Union, merge, centroid, intersection, difference, convex hull, spatial join	Merge, dissolve, intersection, difference, convex hull, spatial join
Multi-language support	Yes/no	yes	yes	yes	yes	yes	yes	yes
Support of different Projections/ Coord. Reference Systems		yes	yes	yes	yes	yes	yes	yes
Data Exploration Tools	Histograms	yes	yes	no	no	yes	No	yes
	classification	yes	GRASS functions via GRASS Plugin	no	GRASS functions	yes	no	yes
Topology creation		yes	GRASS functions via GRASS Plugin	no	no	no	TIN creation and viewing ability	yes
	On the fly topology editing	yes	under development	no	no	no	no	yes
	Triangulation (planar)	yes	no	no	no	no	no	yes
3D-Views		yes	GRASS functions via GRASS Plugin	no	Yes, In development	no	yes	yes
Histogramming	yes	GRASS functions via GRASS Plugin	no	GRASS functions		yes	yes	
Image Analysis Tools	Geo-Referencing	yes	Geocoding of scanned maps	no	GRASS functions		yes	yes
	Ortho-rectification	yes	no	no	GRASS functions		Under development	no
	Filter operations	yes	GRASS functions via GRASS Plugin	no	GRASS functions		Under development	yes
Version		GRASS 6.4	QGIS 1.3	Version 1.1-RC12			Version 4.5 RC2 (April 2008)	Release 9.3.1