SEMESTER-II (Geography Honours)

Paper code: GEOACORO4T (Cartography and Thematic Mapping)
TOPIC (4): Preparation and interpretation of landuse and landcover mapping:

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Introduction:

Land is a finite resource put to multiple competing uses. In geographical context land is considered to be a surface of the earth on which man performs various activities which leads to temporal modifications and evolution to its present form. It is not only on the earth's surface resources but also resources below the surface like minerals etc which are used by man over the period of time. The morphological changes on the surface of the lithosphere are caused both due to nature and human interference. All such changes are major driving forces for moderations in biogeochemical cycles, climate change and food production from regional to global scales. The face of the Earth has been altered by a continuous deformation process. Human alteration of land and its resources is a reflection of his needs and desires.

Land is to be considered the most important aspect of production, especially agricultural production. Regardless of the advancement of power-machine civilization and the subsequent decline of vegetable civilization or agriculture, the problem of food production and supply and the question of limitations in the availability of cultivable or arable land still remains crucial.

The problem seems to be quite insoluble due to the fact that explosive population growth in some parts of the world is fast outpacing the growth of agricultural output. Thus, the problem of providing sustenance to very rapidly increasing human family is serious.

Concept: Although the terms land cover and land use are often used interchangeably, their actual meanings are quite distinct. Land cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, bare soil or other. Identifying, delineating and mapping land cover is important for global monitoring studies, resource management, and planning activities. Identification of land cover establishes the baseline from which monitoring activities (change detection) can be performed, and provides the ground cover information for baseline thematic maps.

Land use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year to year. This knowledge will help develop strategies to balance conservation, conflicting uses, and developmental pressures. Issues driving land use studies include the removal or disturbance of productive land, urban encroachment, and depletion of forests.

It is important to distinguish this difference between land cover and land use, and the information that can be ascertained from each. The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge.

Land cover / use studies are multidisciplinary in nature, and thus the participants involved in such work are numerous and varied, ranging from international wildlife and conservation foundations, to government researchers, and forestry companies. Regional (in Canada, provincial) government agencies have an operational need for land cover inventory and land use monitoring, as it is within their mandate to manage the natural resources of their respective regions. In addition to facilitating sustainable management of the land, land cover and use information may be used for planning, monitoring, and evaluation of development, industrial activity, or reclamation. Detection of long term changes in land cover may reveal a response to a shift in local or regional climatic conditions, the basis of terrestrial global monitoring

According to Food and Agriculture Organization, **Land cover** refers to the observed physical and biological cover of the earth's land. Land is covered by various forms of vegetation, grasslands, scrubs, water bodies, bare soil etc. All the naturally occurring vegetation cover is called land cover.

Food and Agricultural Organization, defines land use as “the total of arrangements, activities, and inputs that people undertake in a certain land cover type". According to Fox, “The land use is the actual and specific use to which a land surface is put in terms of inherent land use characteristics”. Therefore, land cover is a natural vegetation; land use is utilization of land by man as per his needs and choices. In other words, land use in general terms is human modifications of Earth’s terrestrial surface.

Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods. Land use is "the total of arrangements, activities, and inputs that people undertake in a certain land cover type" (FAO, 1997a; FAO/UNEP, 1999).

Besides needs and choices, land is also put to its use depending upon its usefulness and capability. The topological variations, soil type, soil’s pH value, soil quality and moisture content also determine its utility. The modern economic men use land by evaluating its economic and social viability. The land utilization is also determined by evaluating the cost-benefit analysis of the economic activity per se.

The term **"Land use"** is important to city planners and policy makers. The management of land is utmost important task as the process of urbanization is a complex phenomenon, that deals with population pressure and competing land uses. The cities nest multiple economic activities that demand land, like residential and commercial complexes, parks, industrial units, markets, transport and communication etc. Therefore, it becomes the task of the planners to create master plans and choose the optimum land use plan.

In most of the cases the forest land is burned or slashed to transform to a farm or some infrastructure development. This leads to loss in biodiversity, i.e. loss of floral and faunal species. Due to deforestation or removal of forest cover, the impact can also be felt on the adjoining ecosystems that are depended upon it. It also has tremendous impact on the social, economic and cultural units around it. The change in land cover also results in change in the micro- climate of the areas. It effects the albedo i.e. reflection of sunlight from land surface, evapo- transpiration i.e. evaporation from the surface of the leaves and trees and overall precipitation and heat balance.

Land use and Land Cover change, together alter the atmospheric and hydrological systems of the area. Therefore, it becomes the duty of the policy makers and planners to classify and plan the land use of an area in such a way so that it can support the existing habitats and do not hamper its ecosystem. The land use plans should lead to smart growth and encourage more efficient and desirable land use. In 1992, Agenda 21 recognized the need for integrated planning and management of land resources, stating that it should be a decision making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits". (Agenda 21, paragraph 10.5).

Land Categories and Definitions

Category	Definition
Country area	The total of areas under "Land area" and "Inland water," excluding offshore territorial waters.
Land area	The total of areas under "Agricultural area," "Forest or other wooded land," and "Other land."
Agricultural area	The total of areas under "Arable land and permanent crops" and "Permanent meadows and pastures".
Arable land and Permanent crops	The total of areas under "Arable land" and "Land under permanent crops".
Arable land	Land used for growing temporary crops (Ref: in the land use questionnaire, multiple- cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). It does not include land under permanent crops or land that is potentially cultivable but is not normally cultivated.

Land under temporary crops	Land used for crops with a less than one-year growing cycle, which must be newly sown or planted for further production after the harvest. Some crops that remain in the field for more than one year may also be considered as temporary crops. Asparagus, strawberries, pineapples, bananas and sugar cane, for example, are grown as annual crops in some areas. Such crops should be classified as temporary or permanent according to the custom in the country.
Land under temporary meadows and pastures	Land temporarily cultivated with herbaceous forage crops for mowing or pasture. A period of less than five years is used to differentiate between temporary and permanent meadows.
Land temporarily fallow	Arable land that is not seeded for one or more growing seasons. The maximum idle period is usually less than five years. Land remaining fallow for too long may acquire characteristics requiring it to be reclassified, such as "permanent meadows and pastures" (if used for grazing), "forest or other wooded land" (if overgrown with trees), or "other land" (if it becomes wasteland).
Land under permanent crops	Land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers (such as roses and jasmine); and nurseries (except those for forest trees, which should be classified under "forest"). Permanent meadows and pastures are excluded from land under permanent crops.
Permanent meadows and pastures	Land used permanently (for five years or more) to grow herbaceous forage crops through cultivation or naturally (wild prairie or grazing land).

Land Use Information: The Food and Agricultural Organization highlights some relevant and important aspects of Land use information. So why is land use information important? Land use information can provide information regarding

1. Where: The spatial extent and geographic location
2. What: The purpose of activity undertaken
3. When: The temporal changes
4. How: The technology employed and quantitative measures
5. Why: The reason for current land use

Its important to note that the national categories of land use differ, but many have been harmonized under the influence of FAO's periodical World Census of Agriculture. The FAO recognizes 15 categories in all. The table 1 shows such 15 categories and the type of landuse falling in these categories.

Land-use categories recognized in FAO's World Census of Agriculture (FAO, 1986, 1995a; FAO/UNEP, 1999).	
In Sequence of Increasing Intensity of Use	**Equivalents**
(a) *Deserts* (barren land and waste land)	-
(b) *Non-Forest Wooded Lands* (scrubland; may include national parks and wilderness recreational areas)	-
(c) *Wetlands, Non-Forest* (marshes)	Wetlands
(d) *Land under Forest* (natural forests and most non-	Forest Land

managed woodlands)	
(e) *Land under Forestry/Silviculture*	Forest Land
(f) *Land under Shifting Cultivation* (temporarily abandoned land that is not part of a holding)	Agroforestry Land
(g) *Land under Agroforestry* (permanent use of land at holding level, but with mixed crop growing, animal herding, and tree utilization)	Agroforestry Land
(h) *Land with Temporary Fallow* (resting for a period of time, less than 5 years, before it is planted again with annual crops)	Cropland
(i) *Land under Permanent Meadows and Pastures* [used for herbaceous forage crops that are either managed/cultivated (pastures) or growing wild (grazing land); trees and shrubs may be present or grown purposely, but foraging is the most important use of the area; grazed woodlands]	Rangeland/Grasslands
(j) *Land under Temporary Meadows and Pastures* (cultivated temporarily, for less than 5 years, for herbaceous forage crops, mowing, or pasturing, in alternation with arable cropping)	Rangeland/Grasslands
(k) *Land under Permanent Crops* (perennials; cultivated with long-term crops that do not have to be replanted for several years after each harvest; harvested components are not timber but fruits, latex, and other products that do not significantly harm the growth of the planted trees or shrubs: orchards, vineyards, rubber and oil palm plantations, coffee, tea, sisal, etc.)	Agroforestry Land
(l) *Land under Temporary Crops* (annuals; cultivated with crops with a growing cycle of under 1 year, which must be newly sown or planted for further production after harvesting; not only small grain crops such as beets, wheat, and soy bean but also bi-annuals that are destroyed at harvesting, such as cassava, yams, and sugarcane; bananas are transitional to the permanent crops category)	Cropland
(m) *Land under Temporary Crops Requiring Wetland Conditions* [wet-foot crops such as irrigated rice and jute (dry-foot crops with intermittent irrigation included in other categories)]	Wetlands
(n) *Land under Protective Cover* (greenhouses and other urban or peri-urban intensive use, formal or informal; vegetable growing, home gardening, residential parks, golf courses, etc.)	Peri-Urban Land
(o) *Land under Residential/Industrial/Transportation Facilities*	Peri-Urban Land

Classification of Land use in India:

The land use classification is essential for understanding present system and apprehending the scope for future changes in land use. The land use classification is done by assessing the quality of land for specific purpose. There are several indicators for classifying the land, like: soil quality, soil fertility, productivity, efficiency, physical properties, socioeconomic controls and many more. Based on different indicators, the land is classified in various categories. The land can be classified broadly quantitatively and qualitatively.

All India Soil and Land Use Survey Organization, in 1960, gave a land use classification which was revised later in 1970. They classified land on the basis of its suitability. Land use that can be defined on the basis of its fitness to a particular use is called land suitability classification. Broadly the classification in done under two categories i.e

S: Suitable – Its states that the land under this category is one which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

N: Not suitable- Land which has qualities that appear to preclude sustained use of the kind under consideration.

They categorized India into 8 categories:

Land Suitable for Cultivation:

Class I: Very good cultivable land with no specific difficulty in farming.

Class II: Good cultivable land which needs protection from erosion or floods, drainage improvement and conservation of irrigation water.

Class III: Moderately good cultivable land where special attention has to be paid to erosional control, conservation of irrigation water, intensive drainage and protection from floods.

Class IV: Fairly good land suited for occasional or limited cultivation, needs intensive erosional control, intensive drainage and very intensive treatment to overcome soil limitations.

Land not Suitable for Cultivation:

Class V: Very well suited for grazing but not for arable farming, needs protection from gullying.

Class VI: Well suited for grazing or forestry but not for arable farming.

Class VII: Fairly well suited for grazing or forestry but not for arable farming.

Class VIII: Suited only for wildlife, recreational facilities and protection of water supplies.

Other way to classify the landuse is on its capability. Capability as such means the ability to do something.

Land Capability Classification:

The land capability classification is based upon the limitations imposed on the sustained use of soils by the basic characteristics of soil in combination with climate, topography, surface drainage, vegetation cover, erodibility and other natural hazards. Based on all these characteristics, the land capability classes are determined from I to VII. They are further subdivided into subclasses and units.

Class I: Very Good soil - The soil of such regions are deep, productive, nearly levelled and easily worked. The soils have no risk of damage. Such soils are very productive and are found in flood-plains of India.

Class II: Soils with moderate limitations - Soils can be cultivated with some applied practices. The land is in an excellent state with some limitations. These soils are subject to moderate risk of damage. These areas are generally the ones with specialized cropping and commercially one of the most suitable parts of the country.

Class III: Moderately good soils- These soils can be used regularly for crops. These areas face some ecological problems like soil erosion and rainfall irregularity. These soils are inherently low in fertility. Such areas require adequate surface drainage and contour tillage.

Class IV: The soils are low in fertility- These soils are prone to severe hazards like water deficiency or water logging, as the case may be. Such areas are demarcated at steep slopes that are prone to soil erosion. People in these areas have small farms and practice mainly subsistence agriculture. They grow coarse grains. These areas are suitable for pastures too.

Class V: The soils with permanent Limitations- These soils are mainly found in foothills or in mountain valley. They are suitable for shrubs, grasses or forestry. Such soils are wet and stoney therefore the cultivation is not possible. They are frequently exposed to wind and water erosion.

Geospatial data and LULC

With the advancements in remote sensing, monitoring networks, and geographic information systems (GIS), the availability of spatial data is rapidly increasing. These geospatial data include not only maps and locations of land use and land cover (LULC), but also multiple attributes of data, such as socioeconomic data from the census. Improvements in the use and accessibility of multi-temporal, satellite-derived environmental data or other thematic raster data have contributed to the growing use in environmental modeling. Remote sensing provides synoptic information on vegetation growth conditions over a large geographic area in near real-time. The vegetation growth pattern is estimated using the normalized difference vegetation index (NDVI), which is based on visible (red) (VIS) and near-infrared (NIR) band reflectance derived from the most widely used global NDVI data sets.

Following are some of the LULC types and their respective classes

Urban or Built-up	• Residential

Land	• Commercial and Services • Industrial • Communications and Utilities • Mixed Urban or Built-up Land • Other Urban or Built-up Land
Agricultural Land	• Cropland and Pasture • Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas • Confined Feeding Operations
Rangeland	• Herbaceous Rangeland • Shrub and Brush Rangeland • Mixed Rangeland
Forest Land	• Deciduous Forest Land • Evergreen Forest Land • Mixed Forest Land
Water	• Rivers • Streams and Canals • Lakes • Reservoirs • Bays and Estuaries
Wetland	• Forested Wetland • No forested Wetland
Barren Land	• Dry Salt Flats • Beaches • Sandy Areas Other than Beaches • Bare Exposed Rock • Strip Mines, Quarries, and Gravel Pits • Transitional Areas • Mixed Barren Land
Perennial Snow or Ice	• Perennial Snowfields • Glaciers

Landuse and Land Cover Classification by United States Geological Survey (USGS)

The United States has already achieved reasonably effective, though not perfect, standardization in some instances, as evidenced by present programs in soil surveys, topographic mapping, collection of weather information, and inventory of forest resources. Recent developments in data processing and remote sensing technology make the need for similar cooperation in land use inventories even more evident and more pressing. Development and acceptance of a system for classifying land use data obtained primarily by use of remote sensing techniques, but reasonably compatible with existing classification systems, are the urgently needed first steps (James., et.al, 1976).

For the standardization in inventory and to address various environmental problems associated with land use and land cover change an interagency Steering Committee on Land Use information and Classification early in 1971. The committee was composed of representatives from the Geological Survey of the U.S. Department of the Interior, the National Aeronautics and Space Administration (NASA), the Soil Conservation Service of the U.S. Department of Agriculture, the Association of American Geographers, and the International Geographical Union, has been supported by NASA and the Department of the Interior and coordinated by the U.S. Geological Survey (U.S.G.S.).

The main objective of the committee was the development of a national classification system that would be receptive to inputs of data from both conventional sources and remote sensors on high-altitude aircraft and satellite platforms, and that would at the same time form the framework into which the categories of more detailed land use studies by regional, State, and local agencies could be fitted and aggregated upward from Level IV toward Level I for more generalized smaller scale use at the national level (James., et.al, 1976).

A land use and land cover classification system which can effectively employ orbital and high-altitude remote sensor data should meet the following criteria (Anderson, 1971):

1. The minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensor data should be at least 85 percent.
2. The accuracy of interpretation for the several categories should be about equal.
3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another.
4. The classification system should be applicable over extensive areas.
5. The categorization should permit vegetation and other types of land cover to be used as surrogates for activity.
6. The classification system should be suitable for use with remote sensor data obtained at different times of the year.

7. Effective use of subcategories that can be obtained from ground surveys or from the use of larger scale or enhanced remote sensor data should be possible.

8. Aggregation of categories must be possible.

9. Comparison with future land use data should be possible.

10. Multiple uses of land should be recognized when possible.

Classification Level

Typical Data Characteristics

I LANDSAT (formerly ERTS) type of data

II High-altitude data at 40,000 ft (12,400 m) or above (less than l:8O,OOO scale)

III Medium-altitude data taken between 10,000 and 40,000 ft (3,100 and 12,400 m) (1:20,000 to 1:80,000 scale)

IV Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale) Land use and land cover classification system for use with remote sensor data

Level I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals

	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats.
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

LULC classification using RS & GIS:

LULC classification is one of the most widely used applications in remote sensing. The most commonly used approaches include:

Unsupervised classification *(calculated by software)*

This type of classification is based on the software analysis of an image without the user provided sample classes. This involves grouping of pixels with common characteristics. The computer uses techniques to determine which pixels are related and groups them into classes. The user can specify which algorithm the software will use and the desired number of output classes but otherwise does not aid in the classification process. However, the user must have knowledge of the area being classified (such as wetlands, developed areas, coniferous forests, etc.).

Supervised classification *(human guided)*

This is based on the idea that a user can select sample pixels in an image that are representative of specific classes and then direct the image processing software to use these training sites as references for the classification of all other pixels in the image. Training sites (also known as testing sets or input classes) are selected based on the knowledge of the user. The user also sets the bounds for how similar other pixels must be to group them together. These bounds are often set based on the spectral characteristics of the training area, plus or minus a certain increment (often based on "brightness" or strength of reflection in specific spectral bands). The user also designates the number of classes that the image is classified into.

Image interpretation for land use land cover mapping using remote sensing techniques:

The principles of image interpretation have been developed empirically for more than 150 years. The most basic are the elements of image interpretation: location, size, shape, shadow, tone/color, texture, pattern, height/depth and site/situation/association. They are routinely used when interpreting aerial photos and analysing photo-like images. An experienced image interpreter uses many of these elements intuitively. However, a beginner may not only have to consciously evaluate an unknown object according to these elements, but also analyze each element's significance in relation to the image's other objects and phenomena.

Elements of interpretation

Location

There are two primary methods to obtain a precise location in the form of coordinates. 1) survey in the field by using traditional surveying techniques or global positioning system instruments, or 2) collect remotely sensed data of the object, rectify the image and then extract the desired coordinate information. Most scientists who choose option 1 now use relatively inexpensive GPS instruments in the field to obtain the desired location of an object. If option 2 is chosen, most aircraft used to collect the remotely sensed data have a GPS receiver.

Size

The size of an object is one of the most distinguishing characteristics and one of the more important elements of interpretation. Most commonly, length, width and perimeter are measured. To be able to do this successfully, it is necessary to know the scale of the photo. Measuring the size of an unknown object allows the interpreter to rule out possible alternatives. It has proved to be helpful to measure the size of a few well-known objects to give a comparison to the unknown-object. For example, field dimensions of major sports like soccer, football, and baseball are standard throughout the world. If objects like this are visible in the image, it is possible to determine the size of the unknown object by simply comparing the two.

Shape

There is an infinite number of uniquely shaped natural and man-made objects in the world. A few examples of shape are the triangular shape of modern jet aircraft and the shape of a common single-family dwelling. Humans have modified the landscape in very interesting ways that has given shape to many objects, but nature also shapes the landscape in its own ways. In general, straight, recti-linear features in the environment are of human origin. Nature produces more subtle shapes.

Shadow

Virtually all remotely sensed data are collected within 2 hours of solar noon to avoid extended shadows in the image or photo. This is because shadows can obscure other objects that could otherwise be identified. On the other hand, the shadow cast by an object act as a key for the identification of the object as the length of the shadow will be used to estimate the height of the object which is vital for the recognition of the object. Take for example, the Washington Monument in Washington D.C. While viewing this from above, it can be difficult to discern the shape of the monument, but with a shadow cast, this process becomes much easier. It is a good practice to orient the photos so that the shadows are falling towards the interpreter. A pseudoscopic illusion can be produced if the shadow is oriented away from the observer. This happens when low points appear high and high points appear low.

Tone and color

Real-world materials like vegetation, water and bare soil reflect different proportions of energy in the blue, green, red, and infrared portions of the electro-magnetic spectrum. An interpreter can document the amount of energy reflected from each at specific wavelengths to create a spectral signature. These signatures can help to understand why certain objects appear as they do on black and white or color imagery. These shades of gray are referred to as tone. The darker an object appears, the less light it reflects. Color imagery is often preferred because, as opposed to shades of gray, humans can detect thousands of different colors. Color aids in the process of photo interpretation.

Texture

This is defined as the "characteristic placement and arrangement of repetitions of tone or color in an image." Adjectives often used to describe texture are smooth (uniform, homogeneous), intermediate, and rough (coarse, heterogeneous). It is important to remember that texture is a product of scale. On a large scale depiction, objects could appear to have an intermediate texture. But, as the scale becomes smaller, the texture could appear to be more uniform, or smooth. A few examples of texture could be the "smoothness" of a paved road, or the "coarseness" a pine forest.

Pattern

Pattern is the spatial arrangement of objects in the landscape. The objects may be arranged randomly or systematically. They can be natural, as with a drainage pattern of a river, or man-made, as with the squares formed from the United States Public Land Survey System. Typical adjectives used in describing pattern are: random, systematic, circular, oval, linear, rectangular, and curvilinear to name a few.

Height and depth

Height and depth, also known as "elevation" and "bathymetry", is one of the most diagnostic elements of image interpretation. This is because any object, such as a building or an electric pole that rises above the local landscape will exhibit some sort of radial relief. Also, objects that exhibit this relief will cast a shadow that can also provide information as to its height or elevation. A good example of this would be buildings of any major city.

Site/situation/association

Site has unique physical characteristics which might include elevation, slope, and type of surface cover (e.g., grass, forest, water, bare soil). Site can also have socioeconomic characteristics such as the value of land or the closeness to water. Situation refers to how the objects in the photo or image are organized and "situated" in respect to each other. Most power plants have materials and building associated in a fairly predictable manner. Association refers to the fact that when you find a certain activity within a photo or image, you usually encounter related or "associated" features or activities. Site, situation, and association are rarely used independent of each other when analyzing an image. An example of this would be a large shopping mall. Usually there are multiple large buildings, massive parking lots, and it is usually located near a major road or intersection.

Interpreting Optical Remote Sensing Images

Four main types of information contained in an optical image are often utilized for image interpretation:

- **Radiometric Information (i.e. brightness, intensity, tone),**
- **Spectral Information (i.e. colour, hue),**
- **Textural Information,**
- **Geometric and Contextual Information.**

They are illustrated in the following examples.

Panchromatic Images

A **panchromatic image** consists of only one band. It is usually displayed as a **grey scale image**, i.e. the displayed brightness of a particular pixel is proportional to the pixel digital number which is related to the intensity of solar radiation reflected by the targets in the pixel and detected by the detector. Thus, a panchromatic image may be similarly interpreted as a black-and-white aerial photograph of the area. The Radiometric Information is the main information type utilized in the interpretation.

A panchromatic image extracted from a **SPOT** panchromatic scene at a ground **resolution**of 10 m. The ground coverage is about 6.5 km (width) by 5.5 km (height). The urban area at the bottom left and a clearing near the top of the image have high reflected intensity,while the vegetated areas on the right part of the image are generally dark. Roads and blocksof buildings in the urban area are visible. A river flowing through the vegetated area, cutting across the top right corner of the image can be seen. The river appears bright due to sediments while the sea at the bottom edge of the image appears dark.

Multispectral Images

A **multispectral image** consists of several bands of data. For visual display, each band of the image may be displayed one band at a time as a **grey scale image**, or in combination of three bands at a time as a **colour composite image**. Interpretation of a multispectral colour composite image will require the knowledge of the **spectral reflectance signature** of the targets in the scene. In this case, the spectral information content of the image is utilized in the interpretation.

The following three images show the three bands of a multispectral image extracted from a **SPOT** multispectral scene at a ground resolution of 20 m. The area covered is the same as that shown in the above panchromatic image. Note that both the **XS1 (green) and XS2 (red)** bands look almost identical to the panchromatic image shown above. In contrast, the vegetated areas now appear bright in the **XS3 (near infrared)** band due to high reflectance of leaves in the near infrared wavelength region. Several shades of grey can be identified for the vegetated areas, corresponding to different types of vegetation. Water mass (both the river and the sea) appear dark in the XS3 (near IR) band.

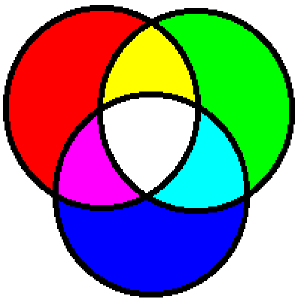
SPOT XS1 (green band)

SPOT XS2 (red band)

SPOT XS3 (Near IR band)

Colour Composite Images

In displaying a colour composite image, three primary colours (red, green and blue) are used. When these three colours are combined in various proportions, they produce different colours in the visible spectrum. Associating each spectral band (not necessarily a visible band) to a separate primary colour results in a colour composite image.

	**Many colours can be formed by combining the three primary colours (Red, Green, Blue) in various proportions.**

True Colour Composite

If a multispectral image consists of the three visual primary colour bands (red, green, blue), the three bands may be combined to produce a "true colour" image. For example, the bands 3 (red band), 2 (green band) and 1 (blue band) of a **LANDSAT TM** image or an **IKONOS** multispectral image can be assigned respectively to the R, G, and B colours for display. In this way, the colours of the resulting colour composite image resemble closely what would be observed by the human eyes.

A 1-m resolution true-colour IKONOS image.

False Colour Composite

The display colour assignment for any band of a **multispectral image** can be done in an entirely arbitrary manner. In this case, the colour of a target in the displayed image does not have any

resemblance to its actual colour. The resulting product is known as a **false colour composite** image. There are many possible schemes of producing false colour composite images. However, some scheme may be more suitable for detecting certain objects in the image.
A very common false colour composite scheme for displaying a SPOT multispectral image is shown below:

R = XS3 (NIR band)
G = XS2 (red band)
B = XS1 (green band)

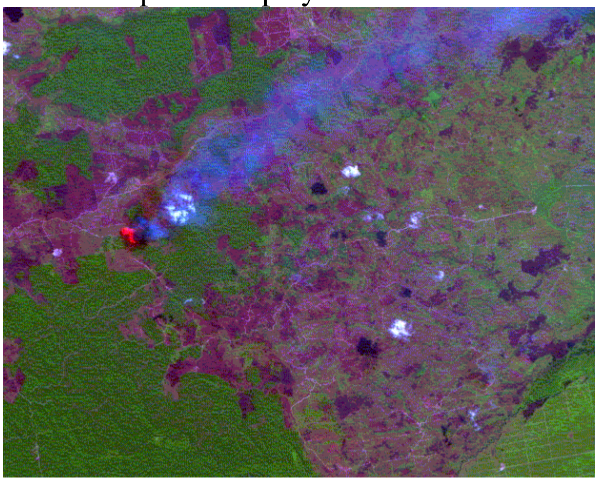
This false colour composite scheme allows vegetation to be detected readily in the image. In this type of false colour composite images, vegetation appears in different shades of red depending on the types and conditions of the vegetation, since it has a high reflectance in the NIR band (as shown in the graph of **spectral reflectance signature**).
Clear water appears dark-bluish (higher green band reflectance), while turbid water appears cyan (higher red reflectance due to sediments) compared to clear water. Bare soils, roads and buildings may appear in various shades of blue, yellow or grey, depending on their composition.

False colour composite multispectral SPOT image:
Red: XS3; Green: XS2; Blue: XS1

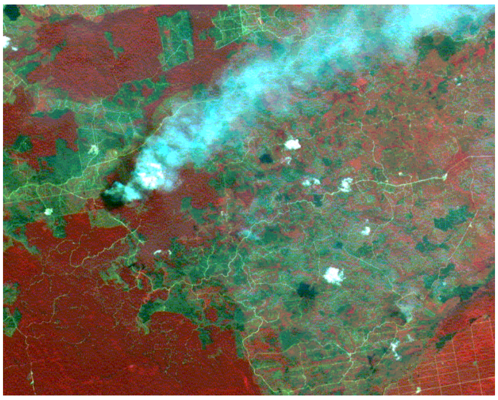
Another common false colour composite scheme for displaying an optical image with a short-wave infrared (SWIR) band is shown below:

R = SWIR band (SPOT4 band 4, Landsat TM band 5)
G = NIR band (SPOT4 band 3, Landsat TM band 4)
B = Red band (SPOT4 band 2, Landsat TM band 3)

An example of this false colour composite display is shown below for a SPOT 4 image.



False colour composite of a SPOT 4 multispectral image including the SWIR band:
Red: SWIR band; Green: NIR band; Blue: Red band. In this display scheme, vegetation appears in shades of green. Bare soils and clearcut areas appear purplish or magenta.
The patch of bright red area on the left is the location of active fires.
A smoke plume originating from the active fire site appears faint bluish in colour.



False colour composite of a SPOT 4 multispectral image without displaying the SWIR band:
Red: NIR band; Green: Red band; Blue: Green band. Vegetation appears in shades of red.
The smoke plume appears bright bluish white.

Natural Colour Composite

For optical images lacking one or more of the three visual primary colour bands (i.e. red, green and blue), the spectral bands (some of which may not be in the visible region) may be combined in such a way that the appearance of the displayed image resembles a visible colour photograph, i.e. vegetation in green, water in blue, soil in brown or grey, etc. Many people refer to this composite as a "**true colour**" composite. However, this term is misleading since in many instances the colours are only simulated to look similar to the "true" colours of the targets. The term "natural colour" is preferred.

The **SPOT** **HRV multispectral** sensor does not have a blue band. The three bands, XS1, XS2 and XS3 correspond to the green, red, and **NIR** bands respectively. But a reasonably good natural colour composite can be produced by the following combination of the spectral bands:

R = XS2
G = (3 XS1 + XS3)/4
B = (3 XS1 - XS3)/4

where R, G and B are the display colour channels.

Natural colour composite multispectral SPOT image:
Red: XS2; Green: 0.75 XS2 + 0.25 XS3; Blue: 0.75 XS2 - 0.25 XS3

Vegetation Indices

Different bands of a **multispectral image** may be combined to accentuate the vegetated areas. One such combination is the ratio of the near-infrared band to the red band. This ratio is known as the **Ratio Vegetation Index (RVI)**

RVI = NIR/Red

Since vegetation has high NIR reflectance but low red reflectance, vegetated areas will have higher RVI values compared to non-vegetated aeras. Another commonly used vegetation index is the **Normalised Difference Vegetation Index (NDVI)** computed by

NDVI = (NIR - Red)/(NIR + Red)

Normalised Difference Vegetation Index (NDVI) derived from the above SPOT image

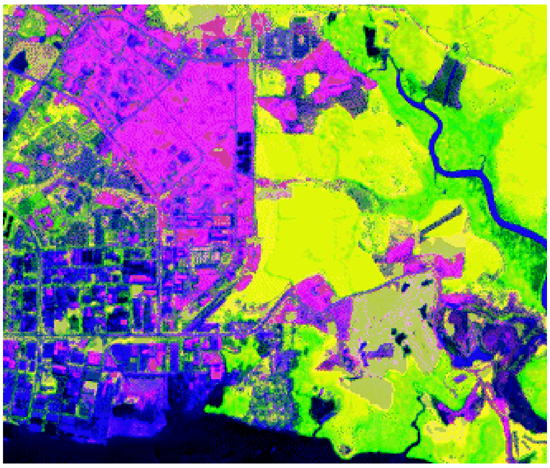
In the NDVI map shown above, the bright areas are vegetated while the nonvegetated areas (buildings, clearings, river, sea) are generally dark. Note that the trees lining the roads are clearly visible as grey linear features against the dark background.

The NDVI band may also be combined with other bands of the multispectral image to form a colour composite image which helps to discriminate different types of vegetation. One such example is shown below. In this image, the display colour assignment is:

R = XS3 (Near IR band)

G = (XS3 - XS2)/(XS3 + XS2) (NDVI band)

B = XS1 (green band)



NDVI Colour Composite of the SPOT image:Red: XS3; Green: NDVI; Blue: XS1.

At least three types of vegetation can be discriminated in this colour composite image: green, bright yellow and golden yellow areas. The green areas consist of dense trees with closed canopy. The bright yellow areas are covered with shrubs or less dense trees. The golden yellow areas are covered with grass. The non vegetated areas appear in dark blue and magenta.

Textural Information

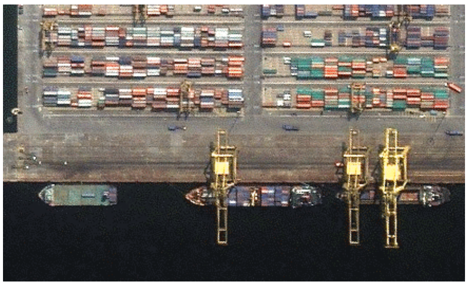
Texture is an important aid in visual image interpretation, especially for high spatial resolution imagery. An example is shown below. It is also possible to characterize the textural features numerically, and algorithms for computer-aided automatic descrimination of different textures in an image are available.

	This is an IKONOS 1-m resolution pan-sharpened color image of an oil palm plantation. The image is 300 m across. Even though the general colour is green throughout, three distinct land cover types can be identified from the image texture. The triangular patch at the bottom left corner is the oil palm plantation with matured palm trees. Individual trees can be seen. The predominant texture is the regular pattern formed by the tree crowns. Near to the top of the image, the trees are closer together, and the tree canopies merge together, forming another distinctive textural pattern. This area is probably inhibated by shrubs or abandoned trees with tall undergrowths and shrubs in between the trees. At the bottom right corner, colour is more homogeneous, indicating that it is probably an open field with short grass.

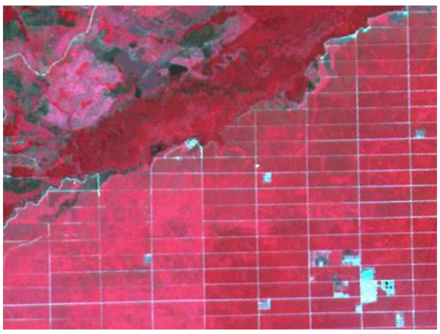
Geometric and Contexture Information

Using geometric and contextual features for image interpretation requires some a-priori information about the area of interest. The "interpretational keys" commonly employed are: shape, size, pattern, location, and association with other familiar features.

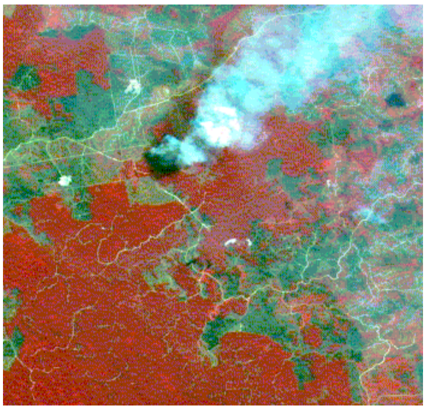
Contextual and geometric information plays an important role in the interpretation of very high resolution imagery. Familiar features visible in the image, such as the buildings, roadside trees, roads and vehicles, make interpretation of the image straight forward.



This is an IKONOS image of a container port, evidenced by the presence of ships, cranes, and regular rows of rectangular containers. The port is probably not operating at its maximum capacity, as empty spaces can be seen in between the containers.



This SPOT image shows an oil palm plantation adjacent to a logged over forest in Riau, Sumatra. The image area is 8.6 km by 6.4 km. The rectangular grid pattern seen here is a main characteristic of large scale oil palm plantations in this region.



This SPOT image shows land clearing being carried out in a logged over forest. The dark red regions are the remaining forests. Tracks can be seen intruding into the forests, implicating some logging activities in the forests. The logging tracks are also seen in the cleared areas (dark greenish areas). It is obvious that the land clearing activities are carried out with the aid of fires.
A smoke plume can be seen emanating from a site of active fires.

Applications of LULC maps

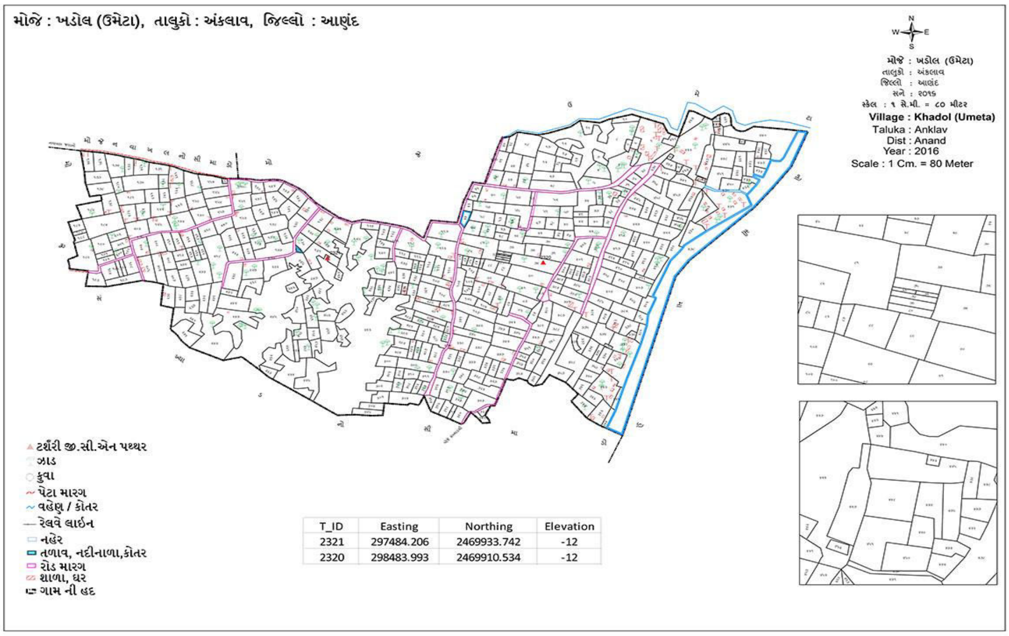
- Natural resource management
- Wildlife habitat protection
- Baseline mapping for GIS input
- Urban expansion / encroachment
- Routing and logistics planning for seismic / exploration/resource extraction activities
- Damage delineation (tornadoes, flooding, volcanic, seismic, fire)
- Legal boundaries for tax and property evaluation
- Target detection - identification of landing strips, roads, clearings, bridges, land/water interface

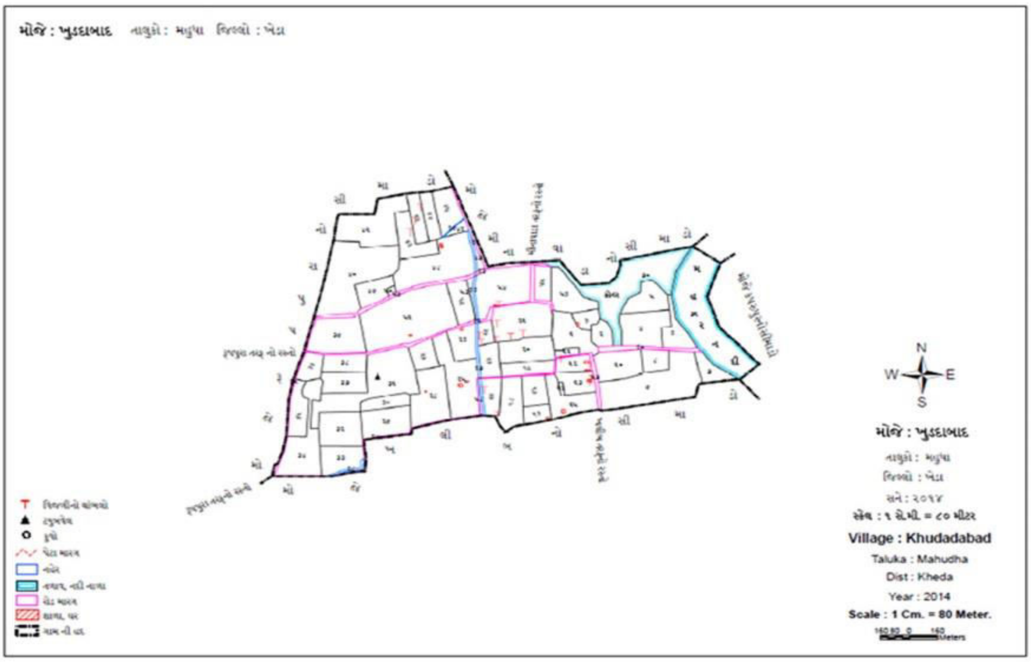
Traditional method for land use and land cover mapping:

Cadastral maps were used for localized land use and land cover maps. A cadastral map is a map which provides detailed information about real property within a specific area. A simple example of a cadastral map might be a map of a village which shows the boundaries of all of the parcels or lots within the village, although cadastral maps can show other types of areas as well. These maps are usually maintained by the government, and they are a matter of public record; anyone who wishes to go to the office which maintains the records can ask to see them.
Also known as a cadaster or cadastre, a cadastral map can include a number of details, including information about tax rates, who owns the land, which kinds of structures are present, what the zoning is in the region, and so forth. All of this information is intended to contexualize the area of the map by providing the viewers with as much data as possible about the land.
One key feature of a cadastral map is that it carries detailed information about location. These maps do not just show the boundaries of lot lines, they provide measurements on each lot, and may use GPS locations as well, so that people clearly understand where everything on the map is in the real world. A cadastral map will also highlight specific landmarks which people can use to orient themselves within the map, including buildings and natural features such as lakes and

streams. The map also provides people with information about property rights, and a history of the rights in that area. Cadastral maps can show who retains mining or timber rights, for example, in contrast with who owns the land. The map can also provide a history of the owners, or a perusal through old maps can provide people with this information. Maps can also detail how the land is being used, so that people interested in land use patterns can easily identify areas of interest.

These maps are updated on a regular basis. It is a good idea to keep track of the cadastral survey, as information can change. Property owners would also do well to hire a surveyor to confirm that their property adheres to the information on the maps. If, for example, a neighbor moves a fence, it could cut into a property owner's lot, and if the situation is not recognized and addresses, in some communities, the neighbor would get to keep the land annexed by the fence after a certain period of time has elapsed.





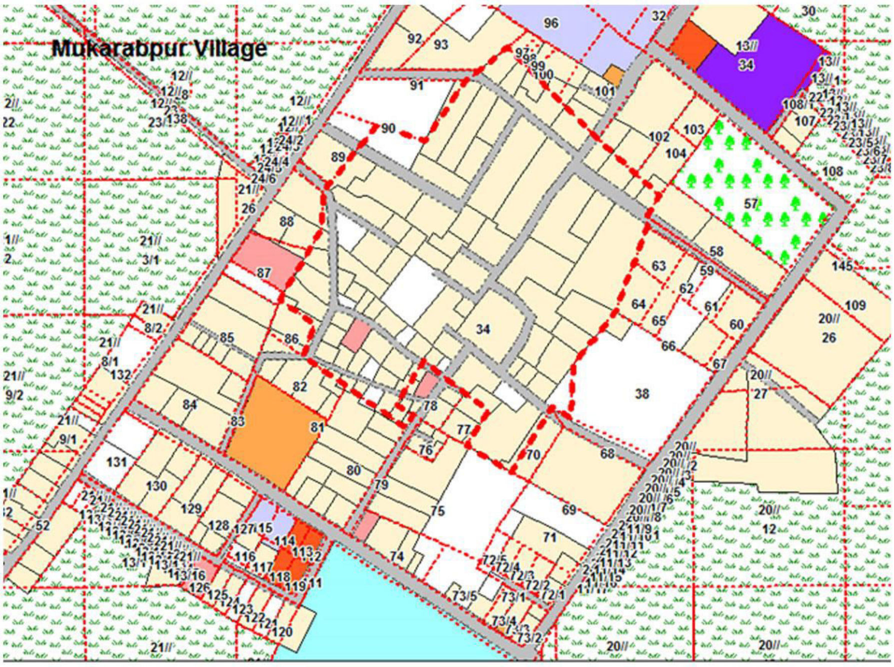


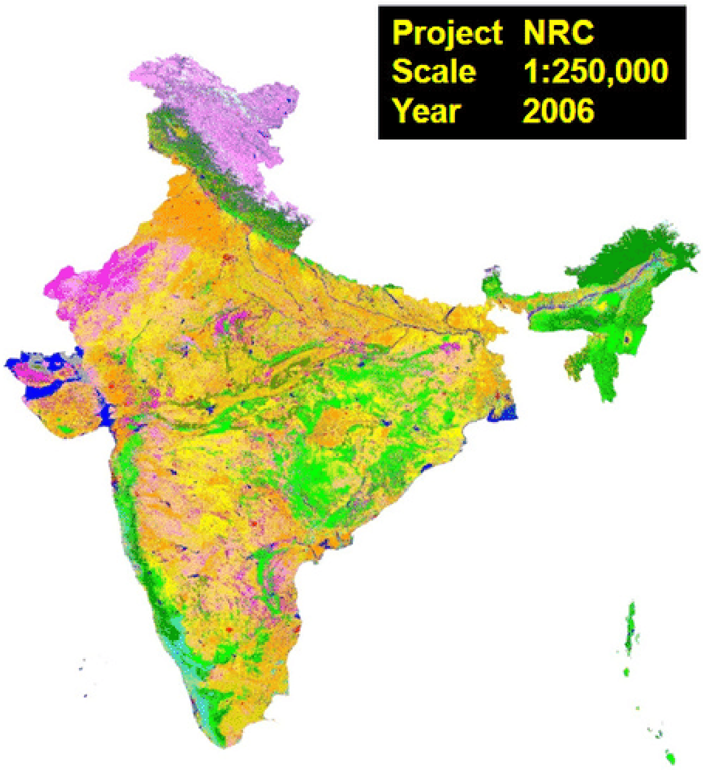
Image Interpretation Keys for Landuse/Land Cover Categories as Derived from Satellite Imagery

Landuse/ Cover	Pattern / Associations	IRS LISS 2B (FCC)		Landsat-TM (FCC)		Spot-HRV - 1 (FCC)	
		Tone/Colour	Texture	Tone/Colour	Texture	Tone/Colour	Texture
High density built-up	Compact, rectan gular, inner parts of city	Dark blue blackish	Medium	Dark bluish grey	Medium	Bluish grey	Medium to fine
Medium density built-up	Rectangular less compact	Bluish brown mixed	Medium	Bluish brown	Medium	Greyish-light blue mixed	Medium to fine

Landuse/ Cover	Pattern / Associations	IRS LISS 2B (FCC)		Landsat-TM (FCC)		Spot-HRV - 1 (FCC)	
		Tone/Colour	Texture	Tone/Colour	Texture	Tone/Colour	Texture
Low density built-up	Rectangular to irregular, open spaces, fringe areas	Light blue mixed brown	Coarse	Pinkish grey	Coarse	Light bluish with grey	Coarse
Rural settlement	Scattered small patches over agricultural land	Dark green brown mixed	Medium to fine	Greyish	Medium	Brown to pink	Medium to fine
Mixed built-up	Irregular, mixed residential with industries, institutions	Brown-blue mixed	Coarse	Blue-brown pinkish	Coarse	Bluish-brown patches mixed	Coarse
Built-up land under construction	Rectangular patches mainly with low built-up	Light blue bright	Medium	Bright	Medium	Bright pinkish	Coarse
Parks/ gardens	Squared/rectan-gular associated with built-up	Brownish-red	Medium	Reddish-brown	Coarse	Reddish-brown	Medium to fine
Play-ground/ stadia	do	Bright -light blue	Medium	Bright	Medium	Bright	Medium to fine
Major roads	Linear contiguous along with built-up	Dark brown blackish	Medium	Dark reddish brown	Medium	Dark brown	Medium to fine
Other important roads	do	Brownish	Coarse	Light pinkish brown	Coarse	Light brown	Medium
Railway track/ station	Linear, straight station at junctions	Brownish	Medium	Dark brown	Medium	Dark brown	Fine
Airport	Rectangular, runway linear & vacant area	Bluish brown white strip	Medium	Bluish pink white strip	Medium	Brownish white strip	Fine to medium
Vacant land	Irregular, enclosed patches	Light grey yellow mixed	Medium	Lighter	Medium	Light brown	Medium
Cultivated land	Contiguous area, rectangular fields spread throughout	Reddish with bright patches of fallow/open	Medium to fine	Reddish grey mixed	Medium to fine	Red to brown grey mixed	Fine to medium
Orchards/ plantation	Rectangular, alongwith agricul-tural land	Brownish red	Medium to fine	Reddish brown	Medium	Reddish brown	Fine to medium
Dense forest	Irregular, compact away from main built-up area	Dark reddish brown-violet mixed	Fine	Red	Medium to fine	Dark brown	Fine
Sparse vegetation	Irregular, open along dense forest	Lighter in tone than forest	Medium	Brownish light red	Medium	Light brown	Fine to medium

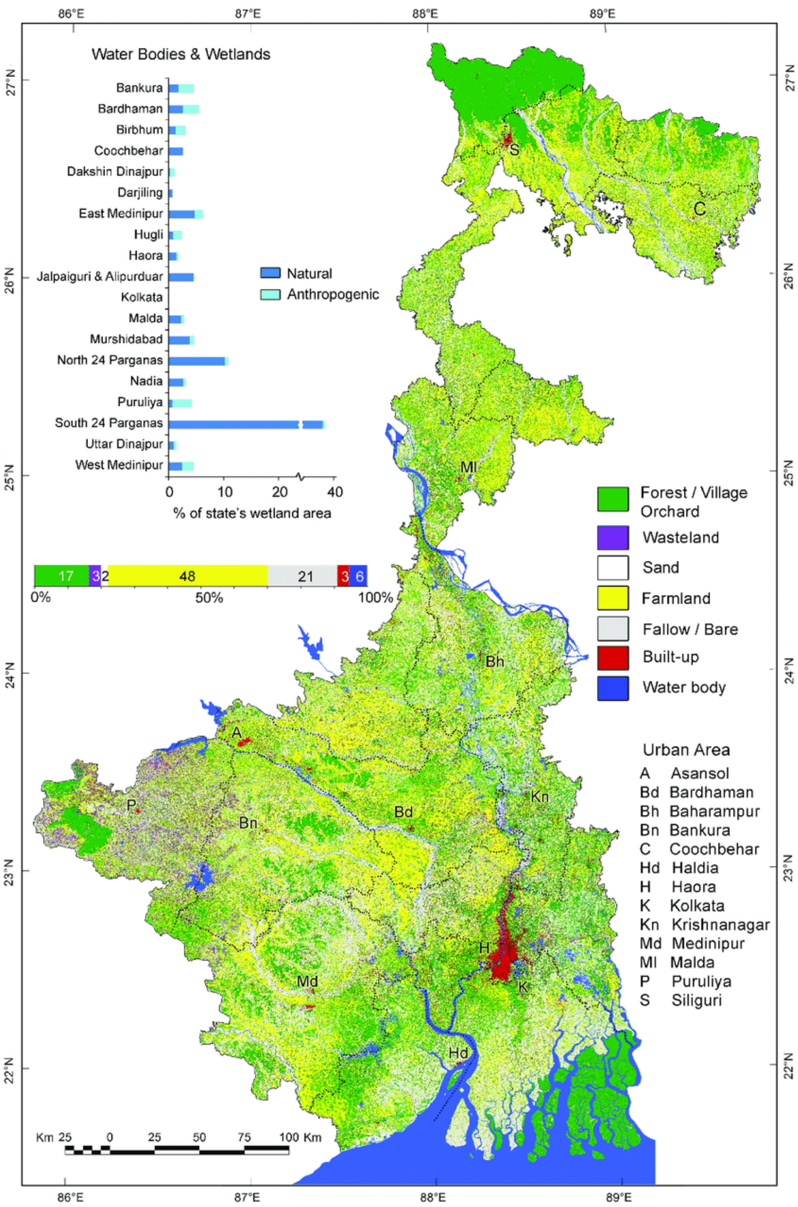
Landuse/ Cover	Pattern / Associations	IRS LISS 2B (FCC)		Landsat-TM (FCC)		Spot-HRV - 1 (FCC)	
		Tone/Colour	Texture	Tone/Colour	Texture	Tone/Colour	Texture
Bush/open scrub/grass	Irregular dispersed along forest/waste land	Light brownish blue mixed	Coarse	Light brownish red	Coarse	Whitish brown	Medium
River/stream	Linear, meandered	Dark blue, dark brown streams	Fine	Dark blue blackish	Fine	Bluish black	Fine
Canal	Linear, rather straight	Dark blue brownish	Fine	Light pink blue mixed	Fine	Dark blue	Fine
Tanks/ ponds	Mainly circular rectangular along settlement	Blue	Fine	Blue	Fine	Sky blue	Fine
Gullied/ eroded land	Irregular, scattered along streams	Brownish	Varying	Light with rills	Varying	Yellowish with black rills	Coarse to medium
Undulating land	Irregular, scattered patches	Yellowish brown	Varying	Pinkish	Varying	Yellowish brown	Coarse
River sands/ sandy area	Irregular patches along main river	Bright light blue	Medium to fine	Bright	Medium to fine	Bright	Fine
Salt affected land	Irregular patches along agricultural land, stream, canals	Bright bluish	Medium	Light	Medium	Bright	Medium
Water logged area/swamps	Meanders & patches along streams	Brownish black	Medium	Blackish blue pink mixed	Medium	Brownish black	Medium

Land use / Land Cover Map – 2005-06

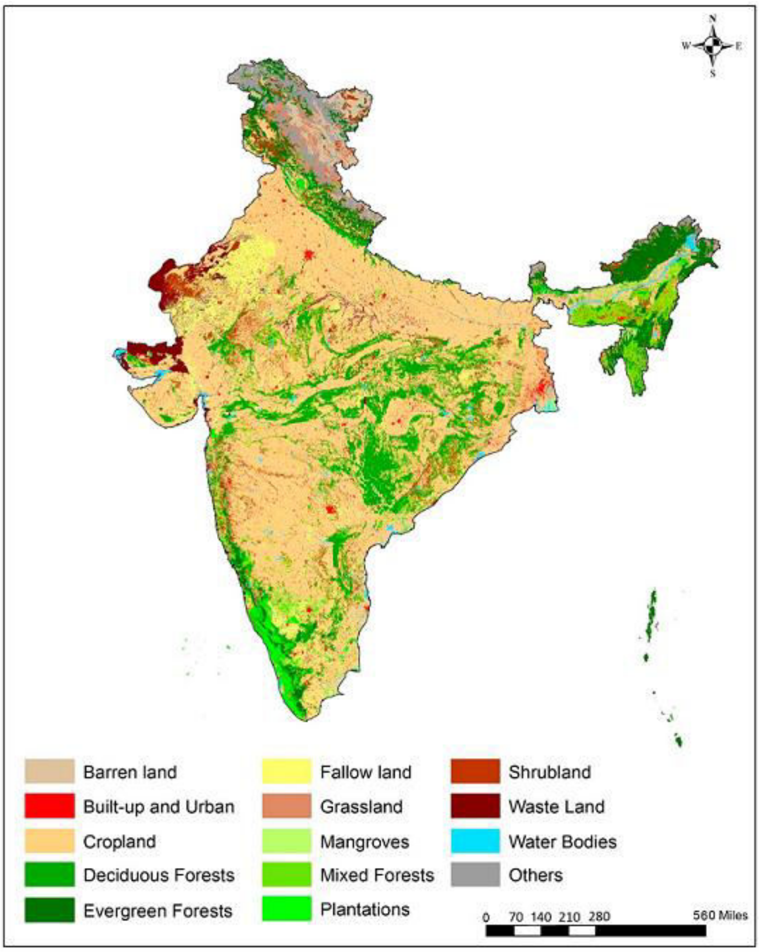


	Class_name	Area in ha	Area (%)
	Built up	1775280.54	0.56
	Kharif only	54334935.05	17.01
	Rabi only	31001026.43	9.71
	Zaid only	828947.10	0.26
	Double / tripple	47816115.41	14.97
	Current fallow	37545986.31	11.76
	Plantation/orchard	6488359.10	2.03
	Evergreen forest	17087248.83	5.35
	Deciduous forest	35621447.13	11.15
	Scrub/Deg. forest	15536443.56	4.86
	Littoral swamp	480964.72	0.15
	Grassland	7458727.98	2.34
	Other wasteland	30592800.56	9.58
	Gullied	1083969.43	0.34
	Scrubland	17013621.54	5.33
	Water bodies	9437901.08	2.95
	Snow covered	3966259.61	1.24
	Shifting Cultivation	154335.20	0.05
	Rann Area	1171486.00	0.37
	Total Area	319395855.57	100%

LAND USE AND LAND COVER OF WEST BENGAL



Land Use	Area (in thousands) (ha)	Percentage
Total geographical area	8875	NA
Reporting area for land utilization	8684	100.00
Forests	1174	13.52
Not available for cultivation	1814	20.89
Permanent pastures and other grazing lands	7	0.08
Land under misc. tree crops and groves	55	0.63
Culturable wasteland	32	0.37
Fallow lands other than current fallows	22	0.25
Current fallows	287	3.30
Net area sown	5294	60.96


N
W
E
S
Barren land
Built-up and Urban
Cropland
Deciduous Forests
Evergreen Forests
Fallow land
Grassland
Mangroves
Mixed Forests
Plantations
Shrubland
Waste Land
Water Bodies
Others
0 70 140 210 280 560 Miles