REMOTE SENSING APPLICATIONS FOR LAND USE AND DROUGHT STUDIES

Sanjay K. Jain
National Institute of Hydrology, Roorkee

1.0 Land use

Land use/land cover inventories are needed for the optimal utilization and management of land resources of the country. Land use controls many hydrological processes in the water cycle e.g. infiltration, evapotranspiration, surface runoff etc. Surface cover provides roughness to the surface. This reduces the discharge, thereby increasing the infiltration. There are many classification systems exist for land use classification. The maps for the land use are prepared following these systems. The maps are useful in hydrological modelling, watershed and irrigation management, water resources inventory and management etc. Thus, they are very good and cost effective source for land use mapping. Land use maps are also available in hardcopy form at many scales. These are prepared using remotely sensed data. For preparing the maps from satellite data, suitable data are selected and processed using various classification techniques. Ground truth information is also required for preparing the maps.

A remote sensor records response, which is based on many characteristics of the land surface, including natural and artificial cover. An interpreter uses tone, texture, pattern, shape, size, shadow, site, and association to derive information land use activities from what is basically information about land cover. The generation of remotely sensed data/images by various types of sensor flown abroad different platforms at varying heights above the terrain, and at different times of the day and the year, does not lead to a simple classification system. To date, the most successful attempt in developing a general purpose classification scheme compatible with remote sensing data has been attempted by Anderson. Many of the other classification schemes used with remotely sensed data are basically modifications of Anderson's classification scheme. The classification system is commonly referred to as USGS or Anderson's classification system. The classification system is a 4-level hierarchical classification system. First two levels are rigidly defined. Next two levels, users can define based on their requirements. At the level 1 and 2, many land use types are placed based on functional aspects e.g. forest clearings are classified as forests, forest area inside the urban class are included in urban class, wetlands where timber produces are exploited are including in wetlands (not as forests) etc. Some classes takes precedence over other e.g. dense trees in residential areas is classified as urban.

2.0 Levels of Classification Using Satellite Data

The National land use/land cover classification system was designed as a reconnaissance scheme applicable in Indian environment with varying needs and perspectives. The land use/cover categories can be expanded or reduced to any degree and be made more responsive to the information the region needs. At this stage, the classification scheme is not intended to be final, but is so designed that it contains all possible categories, which might be encountered in the interpretation process. The following s a brief discussion on each of the categories levels.

Level-I: The level classes are readily available from IRS imagery. The ground area of the minimum unit would vary depending upon the method of interpretation and scale of mapping. The level-I classification has been successfully applied using both the digital and the visual methods of data interpretation.

Level-II: The level II classification is readily achieved on IRS LISS-I FCC imagery of 1:250,000 scale. Satellite imagery of different cropping seasons of the year is required to obtain level-II information. It should be noted the reference level, knowledge of the area and skill of the remote sensing scientist/interpreter have a determining effect on the level of details and accuracy of mapping.

3.0 Comprehensive Classification System Developed by NRSA

The array of information available on land use/cober needs to be grouped under a suitable classification system. The classification system should not only be flexible in its scope, definition, and nomenclature of its categories, but also be capable of incorporating information obtained from different sensor data and other sources. Such a land use classification system, based on the understanding that the remote sensing techniques can be used effectively to complement traditional surveys for an accurate inventory of the land use and land cover in the country has been developed under the National Remote Sensing

Agency, Department of Space. The system is fairly compatible with those followed by most of the other government departments in the country (Table 1)

4.0 Hydrological Applications

In hydrology, land use information is used for surface runoff hydrological modelling. An example of method using land use information for design runoff estimation is the curve number technique of USDA SCS. Imperviousness of the surface, vegetation, surface covers etc. affects the infiltration process thus affecting the surface runoff generated from land. Other applications are watershed prioritization, land capability assessment, flood inundation mapping and damage assessment, flood plain zoning, surface water inventory, reservoir sedimentation etc.

Table 1. A classification system

Level I	Level II
1 Built-up land	1.1 Built-up land
2 Agricultural land	2.1 Crop land (i) Kharif (ii) Rabi (iii) Kharif+Rabi[a] 2.2 Fallows[b] 2.3 Plantations[c]
3 Forest[d]	3.1 Evergreen/semi-evergreen forest 3.2 Deciduous forest 3.3 Degraded or scrub land 3.4 Forest blank 3.5 Forest plantation[e] 3.6 Mangrove
4 Wastelands	4.1 Salt affected land 4.2 Waterlogged land 4.3 Marsh/swampy land 4.4 Gullied/ravinous land 4.5 Land with or without scrub 4.6 Sandy area (coastal and desertic) 4.7 Barren rocky/stony waste/sheet rock area
5. Water bodies	5.1 River/stream 5.2 Lake/reservoir/tank/canal[f]
6. Others	6.1 Shifting cultivation 6.2 Grass land/grazing land 6.3 Snow covered/Glacial area

[a] It includes land under agricultural crops during Kharif, Rabi (both irrigated + unirrigated) and the area under double crop, during both the seasons

[b] It is those land which remains vacant with out crop during both the Kharif and the Rabi seasons

[c] It includes all agricultural plantations like tea, coffee, rubber, coconut, arecanut, citrus and other orchards

[d] It includes those areas, which occur within the notified forest boundary as shown on the Survey of India topographic maps on 1:250,000 scale. Those occurring outside the notified areas are also included under forest class, but the area estimates of the two will be shown separately.

[e] It includes plantations within the notified forest boundary e.g., cashew, casurina etc. Those occurring outside the notified areas will be classified under category 2.3.

[f] It includes inland fresh water lakes, salt lakes, coastal lakes and lagoons.

5.0 Drought

Drought is one of the worst natural hazards having disastrous impact on the Indian society and economy. From time immemorial drought had severe and catastrophic effect on vital activities of mankind. The disastrous consequences may be minimised, if advanced prediction of such drought can be made. Drought may vary in duration, timing and degree of severity. This variety has made the prediction a complex phenomenon. Thus it is important to understand about drought, factors influencing drought, methods of drought monitoring to effectively manage the drought. In this lecture these will be discussed with a particular emphasis on modern method of drought management using remote sensing techniques.

Definition of Drought

A review of the literature indicates that there is no consensus in defining the drought. The basis of definitions includes rainfall, soil moisture & crop parameters and Climate indices & estimation of evaporation etc. The definition based on water deficiency situation is the most general as follow. "Drought corresponds to a water deficiency situation with reference to a given water demand in a given area." This definition emphasis the site specific and user specific nature of the drought.

6.0 Drought Prediction

Since drought presents critical water resources policy problems involving conservation, development and control issues, its prediction becomes quite vital.

Hydrological drought: prediction deals with surface, ground water and soil moisture depletion - their probabilities, intensities, duration and aerial extent.

Meteorological drought: prediction deals with rainfall deficiency - their probabilities, intensities, duration and aerial extent.

Agricultural drought: prediction is concerned with the occurrence, intensity and duration of drought conditions resulting in significant fall in agricultural production. Thus while pre-season agricultural drought prediction will be based on forecasts of meteorological and hydrological drought, with their associate confidence level, early warning in the early parts of agricultural season will take into account the vegetation conditions also.

Need for Drought Prediction

The objective of having drought prediction may be different for different people. A Farmer's objective is to get the information for

- Planning the sowing activities and its timing based on likely time of water availability.
- Planning the crop type based on likely quantum of water availability.

Planner and water resources managers have objective to get information for;

- Disseminating the same to warn people.
- Making suggestions for suitable measure.
- Planning operation and management of irrigation.
- Planning relief measures.

Periodicity of Drought in Meteorological Sub-Divisions

Based on experience of drought in different meteorological subdivisions of the country the broad periodicity is considered as under

Meteorological Sub-division	Recurrence Period of highly Deficient Rainfall
Assam	Very rare, Once in 15 Years
West Bengal, Madhya Pradesh, Konkan Coastal Andhra Pradesh, Madhya Pradesh, Maharastra, Kerala, Bihar, Orissa	Once in 5 Years
South Interior Mysore, East Uttar Pradesh, Vidharba	Once in 4 Years
Gujarat, East Rajasthan, West Uttar Pradesh, Tamil Nadu, Kashmir, Rayalaseema, Telangana	Once in 3 Years
West Rajasthan	Once in 2.5 Years

7.0 Drought Monitoring Methodologies

Conventional

The conventional methods of drought assessment may be grouped into (i) statistical analysis of rainfall data (ii) water balance methods.

Statistical analysis of rainfall data

Statistical analysis consists of rainfall variability in terms of deficits, frequency distribution, extreme value analysis, and spatial correlation with crop conditions. This approach is very subjective and whilst it is certainly practical when backed by experience, it is not always reliable for drought assessment because of its crude method of assessing rainfall variability with crop conditions.

Water balance methods:

Most of the methods use the basic water balance equation such as

$$P - R - U - E - W = 0$$

Where P is the precipitation

R is the runoff

U is deep percolation beyond root zone

E is the evapotranspiration

W is change in soil-water storage

Each of the terms in this equation has special problems associated with its measurement or estimation. Numerous methods or models are in use are i) Thornthwaite method, ii) Palmer method, iii) Crop moisture index method and iv) Aridity anomaly method etc.

Modern

Remote sensing suitability to monitor and measure the various factors influencing drought has made remote sensing a useful modern tool in monitoring and management of drought. The vegetation indices based methodologies are used for drought monitoring.

8.0 Factors Affecting Drought

For drought management it is important to under stand the various influencing factors and their interaction with drought.

Climatic factors: Meteorologists can usually explain drought in a given region in terms of the abnormal atmospheric circulation patterns, which favoured subsidence over the region. The quantum of average annual or seasonal precipitation does not by itself give an indication of drought incidence but its temporal and spatial variability along with its intensity is more important. Ultimately the effective rainfall that is available for plant growth determines agricultural drought and the rainfall component contributing for surface and subsurface storage determines hydrological drought.

Soil type & soil water: Soil type is undoubtedly one of the most important factors in the consideration of drought. Soil texture determines the water storage capacity. The water storage capacity of the soil and its saturation determine the potential energy the plants have to overcome to absorb water. All these together with soil fertility determine the extent of root development, which has so much influence on the water equilibrium of plant tissues.

Plant factors: The plant factors that affect the crop growth are root extension in depth and spread which is important to provide access to a potentially large supply of water. Sorghum is more drought resistant than corn because of differences in root developments. Root growth varies with many factors: species, age, density, radiation, transpiration, soil water potential and other soil characteristics, frequency of defoliation.

The other plant related factor is the type of agricultural practices. The actual evapotranspiration will be less than the potential if the ground is not completely covered, crops in dry areas may be sown at wider spacing than in the moist areas to permit the development of more extensive root systems.

9.0 Remote Sensing Application to Vegetation

In agricultural drought monitoring, the monitoring of vegetation is prime component. Thus it will be appropriate to understand the interaction of EM spectrum in various bands with the vegetation. The optical properties of crop or vegetation depend mainly on the optical properties of leaves and the underlying soil, but in some cases they are also affected by the optical properties of other parts of the plants, such as the bark on tree branches, flowers, fruit, etc. All of the reflectance spectra of plant/ vegetation leaves have the same shape. Differences just appear in the magnitude of the reflectance. Three spectral domains considered according to the different leaf optical properties are visible, near infrared and mid infrared.

The Visible Domain (400-700 Nm)

In this domain leaf, reflectance is low (less than 15%) and leaf transmittance is very low. The8 main part of incident radiation is absorbed by leaf pigments such as chlorophyll, xanthophyll, carotenoids and anthocyanins. The main pigments affecting leaf absorption are chlorophylls a and b (65% of pigments or higher) which exhibit two absorption bands centred in the blue and in the red. For this reason leaves have a maximum reflectance at 550 mm in the yellow-green region.

The Near-Infrared Domain (700-1300 Nm)

In this spectral domain leaf pigments and the cellulose of cell walls are transparent, so leaf absorptance is very low (less than 10%) and incoming radiation is either reflected or transmitted. Reflectance reaches about 50% on the "infrared plateau", this level depending on the anatomical structure of the leaves. Its level increases with the number of cell layers and the size of the cells, the orientation of their walls and the heterogeneity of their content.

The Middle-Infrared Domain (1300-2500 Nm)

In this domain leaf optical properties are mainly affected by their water content Beyond 1300 mm strong water absorption bands at 1450, 1950 and 2500 nm produce leaf reflectance minima. But between these bands, water absorption still exists and affects leaf optical properties. The levels of the two relative maxima therefore vary according to leaf water content (Thematic Mapper channels TM5 and TM7 are centred on these two maxima).

Thermal Infrared Domain (10500-12500nm)

The radiative temperature of a plant canopy is complex. The radiation flux that is detected by a radiometer integrates a series of elementary fluxes that arise from various layers of leaves and soil, all of which may be at different temperatures.

The Need for Thermal Remote Sensing of Vegetation

Though many factors affects the canopy temperature but it indicate water stress. As water stress increases the canopy resistance for vapour transport, incident energy will be partitioned increasingly toward sensible heat. Canopy temperature must then rise in order to dissipate the additional sensible heat. Sensible heat transport between the canopy and the air above it is proportional to the temperature difference, _T =Ts-Ta. The early stress-degree-day concept was based only on measurements of canopy and air temperature. Vapour deficit was later recognised as an important variable. The brightness surface temperature should be a very important indicator since it is related to the energy balance between soil and plants on the one hand and atmosphere and energy balance on the other in which evapotranspiration plays an important role. Surface temperature could be quite complementary to vegetation indices. Water-stress, for example, should be noticed first by an increase in the brightness surface temperature and, if it affects the plant canopy, there will be changes in the vegetation indices. Measured brightness temperatures are affected by water vapour in the atmosphere but the method of the "split Window", which uses two thermal bands of NOAA-AVHRR, offers accuracy in the order of 1 to 2K.

Microwave Radiometry of Vegetation (1cm- m)

Since microwave emission depends on the dielectric constant of emitting bodies, which changes according to their water content. The potential of microwave radiometry for monitoring agricultural crops and for estimating their production and water status has been investigated by G.Luzi et al. in the beginning of the 1980's. Microwave sensors can be passive (radiometers) and active (radar and scatterometers); the former measure the natural emission of observed bodies, whereas the latter measure the backscattered fraction of a power beam which they themselves emit. In contrast to optical frequencies, microwaves can penetrate through clouds and operate in the absence of sunlight.

10.0 Drought Estimation and Management by Remote Sensing

For drought estimation and management, application of remote sensing play very important role, particularly for prediction of drought to estimate soil moisture status, evaporation and biomass. The major areas of application of remote sensing in drought management may be

- Crop stress detection

- Monitoring of vegetation
- Monitoring reduction in surface storages
- Monitoring ground water deficit.

Crop Stress Detection

Crop Stress may be defined as the factor, which reduces the productivity of the canopy below its potential or optimum value. The response of vegetation productivity to stress can be either an effect on the fraction of light intercepted and absorbed by the canopy or an effect on the efficiency with which that light is used to photosynthesis biomass. A large number of studies on crop growth under stress indicate that many stress have a larger effect on the fraction of light intercepted than on efficiency.

Vegetation Indices

Spectral indices have been used for some time for monitoring of vegetation by remote sensing. The original indices were based on combination of visible and near infrared bands, although other techniques have recently been proposed using microwave backscatter. Much development work at the moment centres on how vegetation indices should be constructed and interpreted. Vegetation indices are being used for assessing conditions during early stages of stress before it effects leaf area and biomass. In order to assess the stress, vegetation indices should enable as.

- To measure canopy density or light absorption for photosynthesis
- To establish the presence of significant stress;
- To distinguish different classes of stress and
- To measure the degree of stress and its effect on productivity

The conventional two bands VI such as IR/R or the normalised difference vegetation index NDVI can only meet the first of these requirements, subject to the limitations explained earlier. The other requirements are derived from the experience of VI with previous years known ground conditions.

Construction and Interpretation of Vegetation Indices

The general principles behind the construction of vegetation indices (VIs) is that they should be sensitive to the presence of vegetation, more specifically to the amount and/or density of foliage and insensitive to other environmental variables, such as soil background, atmospheric attenuation or solar angle. These requirements are difficult to achieve given that the environment is uncontrolled.

The interpretation of vegetation indices is also problematical, as there are different ways in which the amount or density of foliage may be specified. Much effort was spent in the past trying to establish relationships between the visible/near- infrared VIs and leaf area index. More recently a wide measure of acceptance has been gained for the interpretation of VIs in terms of intercepted or absorbed photosynthetically active radiation. This interpretation allows a direct relationship with the productivity of vegetation.

Limitations of Vegetation Indices

The conventional vegetation indices are based on ratios or other combinations of bands in the visible and near-infrared regions of the solar spectrum. A variety of indices have been devised with different constructions, but they are all functionally equivalent. In healthy green vegetation there are well-established relationships of VIs with productivity but, when chlorosis occurs in stressed vegetation, these indices confound variations in vegetation cover with vegetation colour.

11.0 Remote Sensing of Reduced Surface Storage

Low streamflow and reduced storage in reservoirs, lakes and tanks are indicative of drought conditions, and in general reflect the precipitation deficiency over the basin. The coarse resolution of NOAA AVHRR data makes it difficult to identify surface water other than in large reservoirs and river systems. Reductions in streamflow exhibited by the decrease in river width are in general not identifiable on the meteorological NOAA satellite data. Even in the case of higher resolution earth resources satellite data marginal decrease in river water width will not be accurately distinguishable. However, severe precipitation deficiencies leading to drastic decreases in streamflow may be discernible on large river systems. Decreased water width and intermittent versus continuous flow may be indicative of drought conditions in such situations.

Significant reductions in storage in large reservoirs may be observable on NOAA imagery with 1.1. km resolution at nadir. Landsat/IRS/SPOT data with much higher spatial resolution help in delineating the surface water fluctuations in almost all water bodies from reservoirs to small tanks. The use of such data however will be opportunistic due to the high probability of cloud cover at the time of satellite overpasses during the agricultural season. Comparison between surface water storages on comparable dates in different years provides information on drought occurrence and relative severity. Under NADAMS estimation of reduced surface storages from medium and minor irrigation tanks using IRS LISS/ WiFS data will be taken up for the country.

12.0 Remote Sensing of Ground Water Deficit

Very few studies have attempted to assess the impact of drought on groundwater in a scientific way. Remote sensing of groundwater deficits during drought years will have to be indirect in terms of reduction in groundwater irrigated cropped areas. Some studies have indicated promise in the delineation of groundwater irrigated areas, where such area is contiguous and not mixed with other irrigation sources such as canal and tank. However in other areas, delineation of areas irrigated solely by groundwater may not be possible. But during drought situation since ground water storage depends on surface storage, monitoring surface water sources can make indirect estimation on ground water.

The other parameters which is frequently used for conventional drought assessment such as rainfall, soil moisture and evapotranspiration are also amenable to remote sensing, which are discussed in the separate lecture in this course.

13.0 Comprehensive Drought Monitoring System

NRSA has taken up an operational project for comprehensive Drought monitoring and developed National Agricultural Drought Assessment and Monitoring System (NADAMS) using NOAA AVHRR based NDVI. The details of NADAMS are as follow.

The satellite based drought assessment methodology with district as the reference unit and monitoring through the kharif season (June to December) is primarily based on normalised difference vegetation index (NDVI) derived from NOAA satellite Advanced Very High Resolution Radiometer (AVHRR) sensor data, acquired daily at the earth station operated by NRSA. NOAA AVHRR data acquired daily is ingested in the Micro Vax based I2S System. This data is corrected for path geometry (earth rotation, earth curvature, scan angle and North-South orientation) and is screened for data quality, cloud cover, India coverage etc., Relatively cloud free, near nadir (less than + 40) is selected. Cloud contaminated pixels are identified through visible band thresholding or visible & thermal band thresholding and masked over the NDVI image generated using the following equation

$$\mathrm{NDVI} = 222.5 - 350\frac{(ch2-ch1)}{(ch2+ch1)}$$

The passwise cloud masked NDVI image is registered to the image base generated from 1:2.5 million scale Survey of India Map. Such daily pass wise arrays for two weekly periods covering the whole country composited to a single image by selecting maximum NDVI values.

At the end of each two weekly period NDVI histogram and statistics of each district and tahsil are generated. Further, the NDVI images for the country overlaid with State boundary, for the States overlaid with district boundary and for the district overlaid with tahsil boundary are generated with standard colour lookup table by assigning different colour for every 0.05 NDVI levels. The colours of Purple-Orange- Green -Red and Violet indicate increasing vegetation index and hence increasing green biomass.

14.0 Conclusions

Regular monitoring of drought conditions has been greatly facilitated by recent developments in space technology, sensors and remote sensing analysis techniques. Higher spatial, temporal resolution with larger swath of Indian satellite sensors like WiFS/ LISS I, II, III and PAN has been a boon for achieving the objective of monitoring drought and natural resources such as agriculture and water resources as well implementation of strategies for effective management of these.