Lecture Notes

on

Practical Training on Remote Sensing and GIS with Special Emphasis to Soil & Water Conservation and Management

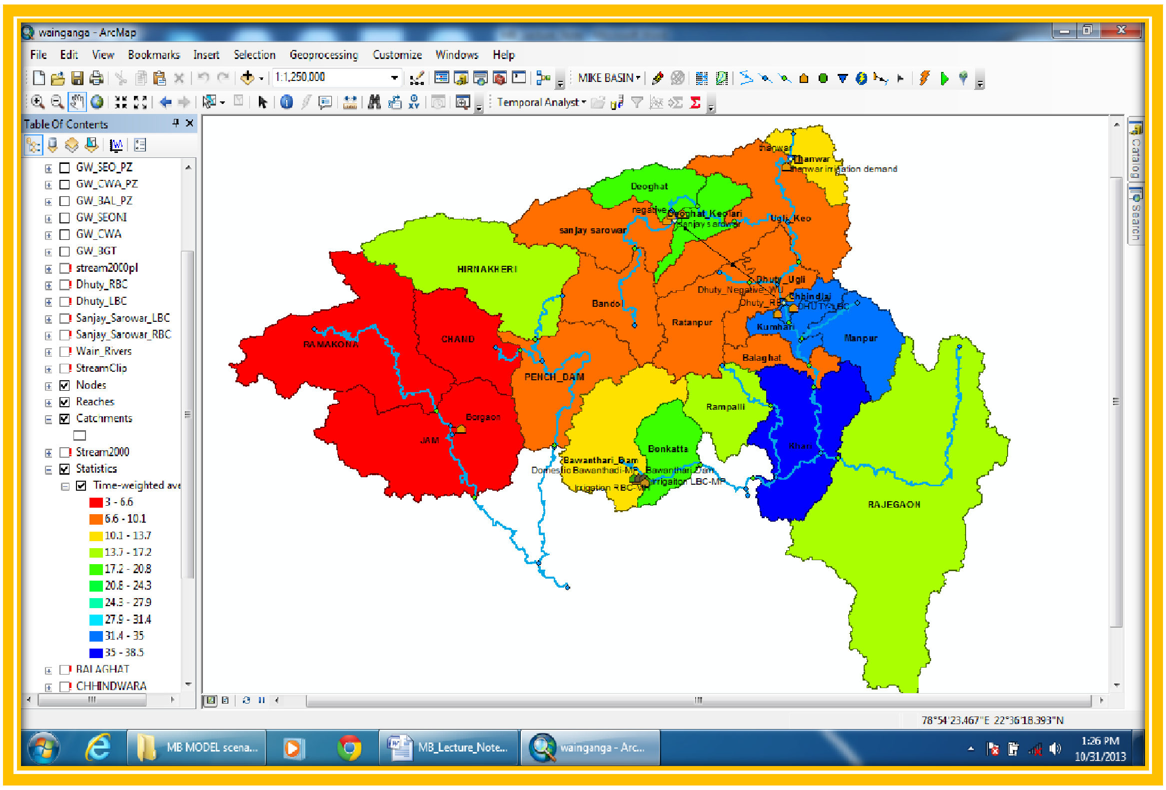
May 15 to 19, 2014

Institute of Agriculture Sciences, BHU Varanasi (U.P.)

Edited by

R.K. Jaiswal, T.R. Nayak, R.V. Galkate, GPSRC National Institute of Hydrology Bhopal (M.P.)

Dr. A.K. Nema, Institute of Agriculture Sciences, BHU, Varanasi (U.P.)



Organized by

Ganga Plains South Regional Centre,
National Institute of Hydrology,
WALMI Campus, Kolar Road
Bhopal (M.P.)

Deptt. of Farm Engineering,
Institute of Agriculture Sciences,
Banaras Hindu University,
Varanasi (U.P.)

PREFACE

Remote Sensing and Geographic Information System (GIS) technologies are well-established tools and regularly used in hydrology, soil & water recourses conservation and management, forestry, land use dynamics analyses etc. The abilities of remote sensing in these fields are to measure spatial, spectral and temporal information and provide data on the state of the earth's surface. GIS is the tool available to store, retrieve and analyze different types of data for management of natural resources and facilitates systematic handling of data to generate information in a devised format. Thus application of RS data and analysis using GIS are useful to evolve alternate scenarios for natural resources management and conservation. Various paid and freely available GIS software are available in the market having suitability for different objectives. The Integrated Water and Land Information System (ILWIS) is a windows-based, integrated GIS and remote sensing application consisting of display of raster and multiple vector maps in map windows, image processing facilities, manipulation of maps in a Map Calculator, display of tables in table windows, interactive retrieval of attribute information, Manipulation of tables in a Table Calculator, GIS analysis tools, Script language to perform 'batch' jobs and many more. Looking into the importance of synoptic viewing of large areas with the help of RS data and specialty of handling vector, raster and tabular data by GIS, it is necessary to impart detailed training with tutorials to water resources engineers, researchers and students.

The 5-Day training program titled "Practical Training on Remote Sensing and GIS with Special Emphasis to Soil & Water Conservation and Management" at Deptt. of Farm Engineering, Institute of Agriculture Sciences, Banaras Hindu University, Varanasi (U.P.) from May 15 to May 19, 2014 is being organized to give detailed knowledge to engineers, researchers and students with the help of lectures and tutorials. In the training, application of ILWIS for import and geo-referencing of toposheets, remote sensing and tabular data, raster and vector operations, development of digital elevation model (DEM), principles of remote sensing, satellites and sensors, digital image processing, application of RS and GIS for hydrological modeling and soil & water resource conservation and management. Also, introduction of ARC GIS and GPS will be discussed in detail and demonstrated through tutorials. This lecture-note will be helpful to the participants of the training Program and bingers to learn different facet of RS and GIS. This lecture-note has been edited by Sri R. K. Jaiswal, Scientist-C, Sri T. R. Nayak, Scientist-D, Sri R. V. Galkate, Scientist-D of Ganga Plains South Regional Centre, Bhopal (M.P.) of National Institute of Hydrology and Dr. A. K. Nema, Deptt. of Farm Engineering, Institute of Agriculture Sciences, Banaras Hindu University, Varanasi (U.P.).

Raj Deva Singh

R. D. Singh

Director, NIH, Roorkee

CONTENTS

EXPERT LECTURE- APPLICATION OF REMOTE SENSING & GIS IN HYDROLOGICAL MODELING

R.D. Singh
Director, National Institute of Hydrology
Jal Vigyan Bhavan, Roorkee (Uttarakhand)
E-mail: rdsingh3@gmail.com

General

Hydrological processes are no longer stationary due to point and non-point changes taking place in the catchment. The components of the hydrologic cycle are affected because of these changes. It leads to the modification in the temporal and spatial availability of the fresh water. For optimum planning, designing, operation and management of the water resources, an accurate assessment of the available water is required considering the changes taking place in the catchment. Mathematical modelling of the hydrological processes is a tool which may be used for providing such estimate considering the temporal and spatial variability of the processes due to man's influence on the hydrological cycle. Various types of hydrological models are available to solve the specific hydrological problems. However, the modelling philosophy for most of the models is normally the same. In the hydrological modelling the processed historical data are used to calibrate and validate the model. Subsequently, the model may be applied to provide the answers for which it has been developed.

In this lecture a classification of hydrological models has been presented and discussed. Furthermore, the classification of deterministic models is described in brief stating about their structure and scope of applications. Concept of deterministic models is presented in the form of a flow chart. Various sources of uncertainties associated with deterministic modelling are discussed with the help of illustrated examples. The steps involved in the hydrologic modelling are also presented. The methodology for model calibration and validation are discussed in brief. The importance of sensitivity analysis in modelling is also highlighted. Some of the potential applications of the different types of deterministic hydrological models are briefly described. In this lecture important features and capabilities of various hydrological software are also presented. Furthermore, a list of various hydrological and statistical software and their web sites is presented.

Remote Sensing of natural resources and Geographical Information System (GIS) can be utilized to evolve a system for monitoring, assessment and management of natural resources for generation of data base for hydrologic modeling. Although very few remotely sensed data can be directly applied in hydrological modeling, such information is of great value since many hydro logically relevant data can be derived from remote sensing information. One of the greatest advantages of using remote sensing data for hydrological modeling and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. However, the use of remote sensing technology involves large amount of spatial data management and requires an efficient system to handle such data. The GIS technology provides suitable alternatives for efficient management of large and complex databases.

Introduction

Water is the most essential natural resource for life and is likely to become a critical scarce resource in the coming decades due to continuous increase in population. Variations in climatic characteristics both in space and time are responsible for uneven distribution of precipitation. In India precipitation is confined to only about three to four months in the year. This uneven distribution of the precipitation causes highly uneven distribution of available water both in space and time, which leads to floods and drought affecting vast areas of the country. Man's activities such as land use changes, deforestation or afforestation, agricultural practices, urbanization, constructions of water resources structures for irrigation, hydro-power, water supply and navigation, etc. influence the hydrologic cycle to a certain extent which modify the pattern of natural availability of fresh water supplies, with respect to space and time. An accurate assessment of the available water, both on surface and ground is needed for optimum design, planning and operation of the water resources projects as well as for watershed management in order to meet the basic needs of the people in coming decades. Since the hydrological processes are continuous and quite complex, therefore, an accurate assessment of quantities of water simultaneously passing through all these processes is quite a difficult task. The problem becomes even more complex when the natural hydrological cycle is getting distributed by the man's activities. Mathematical modeling of hydrological processes provides a most powerful technique for an accurate assessment of the available water in space and time considering the physical processes to a certain extent close to the reality and incorporating the various factors affecting the natural hydrologic cycle due to man's influence. Such modeling exercises are very much helpful for both the research hydrologists and the water resources engineers involved in developing the integrated approaches for planning, development and management of water resources projects. A model is a simplified representation of a complex system. It aids in making decisions, particularly where data or information are scarce or there are large-number of options to choose from. Hydrological models represent the physical/ chemical/biological characteristics of the catchment and simulate the natural hydrological processes. Hydrological models are essentially mathematical models where the physical processes of hydrologic cycle are described by a set of mathematical equations (often partial differential equations), logical statements, boundary conditions and initial conditions, expressing relationships between inputs, variables and parameters. Hydrological models may be broadly classified in two groups:

(i) Deterministic Hydrological Models

(ii) Stochastic Hydrological Models

A deterministic hydrological model is one in which the processes are modeled based on definite physical laws and no uncertainties in prediction are admitted. It has no component with stochastic behavior, i.e. the variables are free from random variation and have no distribution in probability. Deterministic models can be further classified according to whether the model gives a spatially lumped or distributed description of the catchment area, and whether the description of the hydrological process is empirical, conceptual or fully physically based.

Now-a-days engineers, scientists and planners involved in water resources development have become more concerned with the effect of land use changes related to agricultural and forestry practices, hazards of pollution and toxic waste disposal and general problem arising from conjunctive uses of water. Conventional rainfall runoff models (empirical as well as lumped conceptual models) are often not able to provide satisfactory solutions to such problems. Attention is, therefore, being focused on the physically based distributed catchment models since these have the potential to overcome many of the deficiencies associated with simpler approaches. On the other hand, such models are complex and considerable resources in human expertise and computing capability are needed for their development and applications.

Hydrological Processes

Various hydrological models used for stream flow simulation generally consider the following hydrological processes:

(a) Land Surface Processes
- (i) Interception
- (ii) Infiltration
- (iii) Overland flow
- (iv) Evapotranspiration
- (v) Snow accumulation and Melt

(b) Sub-surface Processes
- (i) Interflow
- (ii) Soil moisture storage and Movement
- (iii) Ground water storage and flow

(c) Channel Processes
- (i) Channel flow
- (ii) Flood plain storage
- (iii) Lakes, Reservoirs and Diversions

Classification of Hydrological Models

A model represents the physical/chemical/biological characteristics of the catchment and simulates the natural hydrological processes. It is not an end in itself but is a tool in a larger process which is usually a decision problem. It aids in making decisions, particularly where data or information are scarce or there are large numbers of options to choose from. It is not a replacement for field observations. Its value lies in its ability, when correctly chosen and adjusted, to extract the maximum amount of information from the available data.

Hydrological models can be classified in different ways. The classification shown in **Fig. 1** is derived mainly from Fleming (1975) and Woolhiser (1973). Not all models fit easily into this classification but it is general with respect to fundamental principles. A related but less general classification is presented by Clarke (1973b) who suggests that many of the models presented in the literature can be divided into the deterministic and the stochastic. These two groups can each be further divided into the conceptual and the empirical and additional subdivisions occur between spatially lumped/spatially distributed and linear/nonlinear models.

Two main groups of mathematical methods emerge from **Fig. 1**: those which involve optimization and those which do not. Here optimization is referred to strictly in the sense of decision making rather than in the optimization of model parameters. The non-optimizing methods are generally associated with the assessment of hydrological data and are used to quantify the physical processes. Methods involving optimization are concerned with the problem of selecting the "best" solution among a number of alternatives in a planning process. Non-optimizing methods are divided into two fundamentally different approaches, the deterministic and the statistical. However, although the deterministic and the statistical methods are fundamentally different, a strong interplay between the two approaches exists, mainly because the processes involved in the hydrological cycle are partly casual and partly random. Hence, some deterministic models contain random functions to relate processes, while some statistical models contain casual or deterministic functions as part of their structure. The interplay between the two approaches also includes the subsequent analysis of the information gained from the different models. For example, a deterministic model using a conceptual representation of the hydrological cycle may be used in producing a record of stream flow at a gauging station. This record may then be analyzed by statistical methods to produce a flood frequency curve for that site. Conversely, a statistical method involving the generation of rainfall data by a stochastic model could provide input to a conceptual model producing information which is then again analyzed statistically.

Classification of Deterministic Models

The model is a simplified representation of the physical system. Deterministic models can be classified according to whether the model gives a spatially lumped or distributed description of the catchment area, and whether the description of the hydrological processes is empirical, conceptual or fully physically based. In practice, most conceptual models are also lumped and most fully physically based models are also distributed, so three main groups of deterministic models can be identified as shown in Fig.1.

Black box or empirical models

These contain no physically based transfer function to relate input to output: in other words no consideration of the physical processes is involved. Such models usually depend upon establishing a relationship between input and output, calibrated from existing hydrometeorological records. Within the range of calibration data such models may be highly successful, often because the formal mathematical structure carries with it an implicit understanding of the underlying physical system. However, in extrapolating beyond the range of calibration, the physical link is lost and the prediction then relies on mathematical technique alone. Given the inherent linearity of many black-box models, which contrasts with the nonlinearity of hydrological systems, such extrapolation is of dubious worth and is not recommended (e.g. Anderson and Burt, 1985). Thus, for example, black box models cannot be used to predict the effects of a future change in land-use.

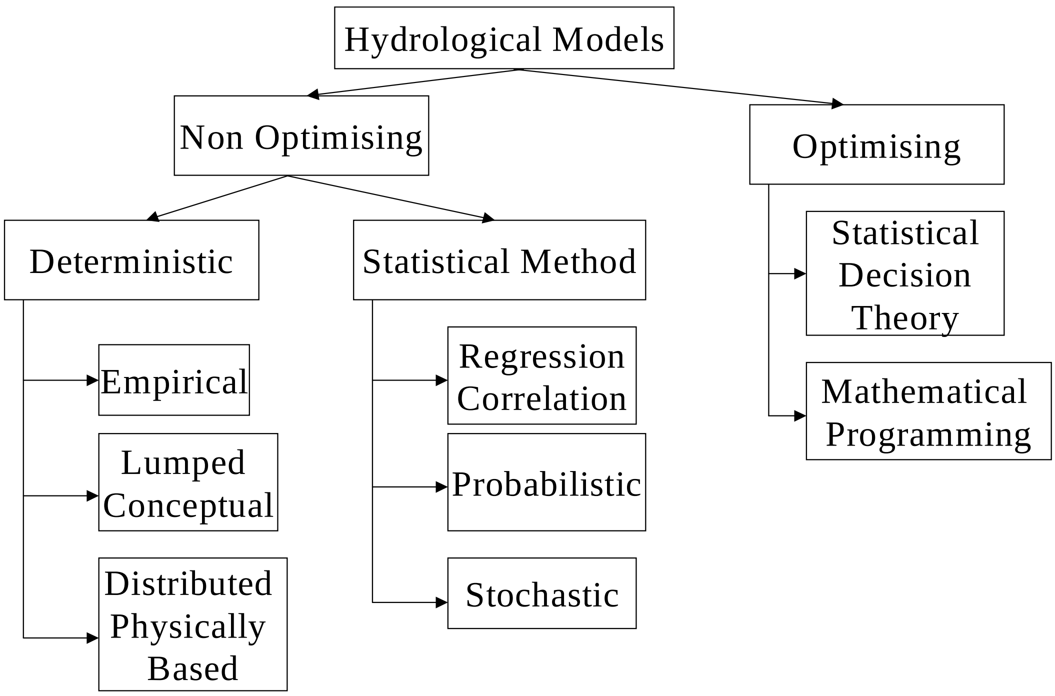


Fig. 1: Classification of Hydrological Models

Probably the best known black box models in hydrology are the unit hydrograph model and the models applying the unit hydrograph principles, Sherman (1932), Lyshede (1955), Nash (1959). Black box models were developed and extensively applied before advances in computer technology made it possible to use more physically correct (and thus more complex) models. Today, black box principles are more often used to form components of a larger model, e.g. the unit hydrograph is often used for stream flow routing in conceptual rainfall-runoff models.

Lumped conceptual models

These occupy an intermediate position between the fully physically based approach and empirical black-box analysis. Such models are formulated on the basis of a relatively small number of components, each of which is a simplified representation of one process element in the system being modeled. The SNSF model has been developed as a part of the Norwegian "Acid Precipitation: Effects on Forests and Fish" - project (Lundquist, 1978). In contrast to NAM and HBV, the SNSF model breaks the catchment down into four parallel sub catchments consisting of lakes, forests, bogs, and impervious areas respectively. The purpose of this breakdown is primarily to enable the runoff from ungauged catchments to be estimated using standard parameters together with data on the actual areal distribution between the four sub catchments and meteorological time series. A detailed treatment of lumped models, including a description of the British Institute of Hydrology Lumped Model, is given by Blackie and Eeles (1985).

Fully distributed, physically based models

These are based on our understanding of the physics of the hydrological processes which control catchment response and use physically based equations to describe these processes. From their physical basis such models can simulate the complete runoff regime, providing multiple outputs (e.g. river discharge, phreatic surface level and evaporation loss) while black box models can offer only one output. Also, almost by definition, physically based models are spatially distributed since the equations from which they are formed generally involve one or more space coordinates. They can therefore simulate the spatial variation in hydrological conditions within a catchment as well as simple outflows and bulk storage volumes. On the other hand, such models make huge demands in terms of computational time and data requirements and are costly to develop and operate. The advantages and disadvantages of physically based models are considered in more detail below.

Unlike lumped conceptual models, physically based distributed models do not consider the transfer of water in a catchment to take place between a few defined storages.

- For example soil conductivity obtained from a single core may not be representative of the effective conductivity at a larger grid scale, where allowance is required for macropore effects and spatial variability within the grid square.
- Conceptual understanding of hydrological processes is not always sufficient or cannot always be expressed mathematically. For example, it may be necessary to assume soil conductivity

to be constant spatially and temporally because there is insufficient information to allow for spatial variations or temporal changes associated with shrinkage or crusting. Macropore effects have similarly to be approximated for lack of a suitable theory.

The various aspects of event based stream flow simulation modes including event based stream flow simulation model and some of the commonly used event based models have been discussed by Singh (1989) are reproduced in Table 2.

Hydrological Modelling Procedures

The following procedures are usually followed for Hydrological Modelling:

- Develop a suitable model structure to simulate various component processes keeping in mind the quantity and quality of the data available and nature of the problems for which the modelling is required.
- Calibrate the developed model using the historical records.
- Validate the model using the historical records which have not been considered for calibration.
- Perform sensitivity analysis study to identify the most sensitive parameters of the model which require proper investigation before arriving at the final parameter values.
- Use the calibrated and validated model for solving the specific hydrological problem for which the development of the model is intended for.

GIS and Hydrological Modeling

GIS a technology to store, manipulate and display spatial and non-spatial data, has gained much attention in many areas that requires spatial description and manipulation of information. The GIS technology provides suitable alternatives for efficient management of large and complex data base. Spatial statistics and grid design capabilities of GIS can improve the modeling effort and aid in reliability assessment. The GIS data base for hydrologic modeling will include details on landuse, water use, soils, hydrological characteristics, drainage network and digital elevation model. These types of data related to catchment characteristics can be accurately and more easily handled in GIS. Further these types of data being in digital form can be easily updated and modified. In the early days GIS were mainly used as hydrological mapping tools. Nowadays they play a more important role in hydrological model studies. Their applications span a wide range from sophisticated analyses and modeling of spatial data to simple inventories and management tool. The application of GIS has enhanced the capacity of models in data management, parameter estimation and presentation of model results, but GIS cannot replace hydrological models in solving hydrological problems.

Table 2: Some Event Based Stream flow Simulation Models

Names	Author(s)	year	Base flow separation	Dr volume	Infiltration and loss	Dr hydrograph	Channel routing	Reservoir routing	Parameter optimization
HEC-1	Hydrologic Engineering Center	1981, 1982	Yes	SCS curve number and two other methods	Variable loss rate method	Clark's and Snyder's unit hydrograph methods	Muskingum method and five other methods	Storage indication method	Automation calibration capability
TR-20	Soil conservation service	1973	Constant rate method	SCS curve number method	SCS curve number method	Unit hydrograph method	Convex method	Storage indication method	No
USGS	Dawdy et al.	1972	Constant rate method	Soil moisture accounting	Philip equation	Clark's unit hydrograph	Translation method	No	Rosen Brock's method
HYMO	Williams and Hann	1973	No	SCS curve number method	SCS curve number method	Nash method	Variable storage coefficient method	Storage indication method	No
SWMM	Metcalf and eddy,inc et al.	1971	No		Horton's equation	Hydraulic method		No	No
WAHS	Singh	1983	Recursion equation	SCS curve number method	Philip's equation	Geomorphological Unit hydrograph method	Linear reservoir	No	RosenBrock-palmer method
RORB	Laurenson and mein	1983	Two options	No	Constant and variable loss methods	Non linear storage routing	Non linear storage routing	Yes	No
WBNM	Boyd et al.	1979a, 1979b	No	Yes	Φ-index	Linear as well as storage element for routing	Storage routing	No	Yes
FHSM	Foroud and Broughton Zhao et al.	1981	Yes	Yes	Modified Horton's equation	Time area curve+linear reservoir	No	No	Non linear least square curve fitting
XJM	Zhao et al.	1980	Yes	Yes	Storage capacity curve	Unit hydrograph method	Muskingum method	No	No
GAWSER	Ghate and Whiteley	1977 1982	Yes	Yes	Holtan's equation	Time area curve+convolution	Hymo method	No	No
MIT	Maddaus and Eagleson	1969	No	No	Any suitable method	Linear channel and reservoir	linear	No	optimization
HM	Huggins and Monke	1968	No	Yes	Holtans' equation	Kinematic wave method	No	No	No
KANSAS	Smith and Lumb	1966	Yes	Yes	Soil moisture accounting	Lag and route method	No	No	No
IHM	Morris	1980	Yes	Yes	Richards equation	St. Venant Equation	St. Venant Equation	No	No

GIS link land cover data to topographic data and to other information concerning processes and properties related to geographic location. When applied to hydrologic systems, non-topographic information can include description of soils, land use, ground cover, ground water conditions, as well as man-made systems and their characteristics on or below the land surface. Description of topography is called terrain modeling, and because of the tendency of surface water to flow downhill, the hydrologic importance of terrain modeling is clear. While maps have been the most common historical form of representing topography, the advent of digital maps in GIS provides an alternate method of storing and retrieving this information.

Due to its data handling and manipulation capabilities, GIS is increasingly being used as an interface and data manager for hydrologic models. There are four levels of linkage of hydrological model with GIS. These levels vary from essentially considering GIS and the model as separate systems to fully integrating the model and GIS. Currently the structure of soil erosion models and GIS systems are quite different preventing their complete integration. The lowest level of integration consists of using GIS as an aid in developing the input data file for the model. A user then takes the preliminary files and modifies them to produce a complete input file in the format required by the model.

A similar procedure in the opposite direction can be applied to the outputs of the model in order to present and store them in GIS. The next level of integration is to use an interfacing program specifically written to communicate between the GIS and the model. The interface program may serve as a control program issuing commands to the GIS and the model. Output from the GIS is converted into the proper input format for the model and then read by the model. Output from the model may likewise be converted to a GIS format and then displayed by the GIS. All these operations are carried out under the control of the interface program. A third level of integration occurs when the interface program is incorporated into the model. This requires modification to the input/output routines of existing models or developing special input/output routines for new models. Some programming may also have to be done within the GIS to alter its input/output structure to make it more compatible with that of the model. If one is making extensive changes to a model or developing a new model, this level of integration would be appropriate. The highest level of integration occurs when the model and GIS is essentially a single, integrated unit. One way of achieving this is by programming the model using the programming language appropriate to the GIS being employed. This makes GIS a master module, which controls the model runs.

Model Calibration

Hydrological models are the mathematical models having some unknown coefficients known as parameters. Model calibration means the estimation of those parameters from historical input-output records. Model calibration in general involves manipulation of a specific model to reproduce the response of the catchment under study within some range of accuracy. In a calibration procedure estimation is made of the parameters, which cannot be assessed directly from field data. All empirical (black box) models and all lumped, conceptual models contain parameters whose values have to be estimated through calibration. The fully distributed physically-based models contain only parameters which can be assessed from field data, so that in theory a calibration should not be necessary if sufficient data are available. However, for all practical purposes the distributed, physically-based models also require some kind of calibration, although the allowed parameter variations are restricted to relatively narrow intervals compared with those for the empirical parameters in empirical or lumped, conceptual models. For model calibration the following methods are commonly used:

a. `Trial and Error', manual parameter assessment
b. Automatic, numerical parameter optimization
c. A combination of (a) and (b)

The trial and error method implies a manual parameter assessment through a number of simulation runs. This method is by far the most widely used and is the most recommended methods, especially for the more complicated models. A good graphical representation of the simulation results is a prerequisite for the trial and error method. An experienced hydrologist can usually achieve a calibration using visual hydrograph inspection within 5-15 simulation runs.

Automatic parameter optimization involves a numerical algorithm which optimizes or minimizes a given numerical criterion. The objective of automatic parameter optimization is to search through the many combinations and permutation of parameter levels to achieve the set which is the optimum or `best' in terms of satisfying the criterion of accuracy. Several optimization techniques have been used for calibration of hydrological models. The details of these optimization techniques are given in the standard textbooks of the operational research and optimization techniques.

Model Validation

If the model contains a large number of parameters it is nearly always possible to produce a combination of parameter values which permits a good agreement between measured and simulated output data for a sort calibration period. However, this does not guarantee an adequate model structure or optimal parameter values. The calibration may have been achieved purely by numerical curve fitting without considering whether the parameter values so obtained are physically reasonable. Further, it might be possible to achieve multiple calibrations or apparently equally satisfactory calibrations based on different combinations of parameter values. In order to find out whether a calibration is satisfactory, or which of several calibrations is the most correct, the calibration should therefore be tested (validated) against data different from those used for the calibration (e.g. Stephenson and Freeze, 1974). Klemes (1986) states that a simulation model should be tested to show how well it can perform the kind of task for which it is intended.

Performance characteristics derived from the calibration data set are insufficient as evidence of satisfactory model operation. Thus the validation data must not be the same as those used for calibration but must represent a situation similar to that to which the model is to be applied operationally.

Klemes (1986) further noted that a central question is: what are the grounds for credibility of a given hydrological simulation model? Usually they concern the goodness of fit of the model output to the historical record in a calibration period, combined with an assumption that the conditions under which the model will be used will be similar to those of the calibration period. Clearly, though, this is insufficient for a physically-based distributed model which is designed specially to simulate conditions different from those likely to be available for calibration, e.g. when simulating the impact of a future land-use change. In that case a demonstration of model transposability is required. Initially, transposability referred to geographical transposability within one hydrologically homogeneous region. However, its scope has since been broaden to include transposability from one land use type to another, from one region to another and, recently, from one climate to another.

Sensitivity Analyses

Two types of sensitivity analysis may be carried out for the hydrological modelling viz. (i) input sensitivity analysis and (ii) model parameter sensitivity analysis. In the input sensitivity analysis various possible scenarios of the model input are considered in the model and the results of the simulation obtained for each scenario are compared with those obtained from the calibrated model and observed input. The model parameter sensitivity may be carried out changing one parameter value at a time within an acceptable range in the hydrological model and comparing the simulation results with those obtained from the calibrated model. Analysis of the sensitivity of the simulation results to changes in parameter values and analysis of parameter stability can serve as model tests. Such analyses can be carried out in different ways. The influence of the length of the calibration period on parameter uncertainty as well as parameter stability with time can also be evaluated from such analysis.

Concluding Remarks

Hydrological models may be developed keeping in mind the hydrological problems, data availability, point and non-point changes within the catchment etc. The structure of the hydrological model may vary for different temporal and spatial scales. The model calibration and validation are the important aspects of the hydrological modeling. Proper calibration and validation of the hydrological model is needed before using it for simulation. The model calibration involves the estimation of the model parameters for best reproduction of the observed output considering observed input. For calibration of the model, three methods are described in the paper. It is recommended to use the combination of trial & error and automatic optimization technique for the model calibration. The calibrated model is required to be validated with the independent data sets (not used for calibration) before using it for the simulation. In order to ascertain the uncertainty in the parameters as well as parameter stability the sensitivity analysis must be carried out.

The use of remote sensing technique for determination of land use/cover not only saves time but is less expensive as compared to conventional methods like ground surveys. Further, the satellite based remote sensing has advantages like large area coverage, synoptic view and capability to provide information over all accessible and inaccessible regions. On the other hand, modern techniques like the GIS serve as an efficient approach for storage, processing and retrieval of large amount of database. Spatial modeling and tabular databases of GIS constitute a powerful tool and enable a kind of analysis which was not possible until recently. Also, the database created and stored in GIS system may be updated as and when required.

Bibliography

1. Abbott, M.B., J.C. Bathurst, J.A. Cunge, P.E. O'Connell and J. Rasmussen, 1986. *An Introduction to the European Hydrological System - System Hydrologique European "SHE". History and Philosophy of Physically based distributed modelling system*. Jour. of Hydrology, 87: pp. 45-59.
2. Aitken, A.P., 1973. *Assessing Systematic Errors in Rainfall Runoff Model*. Journal of Hydrology, 20, 121-136.
3. Askew Aj, 1989. Real time intercomparison of hydrological models, in: New Directions for Surface Water Modelling, (kavas, M.L., Ed), IAHS Pub No. 181, 125-132.
4. Bathurst, J.C., 1986. *Physically-based distributed modelling of an upland catchment using the Systeme Hydrologique European*. J. Hydrol., 87(1/2), 79-102.
5. Bergston, S., 1976. *Development and application of a conceptual runoff model for Scandinavian Catchments.* Department of Water Resources Engineering, University of Lund. Bulletin Series A No. 52.
6. Betson, R.P., R.L. Tucker and F.M. Haller, 1969. *Using Analytical Method to Develop a Surface Runoff Model.* Water Resources Research, Vol. 5, No. 1, pp. 103-111.
7. Carrigan, P.H., Jr., 1973. *Calibration of U.S. Geological Survey Rainfall-Runoff Model for Peak Flow Synthesis - Natural Basins*. Report No. U.S.G.S.-W.R.D.-73-026, U.S. Geological Survey-WRD, Reston, Va, U.S.A.
8. Crawford, N.H. and Linsley, 1966. *Digital Simulation in Hydrology.* The Stanford Watershed Simulation Model `IV'. Technical Report No. 39, Department of Civil Engineering, Stanford Univ., Stanford, California.
9. DHI, 1988. *Lecture notes and Exercises - Training course on Hydrological Computerized Modelling System (SHE).*
10. Fleming, G., 1975. *Computer Simulation Techniques in Hydrology*. Elsevier.
11. Harbaugh, A.W., 2005, MODFLOW-2005, the U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p.
12. James, L.D., 1972. *Hydrologic Modelling, Parameter Estimation and Watershed Characteristics.* Journal of Hydrology, Vol. 17, pp. 283-307.
13. Klemes, V., 1986. *Operational Testing of Hydrological Simulation Models.* Hydrol. Sci. J., 31(1), 13-24.
14. NIH, 1982-83. *Modelling of Daily Runoff for Kasurnala Basin Using Betson and USGS Models.* Report No. CS-2, National Institute of Hydrology, Roorkee.
15. Rosenbrock, K.H., 1960. *An Automatic Method for finding the greatest or least value of a function.* The Computer Journal, Vol. 7(3).
16. Woolhiser, D.A., 1973. *Hydrologic and Watershed Modelling - State of the Art.* Transactions of the ASAE, 16, pp. 533-559.

LECTURE I- BASICS OF GEOGRAPHIC INFORMATION SYSTEM (GIS) AND INTRODUCTION OF ILWIS GIS

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

Geographic Information System (GIS) plays an important role in generating automated spatial datasets and in establishing spatial relationships. During the last few decades GIS software has gained importance for generating overlays and making site-specific decisions. Multi-spectral remotely sensed satellite data plays a vital role in the generation of the overlays. Manual integration of the entire surface and sub-surface information requires huge expenditure of manpower and time. Working on the GIS platform is faster, more accurate and therefore cost-effective. The integration of the satellite imagery and GIS has eased the data integration and analysis of very large data sets. A GIS, captures, stores, analyzes, manages, and presents data that is linked to location. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. How the data can be displayed in GIS software is given in Fig. 1.

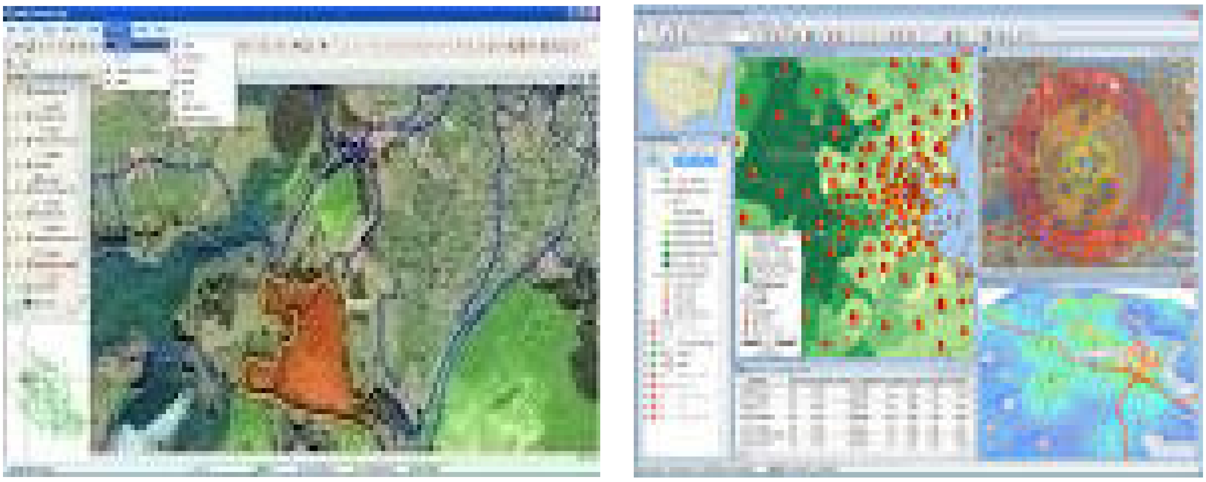


Fig. 1: Geographic data display in GIS software

A commonly accepted definition of a GIS is "a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth". In short, GIS is a computer-based system that can deal with virtually any type of information about features that can be referenced by geographical location. These systems are capable of handling both *location* and attribute data about such features. Most GISs use one of two primary approaches to represent the location component of geographic information: a raster (grid cell) or vector (polygon, point) format. In the raster format, the value stored for each cell indicates the type of object or condition that is found at that location over the entire cell. A coarse grid requires less data storage space but will provide a less accurate geographic description of the original data. In the vector format, feature boundaries are converted to straight-sided polygons that approximate the original regions. These polygons are encoded by determining the coordinates of their vertices, called *nodes*, which can be connected to form arcs.

GIS is important today because it is able to bring together information from multiple sources so that various types of work can be done. In order to do this though, the data must be tied to a specific location on the Earth's surface. Latitude and longitude are usually used for this and the locations to be viewed are attached to their points on the geographic grid. The GIS technology has proved its importance in numerous disciplines. The constant improvement in the software and hardware parts of GIS is due to the activeness of GIS market. This improvement has made the use of GIS technology in different fields like science, business, government and real estate industries, crime mapping, public health, national defense, natural resources, sustainable development, landscape architecture, regional planning, archaeology, logistics and transportation. GIS even means diverging into LBS (Location Based Services). LBS allow devices, which are GPS enabled, to show their locality in relation to the nearest fire stations, restaurants etc. GIS benefits organizations of all sizes and in almost every industry. There is a growing awareness of the economic and strategic value of GIS. The benefits of GIS generally fall into five basic categories:

- Cost Savings and Increased Efficiency
- Better Decision Making
- Improved Communication
- Better Recordkeeping
- Managing Geographically

Geographic Information Science can be used in number of fields including:

- Scientific investigations about the surface of the Earth
- Natural and artificial projections of geospatial character
- Resource management
- Location development and asset management
- Assessing ecological impact
- Archaeology
- Urban planning
- Infrastructure development
- Criminology

- Cartography
- Geographic intelligence
- Geospatial history
- Geographic data development
- Logistics
- Geo marketing
- Demographic studies
- Statistical study
- Military planning
- Disease observation
- Environmental Contamination

Numbers of GIS software are available for different uses in which some are paid, some are freely available and few provide online solutions. Different available GIS are given below (Steiniger and Bocher, 2008/9)

- GRASS GIS – Originally developed by the U.S. Army Corps of Engineers: a complete GIS.
- gvSIG – Written in Java. Runs on Linux, Unix, Mac OS X and Windows.
- ILWIS (Integrated Land and Water Information System) – Integrates image, vector and thematic data.
- ARC GIS-Window based software
- JUMP GIS / OpenJUMP ((Open) Java Unified Mapping Platform) – The desktop GISs OpenJUMP, SkyJUMP, deeJUMP andKosmo all emerged from JUMP.[3]
- MapWindow GIS – Free desktop application and programming component.
- QGIS (previously known as Quantum GIS) – Runs on Linux, Unix, Mac OS X and Windows.
- SAGA GIS (System for Automated Geoscientific Analysis) –- A hybrid GIS software. Has a unique Application Programming Interface (API) and a fast growing set of geoscientific methods, bundled in exchangeable Module Libraries.
- uDig – API and source code (Java) available.

Besides these, there are other open source GIS tools:

- Capaware – A C++ 3D GIS Framework with multiple plugin architecture for geographic graphical analysis and visualization.
- FalconView – A mapping system created by the Georgia Tech Research Institute for the Windows family of operating systems. A free, open source version is available.
- Kalypso – Uses Java and GML3. Focuses mainly on numerical simulations in water management.

- TerraView – Handles vector and raster data stored in a relational or geo-relational database, i.e. a frontend for TerraLib.
- Whitebox GAT – Transparent GIS software.

In the present training, practical training on freely available GIS Integrated land Information System (ILWIS) will be given and its application in the field of soil and water conservation and water resources management will be discussed. The Integrated Land and Water Information System (ILWIS) is a Geographic Information System (GIS) with digital image processing capabilities. The International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands has developed ILWIS. As a GIS package, ILWIS allows to input, manage, analyze and present geographical data. ILWIS is a Windows-based, integrated GIS consisting of:

- Display of raster and multiple vector maps in map windows
- Display of tables in table windows
- Interactive retrieval of attribute information
- Image processing facilities
- Manipulation of maps in a Map Calculator
- Manipulation of tables in a Table Calculator
- Script language to perform 'batch' jobs

ILWIS functionality for vector includes: digitizing with mouse and/or digitizer, interpolation from isolines or points, calculation of segment or point density, pattern analysis. ILWIS functionality for raster includes: distance calculation, creation of a Digital Elevation Model (DEM), calculation of slope/aspect, deriving attribute maps, classify maps, manipulating maps with iff-statements, with Boolean logic, crossing maps, etc. For satellite imagery: creation of histograms, color composites, sampling and classification, filtering, multi-band statistics. ILWIS also provides import and export routines, editing of point, segment, polygon and raster maps, change of projection/coordinate system of maps, and output with annotation. The latitudes and longitudes, scale, legend, compass showing north direction etc. can be easily added on the output map. Basically, there are four ILWIS window types: the Main window, map windows, table windows and the pixel info window. The Main window is the window which is opened when ILWIS is started (Fig. 2). The Main window consists of:

- Command line on which you can type commands to display objects, map calculation formulae, expressions to perform complete operations, run scripts, etc.;
- One or more Catalogs which display the objects available in a certain directory, the raster maps in a map list or the objects in an object-collection; you can for instance drag a map from the Catalog to an existing map window, or to an operation in the Operation-tree or the Operation-list;

- Operation-tree and an Operation-list, and the Operations menu which list all ILWIS operations;
- Navigator to go to other drives or directories.

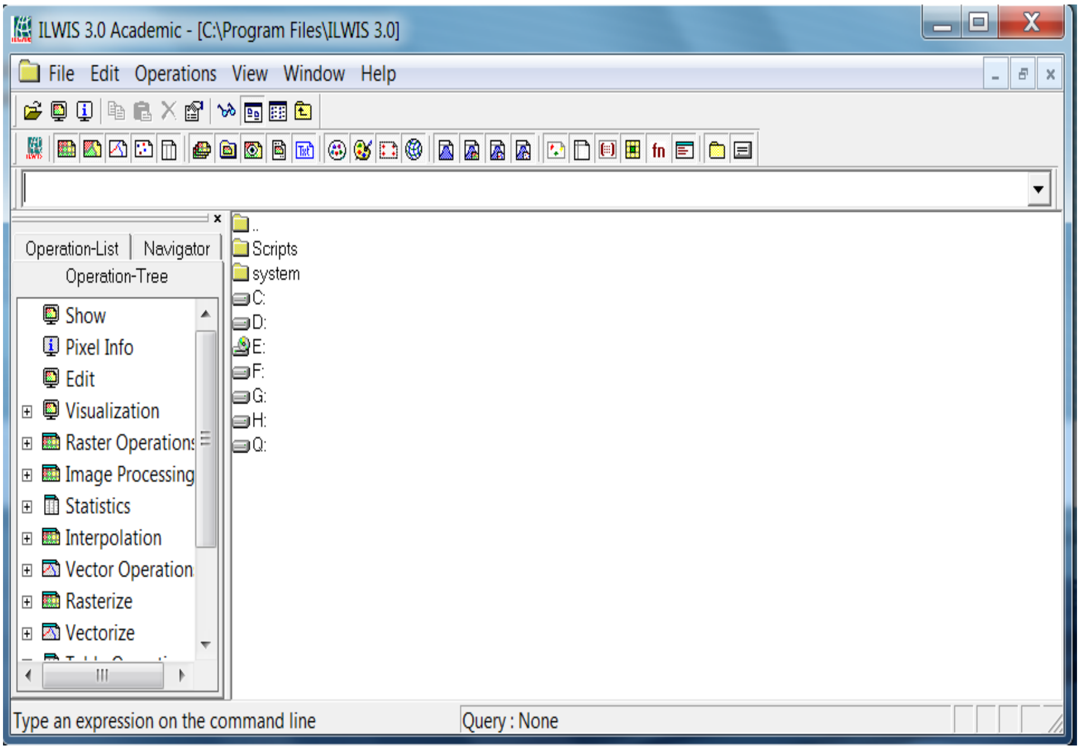


Fig.2: Main Window in ILWIS software

A map window displays one or more maps with grid lines, graticles or annotation text layers. You can open as many map windows as you like. When a raster map is displayed, you can display other point, segment or polygon maps on top of this raster map; add annotation; zoom in and out; and pan or scroll through the map if the map does not fit in the map window. To add or remove layers, to change the order of layers or to change the display options of a layer, you can use the Layer Management pane. To see the value or meaning of a pixel, point, segment, or polygon displayed in a map window, press the left mouse button (info). When the displayed map has an attribute table, you can double-click in the map window to see and edit the attributes. Furthermore, all raster maps in a map list can be displayed one after the other in a map window as a slide show. The contents of a map window can be saved as a map view. From a map view, you can create a layout to which you can and add annotation. You can use the map editors to edit positions, values or meanings of points, segments, polygons and pixels.

A table window displays a table and allows you to edit the table. You can open as many table windows as you like. A table can be shown as a whole, or record by record. When the table does not fit in the table window, scroll bars are provided. Fields in a table can be edited by clicking them.

The width of a column and the order of columns can easily be changed. On the command line in a table window, you can enter table calculation statements. Besides table calculations, you can perform joins between tables, aggregations and a least squares fit. From a table window, you can create graphs in a graph window. Further a table window displays histograms; you can calculate with the columns of the histogram. Also point maps, class/ID/picture domains and class representations can be opened as a table; you can perform special calculation with the coordinates, colors, etc. In the pixel info window, you can see the values or meanings of multiple maps and attribute values stored the attribute tables of the maps at the current position of the mouse pointer in a map window.

Map windows, table windows and the pixel information window are called data windows because they can display data objects. ILWIS functionality for **vectors** includes: digitizing with mouse and/or digitizer, interpolation from isolines or points, calculation of segment or point density, pattern analysis.

ILWIS functionality for **raster** includes: distance calculation, creation of a Digital Elevation Model (DEM), calculation of slope/aspect, deriving attribute maps, classifying maps, manipulating maps with iff-statements, with Boolean logic, crossing maps, etc.

For **satellite imagery**: creation of histograms, color composites, sampling and classification, filtering, multi-band statistics.

Furthermore ILWIS provides import and export routines, editing of point, segment, polygon and raster maps, change of projection/coordinate systems of maps, and output possibilities with annotation. With Windows, you can start one operation and keep it running while you start one or more additional applications. This is a sort of multitasking. You may work with both Windows and DOS application programs, you can perform one or more ILWIS calculations in the background and at the same time display maps, run other ILWIS operations, print, etc.

When the ILWIS icon is double-clicked on the desktop, the ILWIS logo appears, followed by the ILWIS Main window.

Main window:

Just below the menu bar a line can be seen in which text appears as soon as you click a map or menu command. This is the command line, on which you can type for example MapCalc statements. Below the command line is a toolbar which allows you to quickly display maps or tables. If you want to change to another directory or drive you can use the navigator: the list boxes to the right of the toolbar. The central right part of the Main window is the Catalog. It displays the ILWIS objects in the current directory. All ILWIS objects are preceded by an icon. The icons preceding data objects are:

for map lists,
for raster maps,
for polygon maps,
for segment maps,
for point maps,
for tables.

For a list of all ILWIS objects and their icons, see ILWIS objects. The objects and their icons in ILWIS are given in Fig. 3. For short Help on an object in the Catalog, click an object with the right mouse button and choose Help from the context-sensitive menu. Below the Catalog, you find a scroll bar which you can use to view more objects of the current directory in the Catalog. Lists of all operations can be found in the Operation-tree and the Operation-list, by default located on the first two tabs at the left hand side of the Main window. The operations are preceded by an icon. At the bottom of the Main window you see the status bar which gives additional information on maps, tables, operations, etc. The Main window can be sized by dragging its borders.

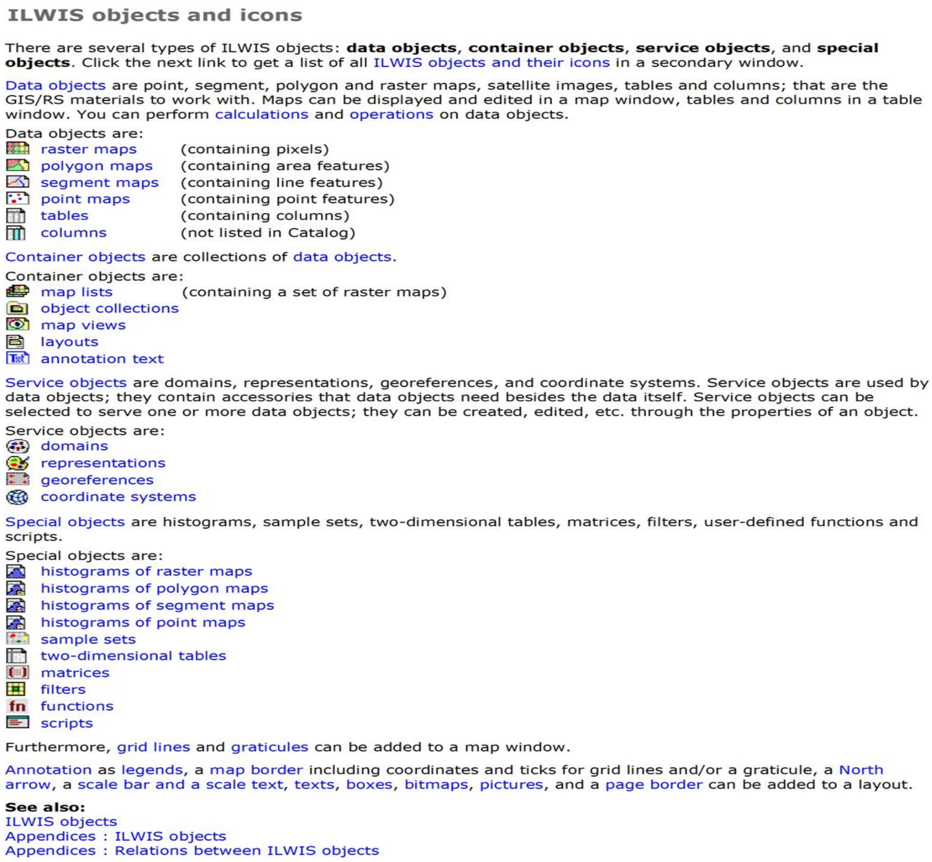
There are several ways to open a map or table in a window:

- open the File menu, choose the Open command, and select a map or table to display, or
- double-click a map or table in the Catalog.

Other ways to display maps and tables are by using the toolbar, the context-sensitive menu under the right mouse button when the mouse pointer is positioned on a map or table, or by double-clicking the Show item in the Operation-tree or the Operation-list. When opening a map, a dialog box appears in which you can specify some display options for the map.

A map is displayed in a map window. You can open as many map windows as you like. A map window can display one raster map and/or one or more point, segment, and polygon maps, a map list as a color composite with additional vector maps, and furthermore, optional grid lines, graticules and annotation text layers. You can zoom in and zoom out, and if the map does not fit in the map window, you can pan or scroll.

You can add other maps to an existing map window, either by dragging the desired map(s) from the Catalog to the existing map window, or by using the Add Layer command on the Layers menu of the map window. To see the value or meaning of a pixel, point, segment, or polygon of displayed maps in a map window, you can press the left mouse button (info). When the displayed map has an attribute table, you can double-click in the map window to see and edit the attributes. You can use Layer Management pane for instance to add or to remove layers from a map window, to change the order of layers or to change display options of a layer. Multiple maps, grid lines, graticules, etc. displayed in a map window can be saved as a map view. You can add one or more map views to a layout, to which you can then add further annotation. A table is displayed in a table window. You can open as many table windows as you like. Each table window displays one table. A table can be shown as a whole, or record by record. When the table does not fit in the table window, you can scroll. Fields in a table can be edited by clicking them. The width of a column and the order of columns can easily be changed. From a table window, you can create graphs in a graph window.


ILWIS objects and icons

There are several types of ILWIS objects: **data objects**, **container objects**, **service objects**, and **special objects**. Click the next link to get a list of all ILWIS objects and their icons in a secondary window.

Data objects are point, segment, polygon and raster maps, satellite images, tables and columns; that are the GIS/RS materials to work with. Maps can be displayed and edited in a map window, tables and columns in a table window. You can perform calculations and operations on data objects.

Data objects are:
- raster maps (containing pixels)
- polygon maps (containing area features)
- segment maps (containing line features)
- point maps (containing point features)
- tables (containing columns)
- columns (not listed in Catalog)

Container objects are collections of data objects.

Container objects are:
- map lists (containing a set of raster maps)
- object collections
- map views
- layouts
- annotation text

Service objects are domains, representations, georeferences, and coordinate systems. Service objects are used by data objects; they contain accessories that data objects need besides the data itself. Service objects can be selected to serve one or more data objects; they can be created, edited, etc. through the properties of an object.

Service objects are:
- domains
- representations
- georeferences
- coordinate systems

Special objects are histograms, sample sets, two-dimensional tables, matrices, filters, user-defined functions and scripts.

Special objects are:
- histograms of raster maps
- histograms of polygon maps
- histograms of segment maps
- histograms of point maps
- sample sets
- two-dimensional tables
- matrices
- filters
- functions
- scripts

Furthermore, grid lines and graticules can be added to a map window.

Annotation as legends, a map border including coordinates and ticks for grid lines and/or a graticule, a North arrow, a scale bar and a scale text, texts, boxes, bitmaps, pictures, and a page border can be added to a layout.

See also:
ILWIS objects
Appendices : ILWIS objects
Appendices : Relations between ILWIS objects

Fig. 2: Icons for different objects in ILWIS

Pixel info

In the pixel information window you can get information on multiple maps and attribute tables which contain attribute data. Open the pixel information window through the command Open Pixel Info on the File menu of the Main or a map window. Add one or more maps to the pixel info window by using the File menu of the pixel info window, or drag map icons from the Catalog to the pixel information window.

Starting ILWIS operations:

ILWIS operations, such as Distance calculation or Filter, are listed in the Operation-tree and the Operation-list. There are five ways to start an ILWIS operation:

1. Open the Operations menu in the Main Window and choose an operation, or
2. Double-click an operation in the Operation-tree, or
3. Double-click an operation in the Operation-list, or
4. Press the right mouse button on an object in the Catalog: a context-sensitive menu appears from which you can choose an operation, or
5. Drag an ILWIS data object from the Catalog to an operation in the Operation-tree or the Operation-list.

Usually a dialog box is opened in which you can select input and output object names and where some parameters necessary for the operation can be set. To obtain short Help on an operation in the Operation-tree or the Operation-list, click an operation with the right mouse button and choose Help from the context-sensitive menu.

LECTURE II- INSTALLATION AND CREATION OF FILES IN ILWIS

R.K. Jaiswal
Scientist-C, National Institute of Hydrology
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

ILWIS is now freely available software and can be downloaded from web site http://www.52north.org. Various versions are available and more applications including drainage extraction, watershed delineation, generation of shadow map, aspect map and other applications have been added in new versions. Presently up to ILWIS 3.8.04 is available on internet. The steps for getting ILWIS are very simple. First go to website and download any of the versions of ILWIS and then run executable file for installation of software. In this chapter, file creation, generation of coordinate system and import of toposheets and other maps in to ILWIS have been described. Before going into steps for import of toposheets or other maps including remote sensing data and digitization etc, it is necessary to understand the need of coordinate system for GIS related works.

Coordinate system

A coordinate system contains information on the kind of coordinates you are using in your maps; you may for instance use user-defined coordinates, coordinates defined by a national standard or coordinates of a certain UTM zone. A coordinate system defines the possible XY- or LatLon-coordinates that can be used in your maps. Point, segment and polygon maps always have a coordinate system. Raster maps have a georeference which uses a coordinate system. A coordinate system is a service object for point, segment and polygon maps, and for georeferences of raster maps. In ILWIS, XY-coordinates are supposed to be in meters and the 90° angle between the positive X-axis and the positive Y-axis is counter-clockwise.

Coordinate system types:

There are five main types of coordinate systems:

- **Coordinate system boundary only**: to define XY-coordinates for maps by only specifying the boundaries of your study area. This type of coordinate system should only be used when you are sure that you will not use projections at all; furthermore, *maps using a coordinate system boundary only, cannot be transformed into any other coordinate system.*
- **Coordinate System Projection**: to define XY-coordinates for maps by specifying the boundaries of your study area and when you want to have the possibility to add projection information, ellipsoid information and/or datum information. You can add the projection information later on or right away. Maps with different coordinate systems and different projections can be transformed into one another.

- **Coordinate System Latlon**: to define LatLon-coordinates for maps by specifying the boundaries of your study area in Latitudes and Longitudes and when you want to have the possibility to add ellipsoid information and/or datum information. You can add the ellipsoid information and/or datum information later on or right away.
- **Coordinate System Formula**: when you obtained data which is using different XY-coordinates than the coordinate system of your project, and when you know the relation between the two coordinate systems. You can create a coordinate system formula for maps with artificial coordinates, i.e. starting at (0, 0) or digitized in millimeters. The coordinate system formula uses a 'related' coordinate system; this is the coordinate system with correct coordinates. When you have defined the formula and when the map with artificial coordinates uses the newly created coordinate system formula, then you can transform the map to the correct coordinate system.
- **Coordinate System Tiepoints**: when you obtained data which is using different XY-coordinates than the coordinate system of your project, and when you do not know the relation between the two coordinate systems. You can create a coordinate system tiepoints for maps with artificial coordinates, i.e. starting at (0, 0) or digitized in millimeters. The coordinate system tiepoints uses a 'related' coordinate system; this is the coordinate system with correct coordinates. When you have specified the tiepoints and transformation method, and when the map with artificial coordinates uses the newly created coordinate system tiepoints, then you can transform the map to the correct coordinate system.

Furthermore, two coordinate systems are available in the SYSTEM directory:

- Coordinate system Unknown: when you do not care about coordinates.
- Coordinate system LatLon: when you obtained raster or vector data which are supposed to use LatLon-coordinates on a sphere (world-wide).

Finally, a coordinate system differential (for a georeference differential) is internally defined by the Variogram surface operation; it is thus not available on disk. This coordinate system is incompatible with any other coordinate system.

General use of coordinate systems:

- For general analysis purposes, it is advised to use single coordinate system for all your maps. This coordinate system should be wide enough to cover all X- and Y-coordinates that should be stored in your maps.
- Coordinate systems enable you to transform vector maps from one coordinate system to the other. There are 3 possibilities:

- When maps use a coordinate system projection or a coordinate system latlon and when this coordinate system actually contains projection, ellipsoid or datum information, then you can transform the map to any other coordinate system of type projection or latlon which contains projection, ellipsoid or datum information.
- When maps use a coordinate system formula (which uses a related coordinate system with correct coordinates), then you can transform the map to the related coordinate system.
- When maps use a coordinate system tiepoints (which uses a related coordinate system with correct coordinates), then you can transform the map to the related coordinate system.

- A map window has the capability to transform vector maps on the fly or temporarily. When a point, segment or polygon map with a certain coordinate system is displayed in a map window, you can drag or add another coordinate system to the map window. If a transformation between both coordinate systems is possible, the map window will use the newly added coordinate system; the vector maps displayed by the map window will be shown in the new coordinate system, i.e. the maps are temporarily transformed.
- When you use pixel information and the map is currently using one coordinate system, you can add another coordinate system to the pixel info window. When a transformation is possible between both coordinate systems, the pixel information window will also show you the coordinates in the new coordinate system. The pixel information window can also retrieve information from maps with another 'transformable' coordinate system.
- The following maps can be displayed with a graticule:
  - maps which use a coordinate system projection with a projection,
  - maps which use a coordinate system latlon,
  - maps which use a coordinate system formula, where the related coordsys is a coordsys projection with a projection or a coordsys latlon,
  - maps which use a coordinate system tiepoints, where the related coordsys is a coordsys projection with a projection or a coordsys latlon.
- When re-sampling raster maps from one georeference to another georeference which uses another coordinate system, then a transformation is automatically performed.

Projection System

A projection defines the relation between the map coordinates (X, Y) and the geographic coordinates latitude and longitude (f, l). The Earth's surface is curved, however in maps it is presented as a flat surface. Therefore, the display of an area on a map will always lead to some deformation or distortion; there is no 'perfect' projection. If you show only a small part of the Earth, like a town, the distortion will be almost insignificant. If, on the other hand, a map shows a continent, deformations and distortions will be a major problem. To correctly represent the curved Earth's surface on a flat map, you need a special projection. The geographic coordinates are converted to a metric coordinate system, measuring the X- and Y-directions in meters. Each projection has unique equations for the transformation from geographic to metric coordinates.

Because of the earth's rotation, the shape of the earth is not a perfect sphere. The earth is flattened towards the poles: the equatorial axis (line from the center to the Equator) is longer than the polar axis. The shape of the earth can be represented by an ellipsoid, or as it is sometimes called, a spheroid (shapes that are generated by revolving an ellipsis around its minor axis). The choice of the ellipsoid which fits best a certain region of the earth surface to be mapped depends on the surface curvature and undulations in that region. Hence every country has its own 'best fit' ellipsoid.

General characteristics of projections

Based on the shape of the projection surface, one can classify the projections in azimuthal, conical and cylindrical projections. Therefore, the cone or cylinder needs to be 'unrolled' to form a plane map.

Cylindrical projections

Cylindrical projections may be imagined as the projection to a plane that is wrapped around the globe in the form of a cylinder. After unrolling, the outline of the world map would be rectangular in shape; the meridians are parallel straight lines which cross at right angles by straight parallel lines of latitude. Examples: Mercator, Plate Carree.

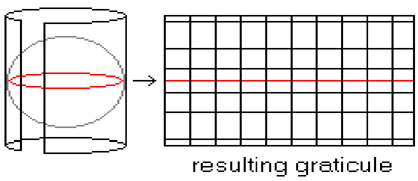


Fig.1: Cylindrical Projection

Azimuthal projections

Azimuthal projections may be imagined as the projection on a plane tangent to the globe. The characteristic outline of the world map would be circular. If the pole is the central point, the meridians are straight lines, spaced at their true angles intersecting at this center point. Parallels are represented as concentric circles. Examples: Gnomonic, Stereographic.

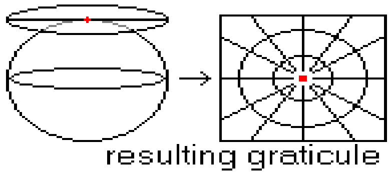


Fig.2: Azimuth Projection

Conical Projection

Conical projections may be imagined as the projection to a plane that is wrapped like a cone around the globe. After unrolling the outline of the world would be fan shaped. The meridians are represented as straight lines and parallels as concentric circles. Only the parallels where the cone touches the globe have the same length as on earth.

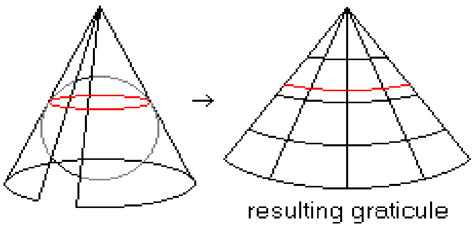


Fig. 3: Conical Projection

Steps for creation of map

In ILWIS, different steps for creating a map which may be either vector or raster maps are described below (The exercise will be done with the help of a toposheets)

Step 1: Determine the area of interest

Suppose the area of our interest lies in following latitude and longitude. Determine coordinates of bottom left and upper right corners

Latitude and longitude of bottom left corner: 24^0 45'N and $79^0$30' E

Latitude and longitude of upper right corner: 25^0 0' N and 80^0 0'E

79^0 25^0	30'E 79^0	45'E 80^0	0'E 25^0
00'N 24^0	Toposheet 54 P 9	Toposheet 54 P 13	00'N 24^0
45' N 79^0	30'E 79^0	45'E 80^0	0'E 45' N

Step 2: Create new Coordinate system

Creating Coordinate System with arbitrary X and Y

- Go to file and create
- In create, select Coordinate system
- Give the new name for coordinate system, Say **test**
- Number of options is available for different purposes and explained earlier, here select----CoordinateSystem Projection and click OK
- Give arbitrary values of minimum and maximum values (100000, 100000) for Min X, Y and (100000, 100000) for Max X, Y.
- Click Projection Tab and select Projection System. Here select ----UTM.
- Then in Ellipsoid-----Select any of the available ellipsoid. Here select WGS 84.
- Click ---Northern Hemisphere
- Give the value of Zone-----Here Give 44 and click OK (Fig. 4). (All earth has been divided into number of Zones and this information is available in HELP of ILWIS.

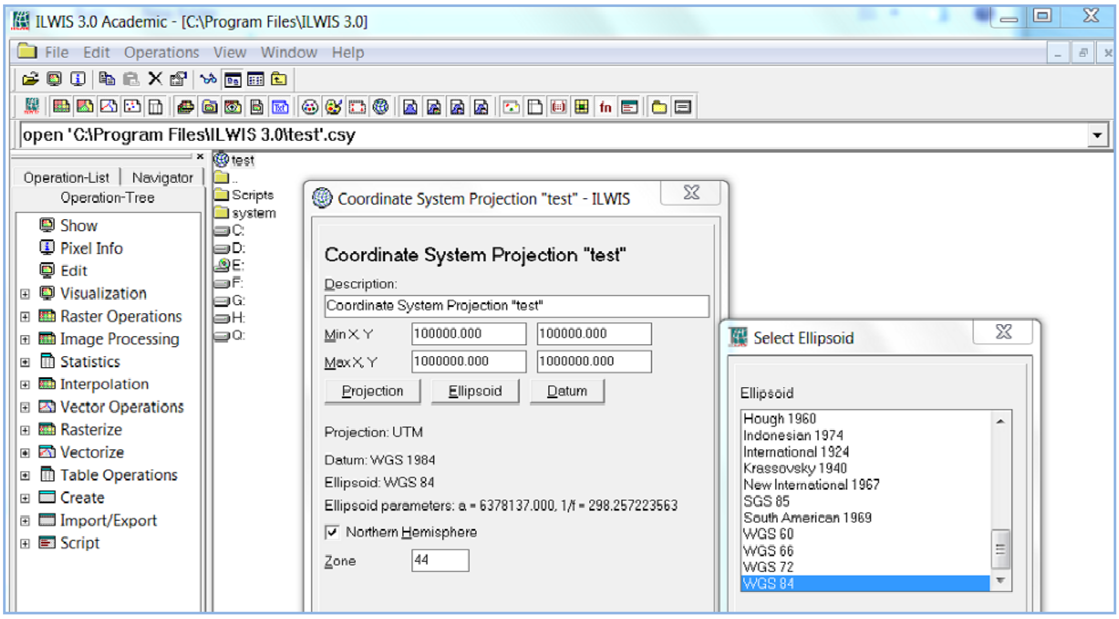


Fig. 4: Creating a coordinate system in ILWIS

Step 3: Determination of coordinates of area of interest

- From Main menu--- Go to Vector Operation and then ----Transform Coordinates
- A new window will appear. Here, Give Input Coordinate System as----LatLon and Output Coordinate System as test (Which has been generated by us)

- Give the values of coordinate of lower left corner and note down the transformed values comes out (Fig. 5). Here values for lower left coordinates 24^0 45' N and 79^0 30' E comes out to be (348000, 2738097.44) and for upper right corner, the X, Y values will be (398285.45, 2765319.94).

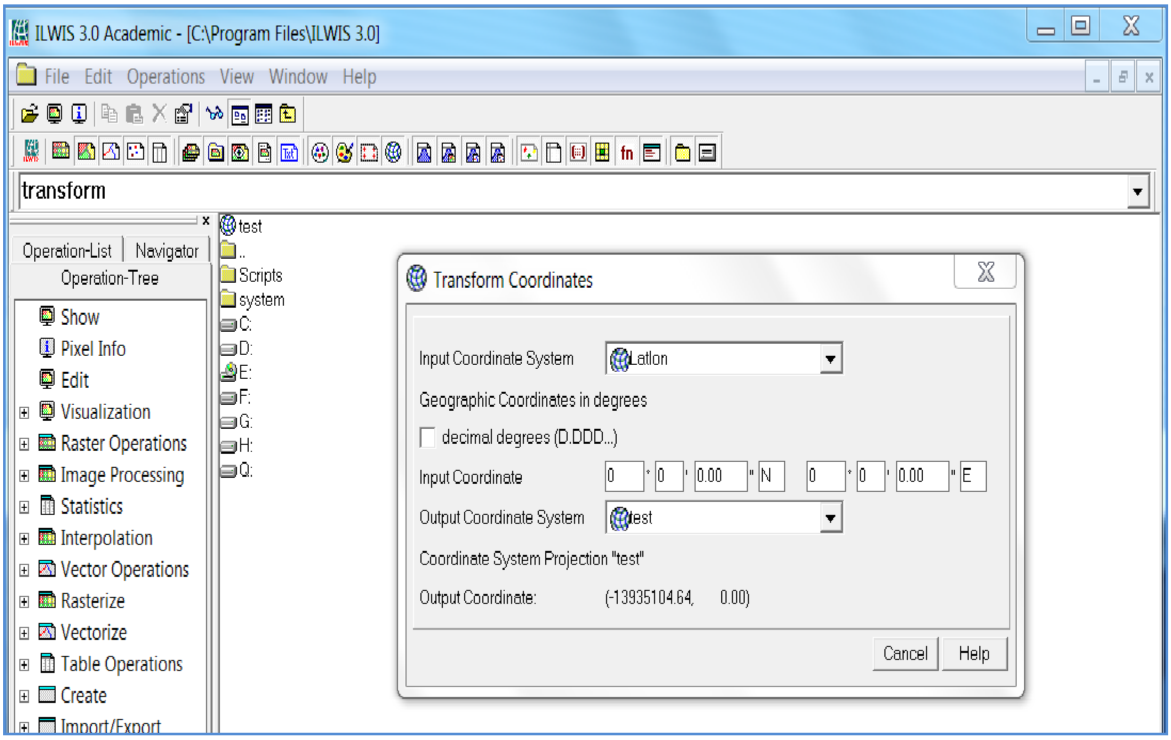


Fig. 5: Transform coordinate in ILWIS

Step 4: Modify the Coordinate System

- Open the coordinate system---- test and modify the X, Y values so that our area of interest can be covered.
- Here give Min X, Y as (348000, 398800) and Max X, Y as (2737000, 2765500) and click OK.

Step 5: creating a new file (vector file)

- In File menu----Go to Create and click either Point Map or Segment Map. Here, we select first a Point map, which may show the village locations in a watershed (Fig. 6).
- Give File name in Map Name Window, Coordinate system Name (Which we have created in Step 4).
- Here, we have to create a domain by radio button and give a name for domain. Here we give domain as---- Test.
- In Domain window, 3 Types can be given for lines, point, polygon and pixels as any one of Class, Identifier and Value. Class are used for nominate number of classes, Identifier gave a

number to each line or point. Where value use to assign a numerical value (Used for creating contours). Here, Class will be given as type of domain.

- A new window will appear where no. of classes can be entered. Classes can be entered during digitization also. Here we will not give any class.
- Now on this file points can be added and if we want to create village map then name of villages can be given.
- Similarly, line map can be created and lines can be digitized.

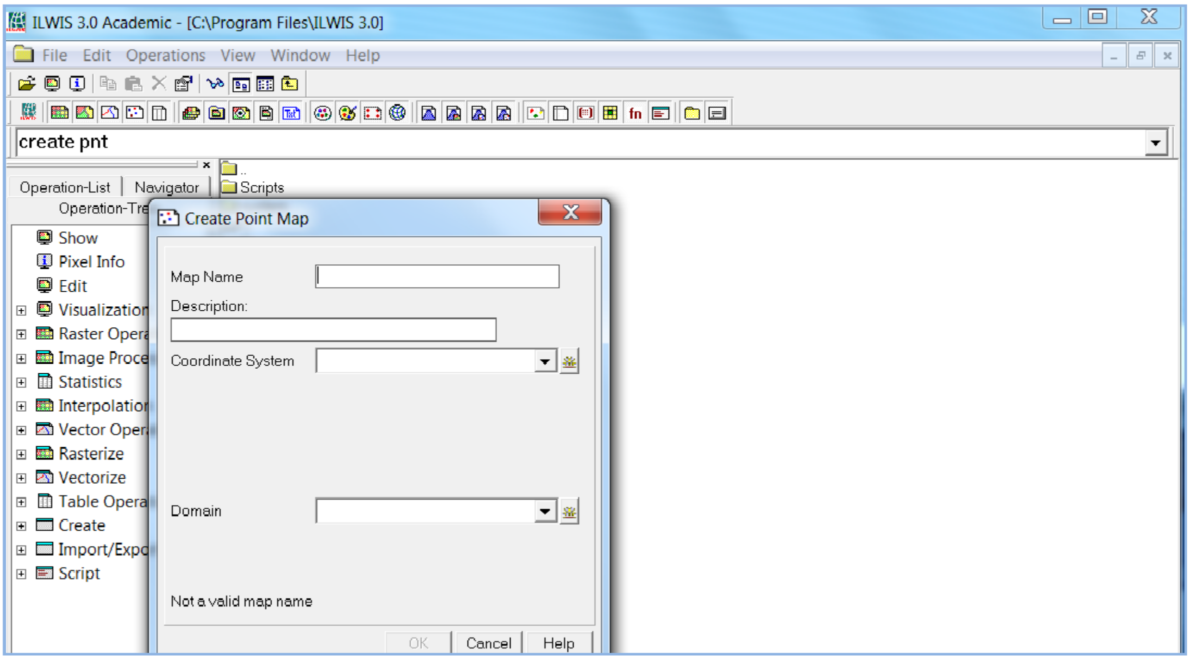


Fig. 6: Creating a point map in ILWIS

LECTURE III- GEOREFERENCING OF TOPOSHEETS

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

A georeference defines the relation between rows and columns in a raster map and X and Y-coordinates. The location of pixels in a raster map is thus defined by a georeference. It is advised that raster maps of the same area use the same georeference. Before georeferencing, a raster map has only XY values for each pixel. After georeferencing, the raster map shows XY as well as coordinates as per applied coordinate system. A georeference uses a coordinate system which may contain projection information. Polygon, segment and point maps merely use a coordinate system. A georeference is a service object, usually for several raster maps. There are five main types of georeferences are available in ILWIS.

- **Georeference corners**: a North-oriented georeference to be used during rasterization of vector data or as the North-oriented georeference to which you want to resample maps;
- **Georeference tiepoints**: a non-North-oriented georeference to add coordinates to a satellite image or to a scanned photograph, a scanned map, etc. without using a DTM;
- **Georeference direct linear**: to add coordinates to a scanned photograph while using a DTM;
- **Georeference orthophoto**: to add coordinates to a scanned aerial photograph while using a DTM and camera parameters;
- **Georeference 3D**: to create a three dimensional view of maps.

When editing a georef tiepoints, one of the following transformation methods can be selected: conformal, affine, second order bilinear, full second order, third order and projective.

- For satellite images an *affine transformation* will usually do;
- For a scanned photograph (without DTM), a *projective transformation* is recommended.

Tiepoint requirements:

- Mathematical minimum number of tiepoints required:
  - Georef tiepoints: conformal 2; affine 3; second order 4; full second order 6; third order 10; projective 4.
  - Georef direct linear: 6
  - Georef orthophoto: 3
- You should always insert more tiepoints than is mathematically required.

- Tiepoints should be well spread over the map (XY-direction).
- For a georef direct linear, the tiepoints should also be well spread in Z-direction and they should not be coplanar, i.e. in Z-direction, the tiepoints should not be on a (tilted) plane.

Step 1: Import toposheets in ILWIS

- Open ILWIS, go to the working directory
- From File Menu use option of import
- According to file type select import format and give input as well as output file name.
- File will open in viewer window as given in Fig. 1.

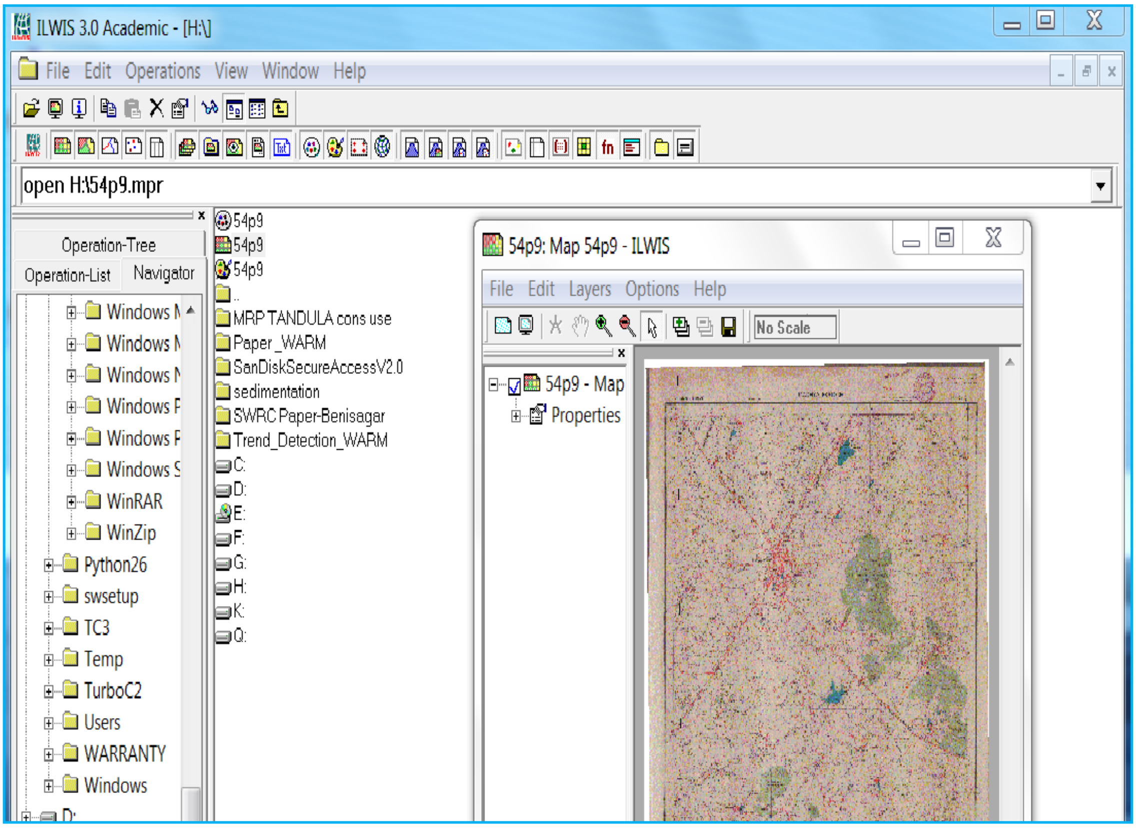


Fig. 1: Toposheet in Window viewer after import

Step 2: Determine XY values for known points

- From Main menu--- Go to Vector Operation and then ----Transform Coordinates

- A new window will appear. Here, Give Input Coordinate System as----LatLon and Output Coordinate System as test (Which has been generated by us)
- Give the values of at least 4 known coordinate points and determine XY values transformed as per our coordinate system (test). Here when we give latitudes and longitudes for these 4 points on the toposheets, the following X and Y value we will get.

S.N.	Latitude	Longitude	X	Y
1.	24^0 45’ N	79^0 30’ E	348319.26	2738097.44
2.	25^0 00’ N	79^0 30’ E	348624.24	2765785.30
3.	25^0 00’ N	79^0 45’ E	373856.38	2765529.34
4.	24^0 45’ N	79^0 45’ E	373602.27	2737843.37
5.	24^0 55’ N	79^0 35’ E	356938.84	2756465.64

Step 3: Georeferencing of toposheet/Raster map

- Either directly or after open the toposheets in a map window, go to file---- create georeference----- give the name of georeference (here we give test).
- Select GeoRef Tiepoints option from five available georeference which is an appropriate option for toposheets and scanned images having coordinates.
- After pressing OK button, a window will appear which contains the toposheets and tie point editor.
- In the editor window, zoom any known point (24^0 45’ N, 79^0 30’ E) and when arrow point is selected, mouse pointer is converted in to cross hair mark. Click on point, a add tie point box will appear, where we have to put the value of X and Y we have got from transformation. Here we have to put X=348319.26 and Y=2738097.44.
- Similarly, all other known points are to be added in tie point editor and their XY values are provided in Box.
- If the Sigma seems low then press exit editor button. Now the toposheet or raster maps will show the XY as well as latitude and longitudes on each pixel and keeping this toposheets in background and digitization can be started.

The georeference windows in ILWIS can be seen in Fig. 2. Now by creating new point map or segment map with same coordinate system and keeping the georeferenced image in background, the digitization can be started. To create a new segment or point map, open the File menu in the map window, and choose Create Segment Map or Create Point Map. The Create Segment Map or the Create Point Map dialog box appears. Type a map name, specify a domain and optionally type a description. Accept the coordinate system and map boundaries which are already filled out. To edit an existing segment or point map, choose the Edit Other Map command from the Edit menu of the map window, then select the desired editor and select a map.

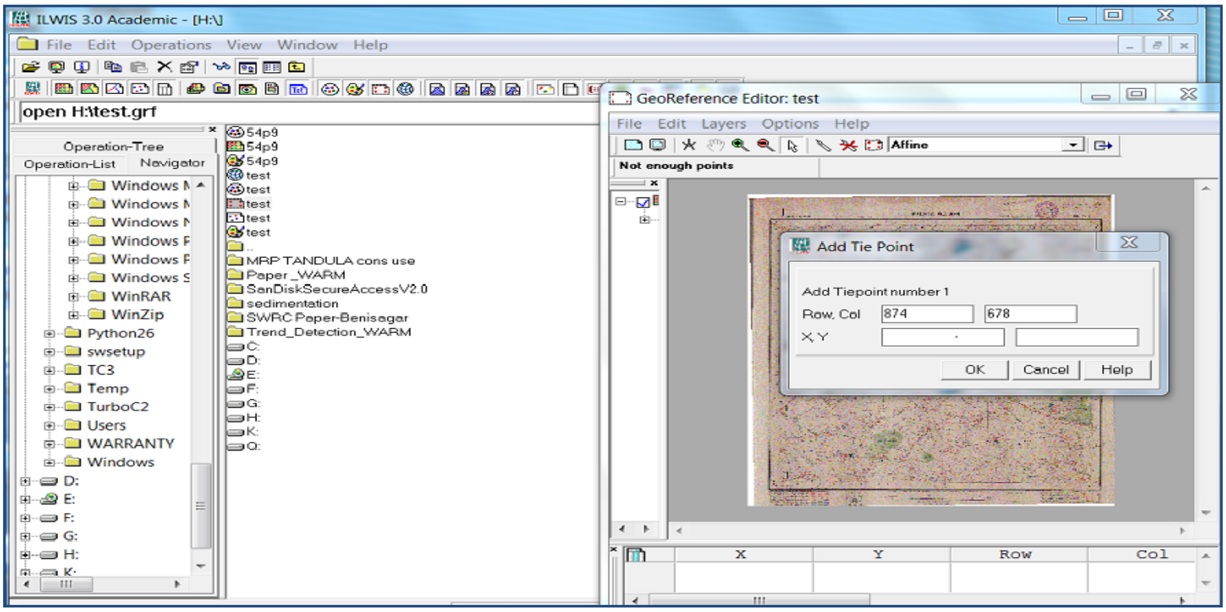


Fig. 2: Georeference window in ILWIS

The Segment editor or the Point editor is opened. You can now add, edit and delete segments or points by using the mouse as usual. When your background map uses a georef direct linear, you may see that an edited segment or point does not exactly appear at the position of the pencil pointer: this is a measure of the quality of your georeference in the area. Errors will usually be larger along the edges of a photograph.

- When the deviation is small, your georeference is good enough;
- When the deviation is large, you can check the number, even distribution and quality of the tiepoints in your georeference, the quality of your DTM, etc.

LECTURE IV-PRINCIPLES OF REMOTE SENSING-PHYSICS OF REMOTE SENSING AND ELECTROMAGNETIC RADIATION

T.R. Nayak
Scientist-D & Head, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology WALMI CAMPUS Kolar Road Bhopal (M.P.)
E-mail: tejramn@yahoo.com

"Remote sensing, in simplest words, means acquiring information about an object without touching the object itself."

The basic principle of remote sensing is that the different objects based on their structural, chemical and physical properties return (reflects or emits) different amount of energy in different wavelength ranges (commonly referred to as bands) of the electromagnetic spectrum incident upon it. Most remote sensing systems utilize the sun's energy, which is a predominant source of energy. These radiations travel through the atmosphere and are selectively scattered and/or absorbed depending upon the composition of the atmosphere and the wavelengths involved. These radiations upon reaching the earth's surface interact with the target objects. Everything in nature has its own unique pattern of reflected, emitted or absorbed radiation. A sensor is used to record reflected or emitted energy from the surface. This recorded energy is then transmitted to the users and then it is processed to form an image, which is then analyzed to extract information about the target.

During early half of twentieth century, aerial photos were used in military surveys and topographical mapping. Main advantage of aerial photos has been the high spatial resolution with fine details and therefore they are still used for mapping at large scale such as in route surveys, town planning, construction project surveying, cadastral mapping etc. Modern remote sensing system provide satellite images suitable for medium scale mapping used in natural resources surveys and monitoring such as forestry, geology, watershed management etc. However the new generation satellites provide much high-resolution images for more versatile applications. The use of different and extended portions of the electromagnetic spectrum, development in sensor technology, different platforms for remote sensing (spacecraft, in addition to aircraft), emphasize on the use of spectral information as compared to spatial information, advancement in image processing and enhancement techniques, and automated image analysis in addition to manual interpretation have made the modern remote sensing system versatile.

Process of Remote Sensing

Detection and discrimination of objects or surface features means detecting and recording of radiant energy reflected or emitted by objects or surface material (Fig. 1). Different objects return different amount of energy in different bands of the electromagnetic spectrum, incident upon it. This depends on the property of material (structural, chemical, and physical), surface roughness, angle of incidence, intensity, and wavelength of radiant energy.

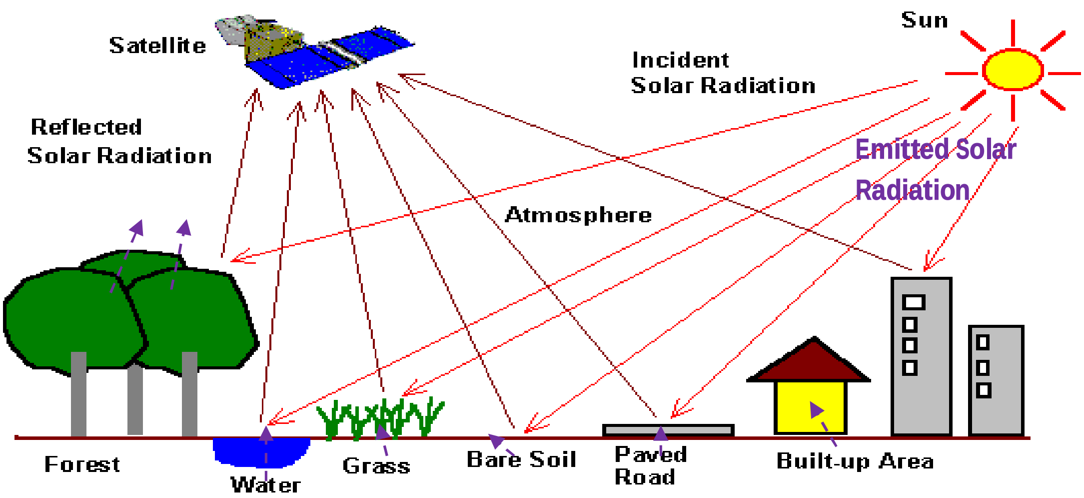


Figure 1: Process of Passive Remote Sensing

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching etc. All these technologies are integrated to act as one complete system in itself, known as Remote Sensing System. There are a number of stages in a Remote Sensing process, and each of them is important for successful operation.

Stages in Remote Sensing

The process of remote sensing involves a number of processes starting from energy emission from source to data analysis and information extraction. The stages of remote sensing are described in follows steps:

Source of Energy:

The source of energy (electromagnetic radiations) is a prerequisite for the process of remote sensing. The energy sources may be indirect (e.g. the sun) or direct (e.g. radar). The indirect sources vary with time and location, while we have control over direct sources. These sources emit electromagnetic radiations (EMRs) in the wavelength regions, which can be sensed by the sensors.

Interaction of EMR with the Atmosphere:

The EMR interacts with the atmosphere while traveling from the source to earth features and from earth features to the sensor. During this whole path the EMR changes its properties due to loss of energy and alteration in wavelength, which ultimately affects the sensing of the EMR by the sensor. This interaction often leads to atmospheric noise.

EMR Interaction with Earth Features:

The incident EMR on the earth features interacts in various ways. It get reflected, absorbed, transmitted & emitted by the features and ground objects. The amount of EMR reflected, absorbed, transmitted and emitted depends upon the properties of the material in contact and EMR itself.

Detection of EMR by the remote sensing sensor:

The remote sensing device records the EMR coming to the sensor after its interaction with the earth features. The kind of EMR which can be sensed by the device depends upon the amount of EMR and sensor's capabilities.

Data Transmission and Processing:

The EMR recorded by the remote sensing device is transmitted to earth receiving and data processing stations. Here the EMR are transformed into interpretable output- digital or analogue images.

Image Processing and Analysis:

The digital satellite images are processed using specialized software meant for satellite image processing. The image processing and further analysis of satellite data leads to information extraction, which is required by the users.

Application:

The extracted information is utilized to make decisions for solving particular problems. Thus remote sensing is a multi-disciplinary science, which includes a combination of various disciplines such as optics, photography, computer, electronics, telecommunication and satellite-launching etc.

Types of Remote Sensing

Based on Source of energy

The sun provides a very convenient source of energy for remote sensing. The sun's energy is either reflected, as it is for visible wavelength or absorbed and then re-emitted (for thermal infrared wavelength). Remote sensing systems, which measure this naturally available energy, are called *passive sensors*. This can only take place when the sun is illuminating the earth. There is no reflected energy available from the sun at night. Energy that is naturally emitted can be detected day and night provided that the amount of energy is large enough to be recorded. Remote sensing systems, which provide their own source of energy for illumination, are known as *active sensors*. These sensors have the advantage of obtaining data any time of day or season.

Solar energy and radiant heat are examples of passive energy sources. Synthetic Aperture Radar (SAR) is an example of active sensor.

Based on Range of Electromagnetic Spectrum

Optical Remote Sensing

The optical remote sensing devices operate in the visible, near infrared, middle infrared and short wave infrared portion of the electromagnetic spectrum. These devices are sensitive to the wavelengths ranging from 300 nm to 3000 nm. Most of the remote sensors record the EMR in this range, e.g., bands of IRS P6 LISS IV sensor are in optical range of EMR.

Thermal Remote Sensing

The sensors, which operate in thermal range of electromagnetic spectrum record, the energy emitted from the earth features in the wavelength range of 3000 nm to 5000 nm and 8000 nm to 14000 nm. The previous range is related to high temperature phenomenon like forest fire, and later with the general earth features having lower temperatures. Hence thermal remote sensing is very useful for fire detection and thermal pollution. e.g., the last five bands of ASTER and band 6 of Landsat ETM+ operates in thermal range.

Microwave Remote Sensing

A microwave remote sensor records the backscattered microwaves in the wavelength range of 1 mm to 1 m of electromagnetic spectrum. Most of the microwave sensors are active sensors, having there own sources of energy, e.g, RADARSAT. These sensors have edge over other type of sensors, as these are independent of weather and solar radiations.

Based on Sensor Platform

Airborne Remote Sensing

In airborne remote sensing, downward or sideward looking sensors are mounted on an aircraft to obtain images of the earth's surface. An advantage of airborne remote sensing, compared to satellite remote sensing, is the capability of offering very high spatial resolution images (20 cm or less). The disadvantages are low coverage area and high cost per unit area of ground coverage. It is not cost-effective to map a large area using an airborne remote sensing system. Airborne remote sensing missions are often carried out as one-time operations, whereas earth observation satellites offer the possibility of continuous monitoring of the earth.

Spaceborne Remote Sensing

In spaceborne remote sensing, sensors are mounted on-board a spacecraft (space shuttle or satellite) orbiting the earth. At present, there are several remote sensing satellites providing imagery for research and operational applications. Spaceborne remote sensing provides the following advantages:

- Large area coverage;
- Frequent and repetitive coverage of an area of interest;
- Quantitative measurement of ground features using radiometrically calibrated sensors;
- Semiautomated computerised processing and analysis;
- Relatively lower cost per unit area of coverage.

Satellite imagery has a generally lower resolution compared to aerial photography. However, very high resolution imagery (up to 1-m resolution) is now commercially available to civilian users with the successful launch of the high resolution satellites like IKONOS-2.

Electromagnetic Radiation (EMR)

At temperature above absolute zero, all objects radiate electromagnetic energy by virtue of their atomic and molecular oscillations. The total amount of emitted radiation increases with the body's absolute temperature and peaks at progressively shorter wavelengths. The sun, being a major source of energy, radiation and illumination, allows capturing reflected light with conventional (and some not-so-conventional) cameras and films. The basic strategy for sensing electromagnetic radiation is clear. Everything in nature has its own unique distribution of reflected, emitted and absorbed radiation. EMR is a dynamic form of energy that propagates as wave motion at a velocity of c = 3 x 10^{10} cm/sec. The parameters that characterize a wave motion are wavelength (λ), frequency (ν) and velocity (c) (Fig. 2). The relationship between the above is: $\mathbf{c = \nu \lambda}$

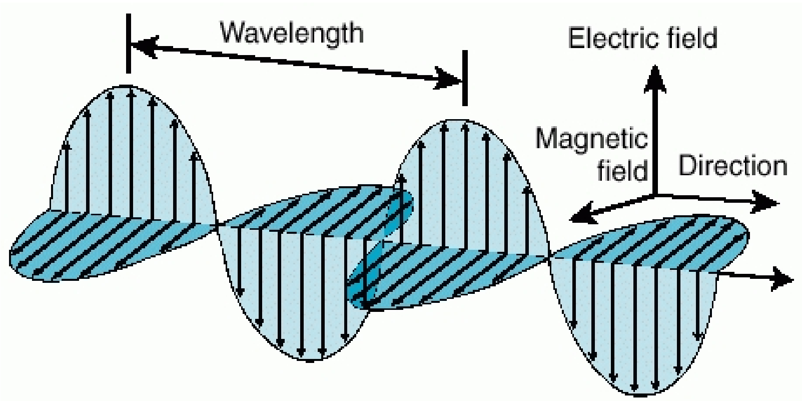


Figure 2: Electromagnetic wave. It has two components, Electric field E and Magnetic field M, both perpendiculars to the direction of propagation

Electromagnetic energy radiates in accordance with the basic wave theory. This theory describes the EM energy as travelling in a harmonic sinusoidal fashion at the velocity of light. Although many characteristics of EM energy are easily described by wave theory, another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta. The energy of photon is

$$\mathbf{Q = hc / \lambda = h\,\nu}$$

Where, Q is the energy of quantum, h = Planck's constant

Electromagnetic Spectrum

Electromagnetic spectrum (EMS) represents the continuum of electromagnetic radiation (EMR) arranged on the basis of wavelengths or frequency. Electromagnetic spectrum ranges from shorter wavelengths (gamma rays to x rays) to the longer wavelengths (microwave and radio waves) as shown in Fig. 3.. Most common remote sensing systems operate in one or several of the visible, infrared and microwave portions of the electromagnetic spectrum. Within the infrared portion of the spectrum it should be noted that only thermal infrared energy is directly related to the sensation of heat; not the near and mid infrared ones. Different radiations which constitute the EMS are as follows:

Radio waves:

These are the longest wavelength (lowest frequency) radiations of the EMS. The wavelength of radio waves is more than 100 cm and passes through Earth's atmosphere easily. Radio signals are used in radios, televisions, aircrafts, ship etc. These are also emitted by stars.

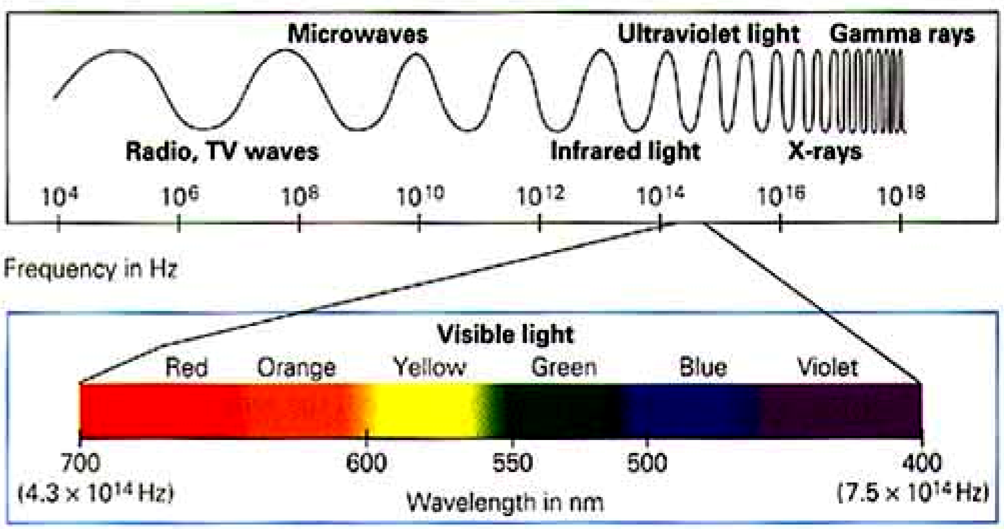


Figure 3: Wavelength of common electromagnetic spectrum

Microwaves:

Their wavelength ranges between 1 mm & 1 m. RADAR (Radio Detection And Ranging) is the most common device used in Microwave Remote Sensing. Other applications are in cooking food (microwave oven), in broadcasting transmissions etc.

Infrared Radiations:

When we feel hot it is because of infrared (IR) radiations. For common understanding we can call them as 'Heat'. The wavelength of IR is longer than visible light and shorter than microwaves approximately ranges between 1 micron and 100 microns. These are very useful radiations for remote sensing. Thermal Imaging Systems detect objects by recording their temperature (infrared emissions).

Visible Radiations:

As their name itself suggests these are the EMRs which are visible to our eyes in different colors. These range between 700 nm to 400 nm. Most of the remote sensing systems and camera records images in this range.

Ultraviolet (UV) Radiations:

These radiations have wavelength shorter violet color of visible light and longer than X-rays. UV radiations can be divided into near UV (400–200 nm), far UV (200–10) and extreme UV 1–31 nm.

X-rays:

These are very short length electromagnetic radiations wavelength in the approximate range from 0.01 to 10 nanometers. In EMS these falls between UV radiations and Gamma-rays and mostly used in medical sciences.

Gamma-rays:

Gamma-rays are the electromagnetic radiations with shortest wavelength in the range of the range of 10^{-11} m to 10^{-14} m. Their very high energy can cause serious damage to living cells.

(http://rsgislearn.blogspot.in/2007/04/spectral-reflectance.html)

LECTURE V- SATELLITE, SENSOR AND IMAGERY

T.R. Nayak
Scientist-D & Head, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology WALMI CAMPUS Kolar Road Bhopal (M.P.)
E-mail: tejramn@yahoo.com

Satellites are usually classified according to the type of orbit they are in. There are four types of orbit associated with satellites, and the type of orbit dictates a satellite's use.

Low Earth Orbits

Satellites in low Earth orbits are normally military reconnaissance satellites that can pick out tanks from 160 km above the Earth. They orbit the earth very quickly, one complete orbit normally taking 90 minutes. However, these orbits have very short lifetimes in the order of weeks compared with decades for geostationary satellites. Simple launch vehicles can be used to place these satellites of large masses into orbit.

Sun-Synchronous orbits

Meteorological satellites are often placed in a sun-synchronous or heliosynchronous orbit. These satellites are in polar orbits. The orbits are designed so that the satellite's orientation is fixed relative to the Sun throughout the year, allowing very accurate weather predictions to be made. Most meteorological satellites orbit the Earth 15 to 16 times per day.

Geosynchronous satellites

Earth-synchronous or geosynchronous satellites are placed into orbit so that their period of rotation exactly matches the Earth's rotation. They take 24 hours to make one rotation. However, the plane of orbit for these satellites is generally not the equatorial plane. Apart from geostationary satellites (see below), the satellites are used for communications at high latitudes, particularly in Russia and Canada. The orbits are called Molniya orbits. The satellites are placed in highly elliptical orbits which enable them to appear to hover above one point on the Earth for most of the day. In twenty four hours they move over the Earth in a figure of eight pattern centered on a fixed longitude, moving slowly where they can be useful and quickly where they are of little use.

Geostationary satellites

The majority of communications satellites are in fact geostationary satellites. Geostationary satellites like geosynchronous satellites take 24 hours to complete a rotation. However, geostationary satellites are positioned directly over the equator and their path follows the equatorial plane of the Earth. As a result geostationary satellites don't move North or South during the day and are permanently fixed above one point on the equator of the Earth. Most video or T.V. communications systems use geostationary satellites. Geosynchronous and geostationary satellites are typically orbiting at 35,788 km (22,238 miles) above the surface of the planet (42,000 km from its centre).

Chronology of Remote Sensing

1826: First photographic Image taken by Joseph Nicephore Niepce.
1839: Beginning of practice of Photography.
1855: Additive Colour Theory postulated by James Clerk Maxwell.
1858: First Aerial Photograph from a balloon, taken by G. F. Tournachon.
1873: Theory of Electromagnetic Energy developed by J. C. Maxwell.
1903: Airplane invented by Wright brothers.
1909: Photography from airplanes.
1910s: Aerial Photo Reconnaissance: World War I.
1920s: Civilian use of aerial photography and Photogrammetry.
1934: American society of Photogrammetry founded.
1935: Radar invention by Robert Watson-Watt.
1939-45: Advances in Photo Reconnaissance and applications of non-visible portion of EMR: World War II.
1942: Kodak patents first false color infrared film.
1956: Colwell's research on diseases detection with IR photography.
1960: Term "Remote Sensing" coined by Office of Naval Research personnel
1972: ERTS-1 launched (renamed Landsat-1).
1975: ERTS-2 launched (renamed Landsat-2).
1978: Landsat-3 launched.
1980s: Development of Hyperspectral sensors.
1982: Landsat-4 TM & MSS launched.
1984: Landsat-5 TM launched.
1986: SPOT-1 launched.
1995: IRS 1C launched.
1999: Landsat-7 ETM+ launched.
1999: IKONOS launched.
1999: NASA's Terra EOS launched.
2002: ENVISAT launched.
2003: ISRO's RESOURCESAT-1 (IRS P6) launched.
2005, 2007: ISRO's CARTOSAT-1, CARTOSAT-2 launched.
2008, 2010: ISRO's CARTOSAT-2A, CARTOSAT-2B launched.
2012: RISAT-1 launched.

For the past four decades, ISRO has launched more than 70 satellites for various scientific and technological applications like mobile communications, Direct-to-Home services, meteorological observations, telemedicine, tele-education, disaster warning, radio networking, search and rescue operations, remote sensing and scientific studies of the space. ISRO has established two major space systems, the Indian National Satellite System (INSAT) series for communication, television broadcasting and meteorological services which isGeo-Stationary Satellites, and Indian Remote Sensing Satellites (IRS) system for resources monitoring and management which is Earth Observation Satellites. ISRO has launched many Experimental Satellites which are generally small comparing to INSAT or IRS, Space Missions to explore the space and Navigation Satellite to provide accurate position information service to users.

Popular Remote Sensing Systems

LANDSAT

Landsat satellite sensors are one of the most popular remote sensing systems, the imagery acquired from these are widely used across the globe. NASA’s Landsat satellite programme was started in 1972. It was formerly known as ERTS (Earth Resource Technology Satellite) programme. The first satellite in the Landsat series Landsat-1 (formerly ERTS-1) was launched on July 23, 1972 .Since then five different types of sensors have been included in various combinations in Landsat mission from Landsat-1 through Landsat-7. These sensors are Return Beam Vidicon (RBV), the Multispectral Scanner (MSS), the Thematic Mapper (TM), the Enhanced Thematic Mapper (ETM) and the Enhanced Thematic Mapper plus (ETM+). In 1999 Landsat ETM+ (or Landsat 7) was launched and it is the recent one in the series. Landsat ETM+ contains four bands in Near Infrared-visible (NIR-VIS) region with 30mx30m spatial resolution, two bands in Short Wave Infrared (SWIR) region with same resolution, one in Thermal Infrared (TIR) region with spatial resolution of 60mx60m and one panchromatic band with resolution. Its revisit period is 16 days.

SPOT

SPOT (Systeme Pour l’Observation de la Terre) was developed by the French Centre National d’ Etuded Spatiales with Belgium and Sweden. The first satellite of SPOT mission, SPOT-1 was launched in 1986. It was followed by SPOT-2 (in 1990), SPOT-3 (in 1993), SPOT-4 (in 1998) and SPOT-5 (in 2002). There are two imaging systems in SPOT-5- HRVIR and Vegetation. The HRVIR records data in three bands in VIS-NIR region with 10mx10m spatial resolution, one band in SWIR region with 20mx20m spatial resolution and one panchromatic band with 5mx5m resolution. The Vegetation instrument is primarily designed for vegetation monitoring and related studies.

Advanced Very High Resolution Radiometer (AVHRR)

Several generations of satellites have been flown in the NOAA-AVHRR series. NOAA-15 is the recent in the series. The sensor AVHRR(Advanced Very High Resolution radiometer) contains five spectral channels two in VIS-NIR region and three in TIR. One thermal band is of the wavelength range 3.55-3.93 mm, meant for fire detection. Spatial resolution of AVHRR is 1100mx1100m. NOAA-AVHRR mainly serves for global vegetation mapping, monitoring land cover changes and agriculture related studies with daily coverage.

Indian Remote Sensing (IRS) Satellites

The Indian Remote Sensing program began with the launch of IRS-1A in 1988. After that IRS-1B (1999), IRS-1C (1995) and IRS-1D (1997) was launched. IRS-1D carries three sensors: LISS III with three bands of 23.5mx23.5m spatial resolution in VIS-NIR range and one band in SWIR region with 70.5x70.5 m resolution, a panchromatic sensor, with 5.8mx5.8m resolution and a Wide Field Sensor (WiFs) with 188mx188m resolution. WiFS is extensively used for vegetation related studies.

ISRO’s IRS-P6 (RESOURCESAT-1) is very advanced remote sensing system. It was launched in 2003. It carries high resolution LISS IV camera (three spectral bands in VIS-NIR region) with spectral resolution of 5.8mx5.8m which has capability to provide stereoscopic imagery. IRS-P6 LISS III camera acquires images in VIS-NIR (3 spectral bands) and SWIR (one spectral band) with spatial resolution of 23.5mx23.5m. IRS-P6 AWiFS (Advanced Wide Field Sensor) operates in VIS-NIR (3 spectral bands) and SWIR (one spectral band) with spatial resolution of 56mx56m.

Satellite Sensor Resolutions

Spatial resolution

Spatial resolution is the measure of smallest object that can be detected by a satellite sensor. It represents area covered by a pixel on the ground. Mostly, it is measured in meters. For example, CARTOSAT-1 sensor has a spatial resolution of 2.5x2.5 m , IRS P6 LISS IV sensor has a spatial resolution of 5.6x5.6 m for its multispectral bands and LISS III has spatial resolution of 23.5x23.5 m in its first three bands. The smaller the spatial resolution, the greater the resolving power of the sensor system. That's why one can detect even a car in the satellite image acquired by IKONOS (spatial resolution 1x1 m) but can see hardly even a village in a satellite image acquired by AVHRR (spatial resolution 1.1x1.1 km).

Spectral resolution

Spectral resolution refers to the specific wavelength intervals in the electromagnetic spectrum for which a satellite sensor can record the data. It can also be defined as the number and dimension of specific wavelength intervals in the electromagnetic spectrum to which a remote sensing instrument is sensitive. For example, band 1 of the Landsat TM sensor records energy between 0.45 and 0.52 µm in the visible part of the spectrum. The spectral channels containing wide intervals in the electromagnetic spectrum are referred to as coarse spectral resolution and narrow intervals are referred to as fine spectral resolution. For instance the SPOT panchromatic sensor is considered to have coarse spectral resolution because it records EMR between 0.51 and 0.73 µm. on the other hand; band 2 of the ASTER sensor has fine spectral resolution because it records EMR between 0.63 and 0.69 µm.

On the basis of spectral properties, satellite images are of two type- panchromatic and multispectral images. In panchromatic images pixels appears in different shades of grey that's why often these are referred to as black & white images. Panchromatic images have single spectral band covering almost whole visible range of electromagnetic spectrum, e.g. CARTOSAT-1 images. The number grey shades which can be displayed by a pixel depend on number of bits per pixel. One bit images will have only two grey levels while 8-bit will have 256 grey levels. Multispectral images contain multiple layer of spectral bands and are displayed in combination of red (R), green (G) and blue (B) colors. Hence these are colored images e.g. IRS-P6 LISS IV MX images.

Radiometric resolution

Radiometric resolution defined as the sensitivity of a remote sensing detector to differentiate in signal strength as it records the radiant flux reflected or emitted from the terrain. It refers to the dynamic range, or number of possible data-file values in each band. This is referred to by the number of bits into which the recorded energy is divided. For instance, ASTER records data in 8-bit for its first nine bands, it means the data file values range from 0 to 255 for each pixel, while the radiometric resolution of LISS III is 7-bit, here the data file values for each pixel ranges from 0 to 128.

Temporal Resolution

The temporal resolution of a satellite system refers to how frequently it records imagery of a particular area. For example, CARTOSAT-1 can acquire images of the same area of the globe every 5 days, while LISS III does it every 24 days. The temporal resolution of a satellite sensor is very much helpful in change detection. For instance, agricultural crops have unique crop calendars in each geographic region. To measure specific agricultural variables it is necessary to acquire remotely sensed data at critical dates in the phenological cycle. Analysis of multiple-date imagery provides information on how the variables are changing through time. Multi-date satellite images are also used to detect change in forest cover. (http://rsgislearn.blogspot.in/2007/05/index.html)

Spectral Reflectance

Electromagnetic energy reaching the earth's surface from the Sun is reflected, transmitted or absorbed. A basic assumption made in remote sensing is that specific targets (soils of differed types, water with varying degrees of impurities, rocks of differing lithologies, or vegetation of various species) have an individual and characteristic manner of interacting with incident radiation that is described by the spectral response of that target.

The spectral response of a target also depends upon such factors as the orientation of the Sun, the height of the Sun in the sky (solar elevation angle), direction in which the sensor is pointing relative to nadir (the look angle), the topogaphic position of the target in terms of slope orientation, the state of health of vegetation if that is the target, and the state of the atmosphere. The spectral reflectance curve is affected by factors such as soil nutrient status, the growth stage of the vegetation, the colour of the soil (which may be affected by recent weather conditions). In some instances, the nature of the interaction between incident radiation and earth's surface materials will vary from time to time during the year, such as might be expected in the case of vegetation as it develops from the leafing stage, through growth to maturity and, finally to senescence. The term 'spectral signature' is sometimes used to describe the spectral response curve for a target. The earth surface materials that are considered here are vegetation, soil, bare rock and water. In principle, a material can be identified from its spectral reflectance signature if the sensing system has sufficient spectral resolution to distinguish its spectrum from those of other materials.

Spectral Reflectance of Common Land Covers

Vegetation has a unique spectral signature which enables it to be distinguished readily from other types of land cover in an optical/near-infrared image. The reflectance is low in both the blue and red regions of the spectrum, due to absorption by chlorophyll for photosynthesis. It has a peak at the green region. 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 identified by the high NIR but generally low visible reflectance. This property has been used in early reconnaissance missions during war times for "camouflage detection". The reflectance of bare soil generally depends on its composition. In the spectral reflectance curves shown in Fig. 1, the reflectance increases with increasing wavelength. The reflectance of clear water is generally low. However, the reflectance is maximum at the blue end of the spectrum and decreases as wavelength increases. Hence, clear water appears dark-bluish. Turbid water has some sediment suspension which increases the reflectance in the red end of the spectrum, accounting for its brownish appearance.

Hyperspectral Remote Sensing

Remote sensing techniques are changing very fast and undergoing a lot of advancements. Hyperspectral Remote Sensing is one of these techniques proving worth for various studies like environment, agriculture geology etc. Hyperspectral remote sensing involves acquisition of the digital images in many, narrow, contiguous spectral bands throughout the visible, Near Infrared (NIR) , Mid-Infrared (MIR) and Thermal Infrared (TIR) regions of the electromagnetic spectrum. Higher spectral resolution enables hyperspectral remote sensing instruments capable of detailed identification of material, geological features and vegetation at finer level, which is not possible with conventional multispectral remote sensors.

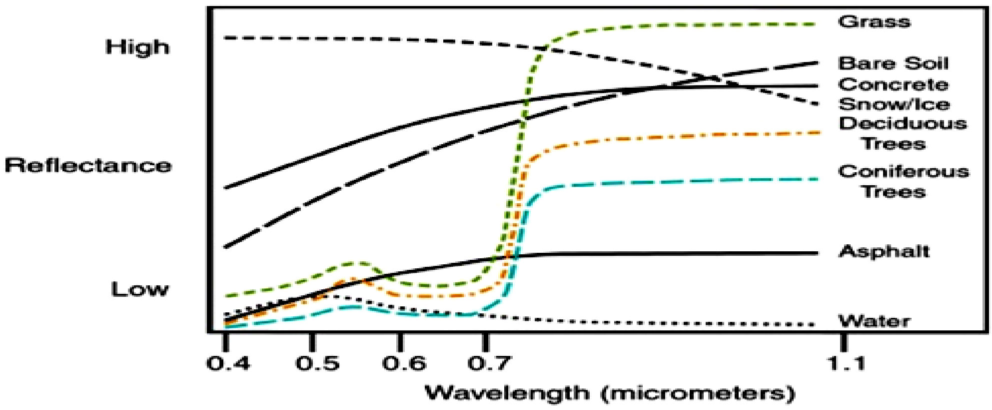


Figure 1: Spectral Reflectance Curve of Common Landcovers

AVIRIS	**Airborne Visible Infrared Imaging Spectrometer**	AVIRIS acquires images in 224 spectral bands which are 9.6 nm wide. The range of these bands is in between 400nm to 2500 nmregion of electromagnetic spectrum.
CASI	**Compact Airborne Spectrographic Imager**	This imaging spectrometer collects data in 288 bands in the range between 400nm to 1000nm. The spectral interval of each band is 1.8nm.
HYMAP	**Hyperspectral Mapping System**	It is an across-track hyperspectral imaging instrument. It collects data in 128 bands in the range of 400-2500nm.
MODIS	**Moderate Resolution Imaging Spectrometer**	This hyperspectral imaging sensor is one of the sensors on TERRA satellite. It acquire data in 36 spectral bands and its spatial resolution ranges between 250m to 1 km (to be precise- Band 1 & 2 : 250m x 250m, Band 3 to 7 : 500m x 500m and Band 8 to 36 : 1km x 1km.)

LECTURE-VI: GEOREFERENCING AND DIGITAL IMAGE PROCESSING OF SATELLITE IMAGERY

T.R. Nayak
Scientist-D & Head, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology WALMI CAMPUS Kolar Road Bhopal (M.P.)
E-mail: tejramn@yahoo.com

Digital Satellite Images

Satellite images are used in two forms – analogue and digital. Analogue images are popularly known as hard copy images. Digital images are made up of tiny picture elements known as 'pixels'. These images are like matrices which are divided into rows and columns.

Digital Numbers

It is obvious from their name that digital images have something to do with digits (or number). In fact these images are numerical representation of the features observed by a remote sensing device. It means every pixel must have some number or value to represent itself. These values are called as pixel values or digital numbers (DN). Digital number of a pixel depends upon the reflectance of a feature recorded by a sensor. Not necessarily a pixel has reflectance of a single object; it may be aggregate of many features 'falling' in that pixel. Suppose we are interpreting a satellite image acquired by IRS-1D LISS III sensor. Its single pixel represents 23.5m x 23.5m of ground area; within this area a pixel may contain composite reflectance of a road, some road side trees and a building close to it.

Image Processing and Analysis

Many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images. The choice of specific techniques or algorithms to use depends on the goals of each individual project. In this section, we will examine some procedures commonly used in analysing/interpreting remote sensing images.

Pre-Processing

Prior to data analysis, initial processing on the raw data is usually carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Depending on the user's requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include **radiometric correction** to correct for uneven sensor response over the whole image and **geometric correction** to correct for geometric distortion due to Earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if accurate geographical location of an area on the image needs to be known, ground control points (GCP's) are used to register the image to a precise map **(geo-referencing).**

Image Enhancement

In order to aid visual interpretation, visual appearance of the objects in the image can be improved by **image enhancement** techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges. An example of an enhancement procedure is shown here.

Image Classification

Different landcover types in an image can be discriminated using some image classification algorithms using spectral features, i.e. the brightness and "color" information contained in each pixel. The classification procedures can be "supervised" or "unsupervised". In supervised classification, the spectral features of some areas of known landcover types are extracted from the image. These areas are known as the "training areas". Every pixel in the whole image is then classified as belonging to one of the classes depending on how close its spectral features are to the spectral features of the training areas.

Unsupervised Classification

In unsupervised classification, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a landcover type by the analyst. Each class of landcover is referred to as a "theme"and the product of classification is known as a "thematicmap". The following Fig. 1 shows an example of a thematic map derived from the multispectral SPOT image of the test area shown in a previous section using an unsupervised classification algorithm.

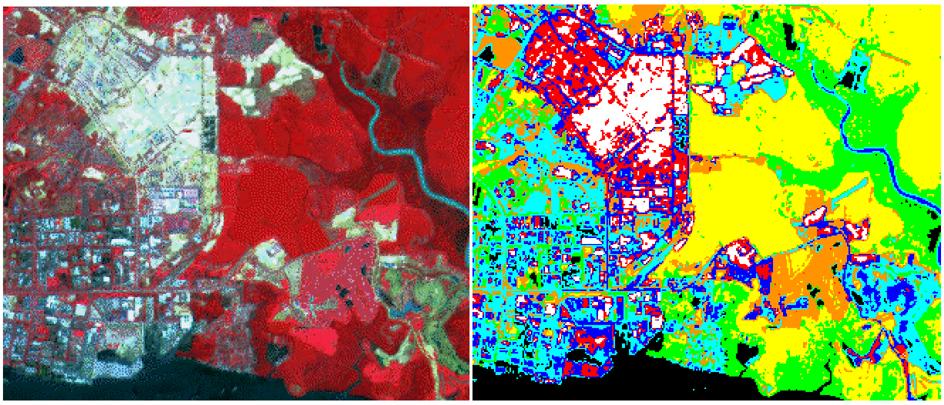


Figure 1: Thematic map derived from the SPOT image using an unsupervised classification.

A plausible assignment of landcover types to the thematic classes is shown in the following table.

Unsupervised Classification in Eight Clusters

Class No. (Colour in Map)	Landcover Type
1 (black)	Clear water
2 (green)	Dense Forest with closed canopy
3 (yellow)	Shrubs, Less dense forest
4 (orange)	Grass
5 (cyan)	Bare soil, built-up areas
6 (blue)	Turbid water, bare soil, built-up areas
7 (red)	bare soil, built-up areas
8 (white)	bare soil, built-up areas

Supervised Classification

With supervised classification, we identify examples of the Information classes (i.e., land cover type) of interest in the image. These are called"training sites". The image processing software system is then used to develop a statistical characterization of the reflectance for each information class. This stage is often called "signature analysis" and may involve developing a characterization as simple as the mean or the rage of reflectance on each bands, or as complex as detailed analyses of the mean, variances and covariance over all bands. Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectance for each pixel and making a decision about which of the signatures it resembles most. Various steps involved in supervised classification of a multispectral satellite image is shown in Fig.2. (http://www.crisp.nus.edu.sg/~research/tutorial/process.htm),http://www.sc.chula.ac.th/courseware/2309507/Lecture/remote18.htm)

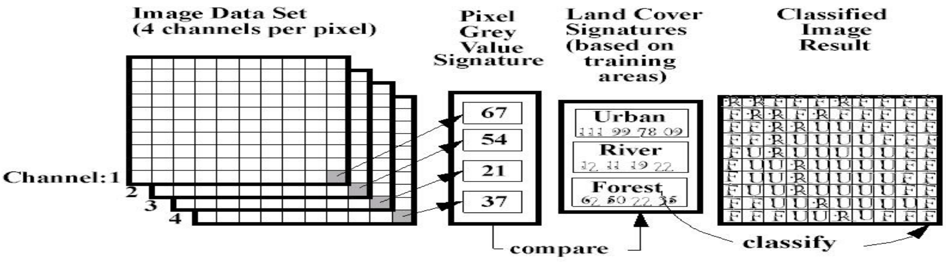


Figure 2: Steps in Supervised classification

Maximum likelihood Classification

Maximum likelihood Classification is a statistical decision criterion to assist in the classification of overlapping signatures; pixels are assigned to the class of highest probability. The maximum likelihood classifier is considered to give more accurate results than parallelepiped classification however it is much slower due to extra computations. We put the word `accurate' in quotes because this assumes that classes in the input data have a Gaussian distribution and that signatures were well selected; this is not always a safe assumption.

Minimum distance Classification

Minimum distance classifies image data on a database file using a set of 256 possible class signature segments as specified by signature parameter. Each segment specified in signature, for example, stores signature data pertaining to a particular class. Only the mean vector in each class signature segment is used. Other data, such as standard deviations and covariance matrices, are ignored (though the maximum likelihood classifier uses this). The result of the classification is a theme map directed to a specified database image channel. A theme map encodes each class with a unique gray level. The gray-level value used to encode a class is specified when the class signature is created. If the theme map is later transferred to the display, then a pseudo-color table should be loaded so that each class is represented by a different color.

Parallelepiped Classification

The parallelepiped classifier uses the class limits and stored in each class signature to determine if a given pixel falls within the class or not. The class limits specify the dimensions (in standard deviation units) of each side of a parallelepiped surrounding the mean of the class in feature space. If the pixel falls inside the parallelepiped, it is assigned to the class. However, if the pixel falls within more than one class, it is put in the overlap class (code 255). If the pixel does not fall inside any class, it is assigned to the null class (code 0). The parallelepiped classifier is typically used when speed is required. The drawback is (in many cases) poor accuracy and a large number of pixels classified as ties (or overlap, class 255).

Spectral Vegetation Indices (SVIs)

A spectral vegetation index (SVI) is generated by combining data from multiple spectral bands into a single value. Usually simple algebraic formulations, SVIs are designed to enhance the vegetation signal in remotely sensed data and provide an approximate measure of live, green vegetation amount. The rationale for spectral vegetation indices (SVIs) is to exploit the unique spectral signature of green vegetation as compared to spectral signatures of other earth materials. Green leaves have a distinct spectral reflectance pattern in the visible (vis) and near-infrared (nir) wavelengths. Reflectances in the blue and red regions are very low, with a slightly higher bump in the green. This is why leaves appear green to human eyes. In the near-infrared (nir), the spectral response of green leaves is much greater than in any portion of the visible. Other materials such as bare soil, sand, exposed rock, concrete, or asphalt, generally show a steady rise in reflectance (with no dramatic jumps) as wavelength increases from the visible to the near-infrared. Two widely used SVIs are the Simple Ratio or SR (sometimes referred to as the RVI or ratio vegetation index) and the Normalized Difference Vegetation Index, or NDVI.

Simple Ratio or Ratio Vegetation Index (SR or RVI)

The simple ratio vegetation index (termed SR or RVI) is calculated using the following formula.

SR or RVI = NIR / RED

Or, if no red band is available,

SR or RVI = NIR / VIS

where NIR and RED (or VIS) are the response in the respective bands.

Normalized Difference Vegetation Index (NDVI)

NDVI is calculated as follows:

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

or, if no red band is available,

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

In the NDVI, the difference between the near-infrared and red (or visible) reflectances is divided by their sum. This normalization is used to minimize the effects of variable irradiance (illumination) levels. Unlike the unbounded Simple Ratio, the NDVI has a range limited to a value from -1 to 1. Data from vegetated areas will yield positive values for the NDVI due to high near-infrared and low red or visible reflectance. As the amount of green vegetation increases in a pixel (picture element), DVI increases in value up to nearly 1. In contrast, bare soil and rocks generally show similar reflectance in the near-infrared and red or visible, generating positive but lower NDVI values close to 0. The red or visible reflectance of water, clouds, and snow are larger than their near-infrared reflectance, so scenes containing these materials produce negative NDVIs.

LECTURE VII: GLOBAL POSITIONING SYSTEM (GPS)

T.R. Nayak
Scientist-D & Head, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology WALMI CAMPUS Kolar Road Bhopal (M.P.)
E-mail: tejramn@yahoo.com

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS.

Requiring a minimum of 4 satellites, three for 3D position and one to keep track of time information to minimize certain types of errors, GPS is the most advanced real time positioning technique based on transmitting a coded satellite message, which could be received by a ground portable receiving unit (receiver) consisting of antenna (radio receiving unit mounted on tripod), power supply source (battery), oscillator (usually quartz crystal), internal clock, and minicomputer.

Background of GPS Evolution

- The US Air Force (USAF) conducted concept studies for a 3-dimensional navigation system called 621B which provided three dimensional (latitude, longitude, and altitude) navigation with continuous service. In April 1973, the Deputy Secretary of Defense designated the Air Force as the lead agency to consolidate the various satellite navigation concepts into a single comprehensive DoD system to be known as the Defense Navigation Satellite System (DNSS).
- By September 1973, a compromise system was conceptualized which combined the best features of earlier Navy and Air Force programs and was called **Nav**igation **S**atellite **T**iming **a**nd **R**anging Global Positioning System or NAVSTAR GPS . The signal structure and frequencies were taken from the Air Force's 621B. Satellite orbits were based on those proposed for the Navy's Timation system, but higher in altitude, giving twelve-hour instead of eight-hour periods.
- Thus NAVSTAR can be expressed as a combination of two systems as: NAVSTAR = USN TIMATION + USAF 621B
- Popularly known as the Global Positioning System (GPS), the system was designed to take over from existing navigation systems.
- NAVSTAR GPS is a satellite-based, radio based, radio-positioning and time positioning and time-transfer system, designed, financed, deployed and operated by the US DoD.

- Developed by the US DoD, GPS is first and foremost a defense military system for providing worldwide coverage at all time and all places with a low end user cost and a navigation position accuracy of 10-20 m.
- The first test signals from space were transmitted from the Navigation Test Satellite 2, launched in June 1977. The first NAVSTAR satellite was launched in 1978. The system was declared to have the full operational capability (FOC) in 1993.

The Satellite Age

Some characteristics of the satellite age are as follows:

- Overcoming the limitations of radio navigation
- Improved radio transmitters
- Wider coverage: due to high altitudes of Satellite's orbit
- The accuracy in computing the position depends on the accuracy in computing the location of reference points (satellites)
- Continuously monitoring of satellite locations and their orbits
- 24 hr, all weather, 3-D positioning

Historical development in satellite positioning

- High Ranging (HIRAN) system was developed during World war II.
- Inertial Survey System (ISS) was developed, which requireed vehicle (truck or helicopter) to occupy a point of known coordinates (X, Y, Z) and remain stationary for zero velocity update.
- Concept of satellite position fixing was tested with the launch of the first Sputnik satellite by USSR in October 1957.
- US Navy developed the Navy Navigation Satellite System (NNSS) in 1967, which is commonly known as the Transit system.
- In mid 1980's US Department of Defense (DoD) began to implement a second generation, satellite positioning system known as NAVSTAR (Navigation System with Time and Ranging), commonly called the Global Positioning System (GPS) which has become fully operational since January 1994.
- Russian GLONASS (Global Navigation Satellite System) similar to GPS and comprises 24 satellites in three orbital planes.
- European Commission is developing its own Global Navigation Satellite System (GNSS) called GALILEO.

Examples of various satellite navigation systems

- Transit developed by US navy

- TIMATION developed by US navy
- NAVSTAR GPS by the DoD USA
- GLONASS by the Russian Federation
- PARUS (TSIKADA-M) and TSIKADA
- GEO-IK
- GALELIO by European countries
- SECOR (Sequential Collation of Range) by US army

NAVSTAR GPS Segments

- 28 Active Satellites (Current deployment)
- 6 Orbital Planes inclined at 55 degrees
- 12 hour orbital period
- 20,000 kilometers high
- 24 hour 3D coverage worldwide

GPS system comprises of three major segments:

- Space Segment
- Control Segment
- User Segment

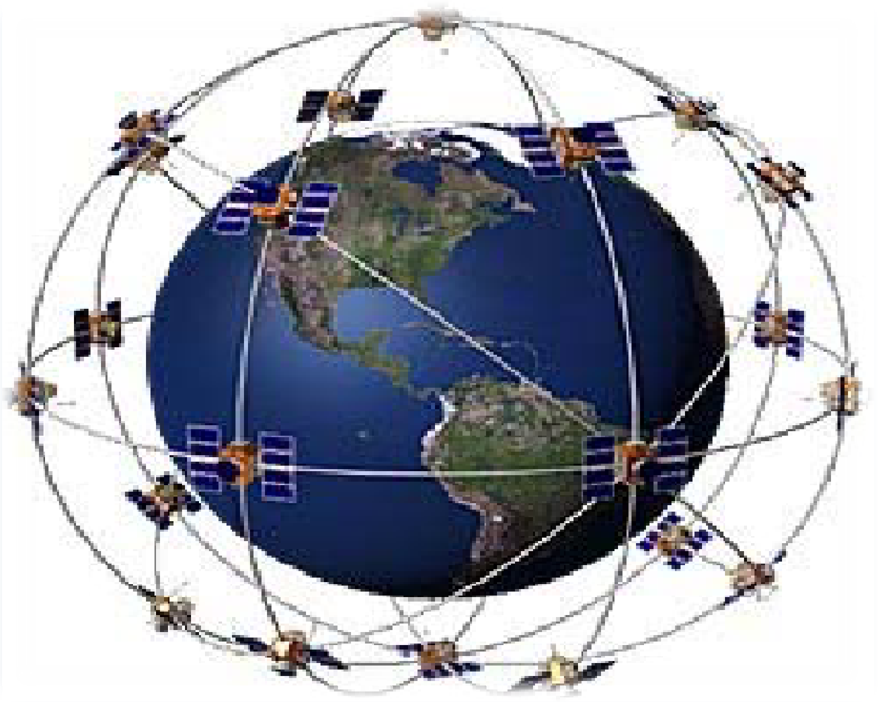


Figure 1: NAVSTAR Satellite Orbiting in Space

Space Segment

Constitutes satellite constellation which downlinks data including coded ranging signals, position information, atmospheric data, and almanac (data about approximate orbit information of all satellites).

Basic functions of satellites include:

- Receive and store information transmitted by the control station
- Perform limited data processing by its own computer
- Maintain very accurate time by means of onboard oscillators
- Transmit information to the user by the signal message
- Maneuver to position in space controlled by the control segment

Control Segment

- This segment is responsible for operating the GPS with the primary function to update navigational message of the satellites. It estimates
    - Parameters describing the satellites' orbit and clock performance
    - Health status of the satellites
    - Requirement for any repositioning of satellites.
- It consists of a network of Master Contro Station (MCS), Tracking or Monitoring Stations, and Transmitting Stations (Figure 5.3). MCS (also known as the Consolidated Satellite Operations Center - CSOC) is located near Colorado Springs, Colorado.
- MCS can implement a controlling methodology referred to as Selective Availability (SA) to limit civilian access to the system's full capabilities that involves introducing slowly varying time errors by dithering the satellite clock and by altering the navigational message (the satellite orbital data). However, from 1 May 2000, SA was switched off.
- Monitoring stations located at Kwajalein, Diego Garcia, Ascension, Hawaii, and Colorado Springs continuously tracks the satellites in view and acts as eyes and ears of the segment. These stations measure range data to satellites which is smoothed using ionospheric and meteorological information before 15 minute normal points are generated and transmitted to the MCS.
- Computations are carried out at MCS using this information and an up-to-date navigation message is uploaded to the satellites several times per day per satellite via uplink or transmitting stations located at the Ascension Island, Diego Garcia and Kwajalein.

User Segment

- Consists of GPS receiver units with capability to obtain real time positioning.

- GPS receivers are hand-held radio-receivers/computers which measure the time that the radio signal takes to travel from a GPS satellite until it arrives at the GPS antenna.
- Using the travel time multiplied by the speed of light provides a calculation of range to each satellite in view. From this and additional information on the satellites orbit and velocity, the internal GPS receiver software calculates its position through a process of resection.

Applications of GPS

GPS has a variety of applications on land, at sea and in the air. Basically, GPS is usable everywhere except where it's impossible to receive the signal such as inside most buildings, in caves and other subterranean locations, and underwater. The most common airborne applications are for navigation by general aviation and commercial aircraft. At sea, GPS is also typically used for navigation by recreational boaters, commercial fishermen, and professional mariners. Land-based applications are more diverse. The scientific community uses GPS for its precision timing capability and position information. Surveyors use GPS for an increasing portion of their work. GPS offers cost savings by drastically reducing setup time at the survey site and providing incredible accuracy. Basic survey units, costing thousands of dollars, can offer accuracies down to one meter. More expensive systems are available that can provide accuracies to within a centimeter.

Recreational uses of GPS are almost as varied as the number of recreational sports available. GPS is popular among hikers, hunters, snowmobilers, mountain bikers, and cross-country skiers, just to name a few. Anyone who needs to keep track of where he or she is, to find his or her way to a specified location, or know what direction and how fast he or she is going can utilize the benefits of the global positioning system.

GPS is now commonplace in automobiles as well. Some basic systems are in place and provide emergency roadside assistance at the push of a button (by transmitting your current position to a dispatch center). More sophisticated systems that show your position on a street map are also available. Currently these systems allow a driver to keep track of where he or she is and suggest the best route to follow to reach a designated location.

Advantages of GPS

- Unlike conventional surveying procedures, there is no need for intervisibility between stations.
- Independent of weather conditions as a result of using radio frequencies to transmit the signals.
- Use of same field and data reduction procedures results in position accuracy which are independent of network shape or geometry and are primarily a function of inter-station distance.
- GPS surveying provides generally homogeneous accuracy. Hence, geodetic network planning in the classical sense is no longer relevant. The points can be established wherever they are

required and need not be located at evenly distributed sites atop mountains to satisfy inter-visibility, or network geometry criteria.

- GPS surveying is more efficient, more flexible and less time consuming positioning technique than using conventional terrestrial survey technologies.
- GPS can be used to obtain high accuracy three dimensional (3D) information, anywhere and anytime with relatively little effort on a global datum.
- The GPS instrumentation and the data processing software do not radically change even if very high or moderately high accuracies are required (from 1 part in 10^4 to 1 part in 10^6).

Current Limitations of GPS

- GPS requires that there is clear opening to sky without any obstruction to the signals by overhanging branches or structures (though the antenna can be raised above the obstruction). Hence, underground usage is not possible. Further, there may be limited applications in densely settled urban areas.
- One needs careful advanced planning to realize true potential of GPS. Various issues related to transportation, travel, and logistic support need to be sorted out before actual survey work for higher efficiency.
- Frequently, GPS surveyed sites may not be useful for conventional surveys due to inter-visibility, shape and geometry requirements.
- Two inter-visible stations would have to be established by GPS in order to satisfy the requirement for azimuth data for use by conventional (line-of-sight) survey methods.
- Since GPS coordinates are available in global WGS-84 datum, reliable coordinate transformation schemes are required for transforming GPS coordinates into a local geodetic system for their integration with results from conventional surveys.
- GPS results are, in general, more accurate than the surrounding control marks established by terrestrial techniques over time. Comparison of GPS and terrestrial results will be the source of confusion, controversy and conflict for many years to come .
- Since GPS vertical information is not available in universally acceptable geoid based height system, GPS heights have to be reduced to a sea level datum by suitable transformation.
- The GPS instrumentation is still comparatively expensive. Although the price of one receiver is likely to soon match that of a theodolite-EDM instrument, generally a minimum of two are required for most survey works.
- Because of complex procedures for planning, data reduction and post-processing, GPS surveys require skilled personnel for operations.

LECTURE VIII- GENERATION OF VECTOR MAPS, RASTER MAPS AND LAYOUT

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

The data in GIS can be stored in raster or vector formats and these data can be linked with tabular information. In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different geographical features are expressed by different types of geometry in following vector formats.

- Points

  Zero-dimensional points are used for geographical features that can best be expressed by a single point reference—in other words, by simple location. Examples include wells, peaks, features of interest, and trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world might be represented by points rather than polygons. No measurements are possible with point features.

- Lines or poly lines

  One-dimensional lines or poly lines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

- Polygons

  Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

A raster data type is, in essence, any type of digital image represented by reducible and enlargeable grids. Raster data type consists of rows and columns of cells, with each cell storing a single value. Raster data can be images (raster images) with each pixel (or cell) containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, color maps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units. The representation of vector and raster format is given in Fig. 1.

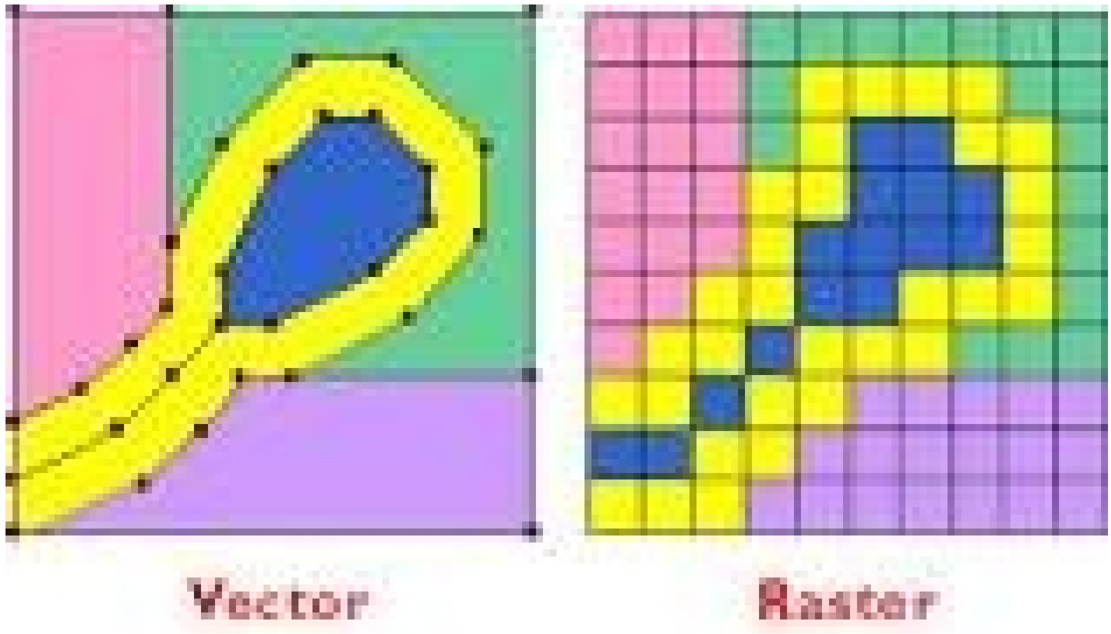


Fig. 1: Vector and Raster formats

Comparison of Raster and Vector Data

- Raster datasets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed.
- Raster data is computationally less expensive to render than vector graphics
- There are transparency and aliasing problems when overlaying multiple stacked pieces of raster images
- Vector data allows for visually smooth and easy implementation of overlay operations, especially in terms of graphics and shape-driven information like maps, routes and custom fonts, which are more difficult with raster data.
- Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. (depending on the resolution of the raster file)
- Vector data can be easier to register, scale, and re-project, which can simplify combining vector layers from different sources.
- Vector data is more compatible with relational database environments, where they can be part of a relational table as a normal column and processed using a multitude of operators.

- Vector file sizes are usually smaller than raster data, which can be tens, hundreds or more times larger than vector data (depending on resolution).
- Vector data is simpler to update and maintain, whereas a raster image will have to be completely reproduced. (Example: a new road is added).
- Vector data allows much more analysis capability, especially for "networks" such as roads, power, rail, telecommunications, etc. (Examples: Best route, largest port, airfields connected to two-lane highways). Raster data will not have all the characteristics of the features it displays.

Generation of Polygon Map from Toposheet

Step 1: Create segment map

- Create a segment map with new name. Here we give name “watershed” with same coordinator as toposheet has. The domain should be as per the requirement. In case of generation watershed boundary, domain as “class” can be used while for contour map, the domain as “value” with upper and lower limit and interval can be assigned.
- Go to Edit tab in Map window and edit the newly created map “watershed”. Before start digitizing, Go to Customize Tab and press enter
- A new window will come where you can change several options for digitizing. Important options are “Snap Tolerance” and “Tunnel Tolerance” which affect the number on nodes in digitization (Fig. 2).
- Add toposheet in map window. The toposheet should be georeferenced as shown in earlier lecture.
- Select Pencil and digitize the segments to form polygon. Care should be taken during digitization, when a segment join to other segment, “Split Segment Tab” will appear and press OK to create node which is essential for creating polygon map.

Step 2: Check the segment map

- In Edit mode, From Map Window select File and Go to Check Segment where at least first three steps need to be followed one by one. These steps are Self Overlap, Dead Ends and Intersection. These steps make the segment map ready for converting polygon map (Fig. 3).
- First go to File and select Self Overlap and press enter. The software will analyze the segment map and if any error indicated if segments overlap.
- After checking Self Overlap, go to File and select Dead Ends and enter. The software will analyze the segment map and any node is not connected with others. It will be indicated in map window that needs to be corrected.

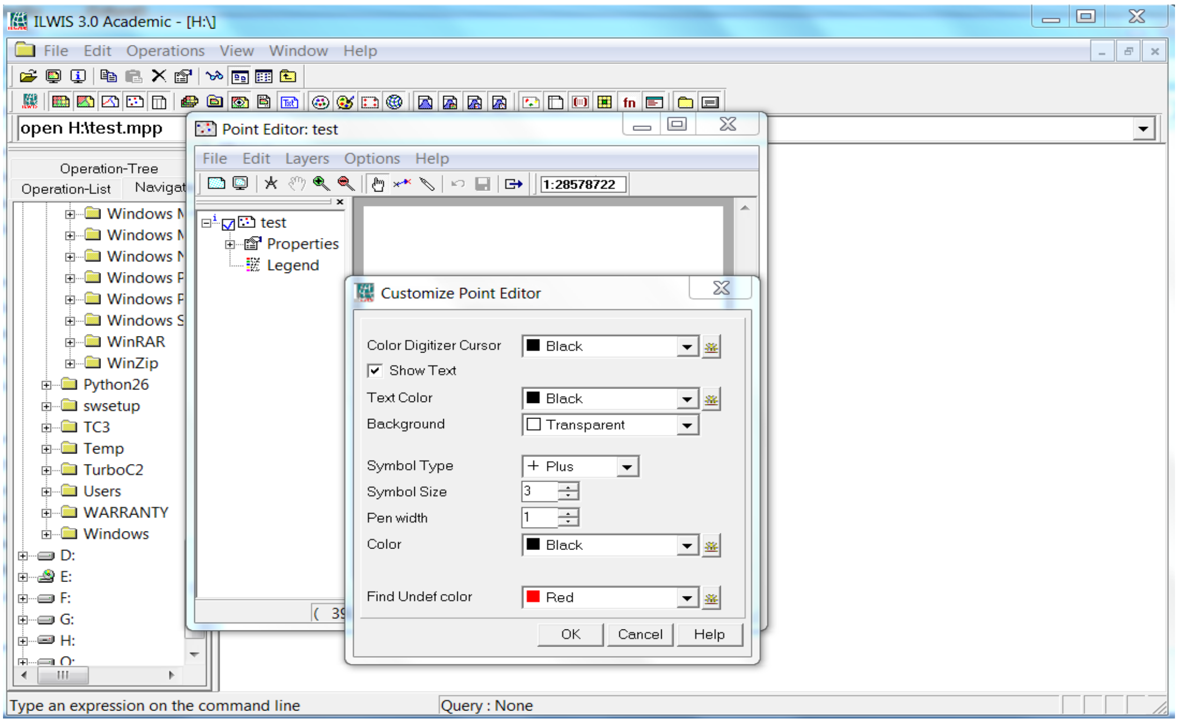


Fig. 2: Customization in ILWIS for setting up tolerance in ILWIS

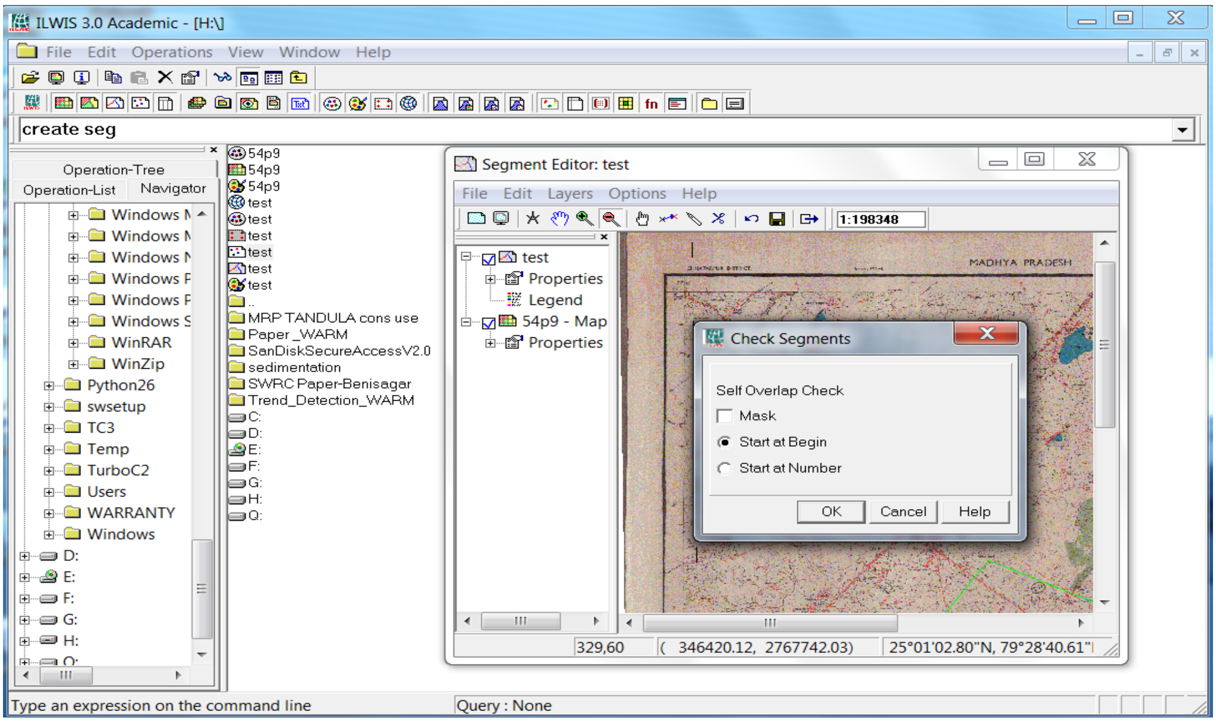


Fig. 3: Checking Segment map for self overlap in ILWIS

- After correcting the map for Dead Ends, go to File and select Intersection. The software will analyze the map and if there is any error for intersection, the errors will be shown in Map Window that should be corrected before go for polygonization.

Step 2: Polygonization of Segment map

- After checking the map for Self Overlap, Dead Ends and Intersection, go to File in Map Window and select Polygonize and press enter.
- A new Window will appear where either earlier created domain need to be selected or a new domain can be created. A new name of Polygon map needs to be given. Here we will give the name “watershed” for new polygon map.
- If there is no error in segment map, a new window will appear where polygon map will be displayed where using types given in domain or by creating new type in domain, each polygon can be classified (Fig. 4).

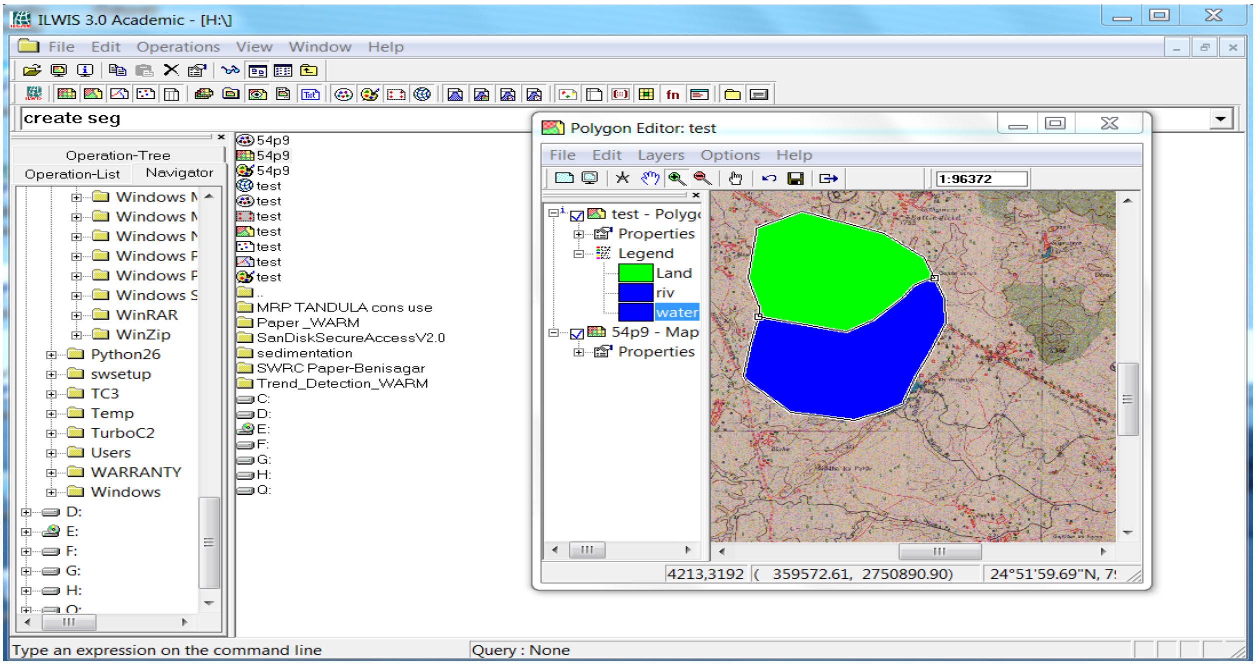


Fig.4: Polygon Editor in ILWIS

Creation of Layout

A layout is required to print maps with annotation. A layout is a virtual sheet of paper on which you can make a composition of one or more map views, specify the scale on which these map views should be printed, and on which you can insert annotation. In the layout editor, you can add to a layout:

- one or more map views, each of which may include one raster map and/or one or more point maps, segment maps and/or polygon maps, annotation text layers, grid lines and/or graticules;
- texts such a titles;
- boxes;
- pictures and/or bitmaps;
- a page border.

For each map view, you can add to the layout:

- a legend for a layer in a map view;
- a map border, including coordinates and ticks for grid lines and/or a graticule;
- a North arrow;
- a scale bar and scale text.

Steps to create a Layout

- First open the segment or raster map in Map Window, save the map as new map view. Here after opening “watershed” polygon map, we save it as “watershed” map view.
- In the Main window, choose the Create Layout command from the File menu ---Go to Create Layout and press enter.
- A new window will appear where you have to give scale for the map and map will be displayed in Layout window
- In the Layout Window, the legends, north arrow, scale, border, text etc. can be given.
- The Layout generated can be exported as bit map or jpg or other formats (Fig. 5).

Conversion from Polygon, Point or Segment Map to Raster Map

A raster map is a data object used to store spatial geographic information and remote sensing data as pixels (picture elements) of a certain size, e.g. 20 x 20 m. These pixels are either codified by IDs, class names, values or colors; this is determined by the domain of the map. The relation between pixels in a raster map and the position on earth is defined by the georeference that the raster map is using. Raster maps can be displayed in a map window, and can be edited with the pixel editor.

Various calculations can be performed with raster maps (MapCalc) and you can perform many other raster and image processing operations on them such as: Filter, Cross, Distance calculation, etc. In ILWIS, most spatial operations are performed on raster maps. Various operation in ILWIS are generally carried out in raster map, hence it is necessary to convert a polygon map, point map or segment map to raster map.

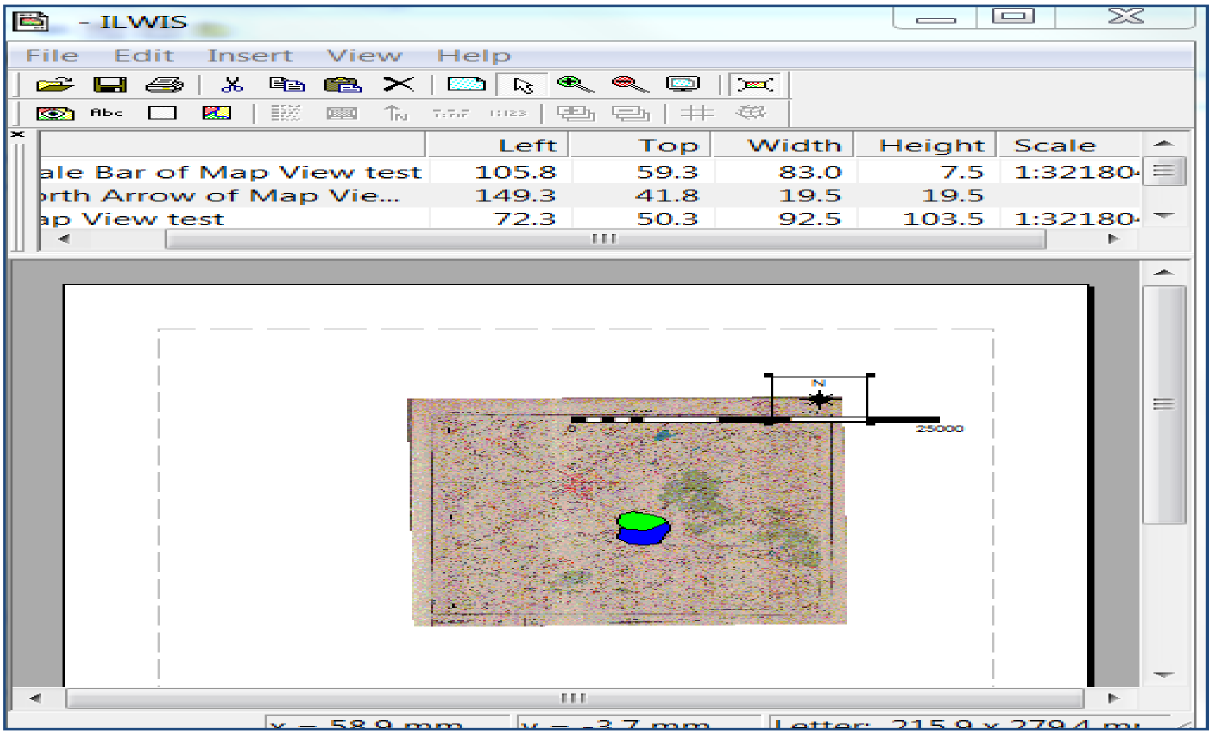


Fig. 5: Layout display in ILWIS

Steps to convert a polygon or point or segment map to raster map

- From main menu, go to Operation and select Rasterize and then select any one of the following as per input data. Here, we do exercise with a polygon map “watershed”.
    - If input map is a polygon map ----- Select Polygon to Raster
    - If input map is a segment map ----- Select Segment to Raster
    - If input map is a point map --------- Select Point to Raster
- A new Window will appear in which name of input file and output file need to be mentioned. We give the name for output file is “watershed”.
- First time we have to create a georeference on the basis of coordinate system of input file. Here, we to click a radio button for creating new georeference and give name “watershed” (Fig. 6).
- Here, this point should be kept in mind that for a study or analysis, all the raster maps should have same georeference.
- After assigning input, output and georeference name, the processor of ILWIS start converting the Polygon map to Raster map (Fig. 7).

- Similarly, point map or segment map can be converted into raster map.
-

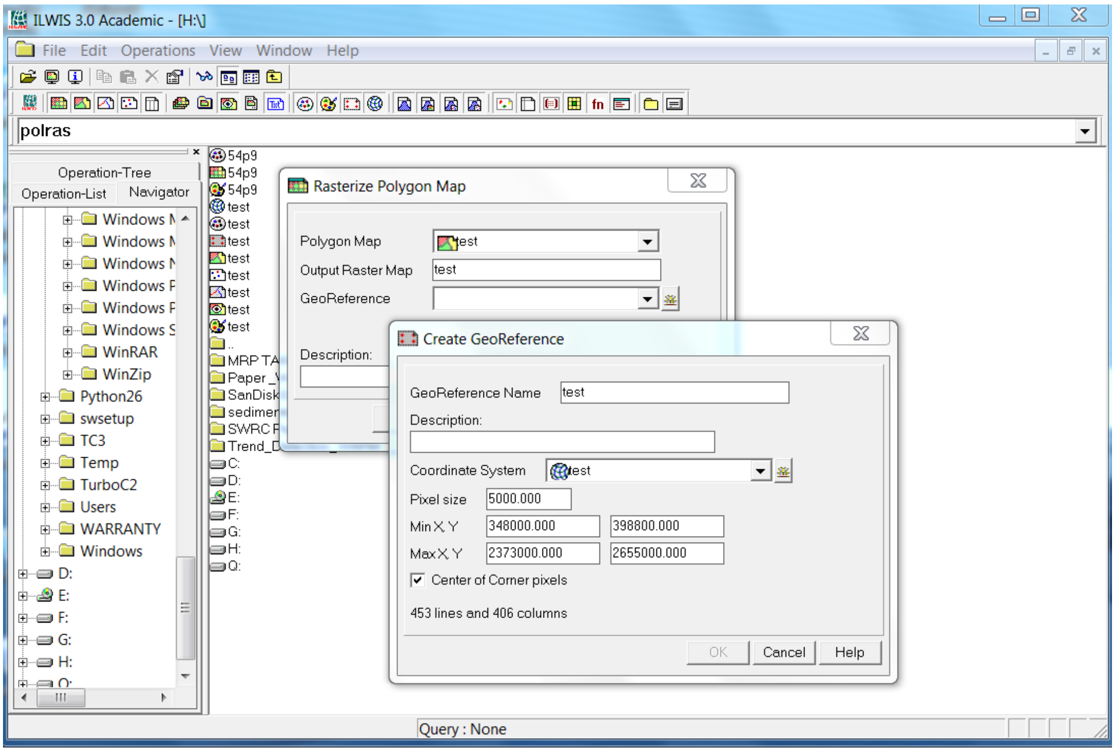


Fig. 6: Rasterization of polygon map in ILWIS

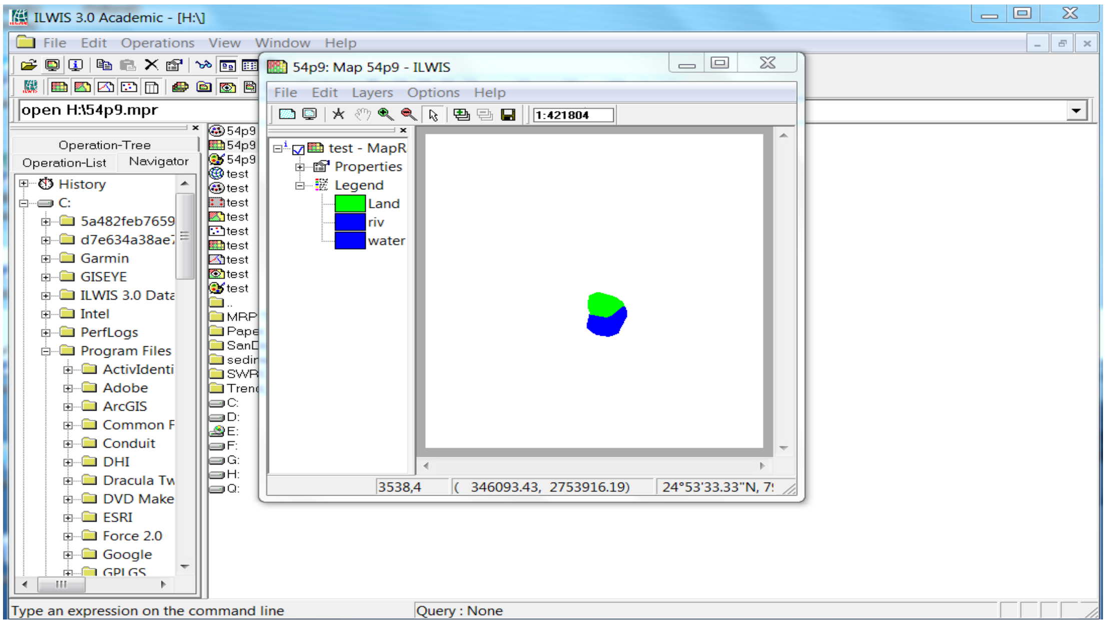


Fig. 7: Generation of Raster map in ILWIS

LECTURE IX- OPERATION WITH VECTOR AND RASTER MAPS

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

Operations in ILWIS are the most important task to carry out number of analysis for hydrological and other studies. ILWIS operations can be carried out from either Operation Menu from Main Menu or type a command in Command Window.

To start an operation:

- open the Operations menu in the Main window, and choose an operation,
- double-click an operation in the Operation-tree or the Operation-list,
- click the *right* mouse button on an operation in the Operation-tree or Operation-list, and select Run from the context-sensitive menu,
- click an input object with the *right* mouse button in the Catalog, and select an operation from the context-sensitive menu,
- drag a data object from Catalog to an operation in the Operation-tree or Operation-list, or
- type a command on the command line of the Main window

A dialog box is opened in which you can enter the input and output object names and other parameters necessary for the operation. When you click the Show or Define button in the operation's dialog box, an ILWIS expression is generated on the command line of the Main window. Output objects that are obtained through an operation's dialog box are always dependent. The commands in ILWIS may be of the following three types:

1. Open, edit, or create an object or open properties of an object.
2. Open the dialog box of an operation.
3. Data management: delete, etc.

Open, edit, create, or open properties

Several commands can be typed on the command line of the Main window to open, edit, or open the properties of an object. To open an object, it is generally faster though to double-click an object in the Catalog. To edit an object, open the properties of an object, open an object as a table or to create objects you can use context-sensitive menu in the Catalog. Open the dialog box of an operation

To obtain the dialog box of an ILWIS operation, type one of the following commands or aliases. To obtain the dialog box of an operation, you can also double-click the operation in the Operation-tree or the Operation-list, or select it from the Operations menu. Any operation which is performed through a dialog box will result in a dependent output object. Data Management

In the ILWIS, without writing command in the command editor, various operations can be performed. Here we will see the steps for some of the useful operation on segment and raster maps.

Sub Maps from a segment/ Polygon/ Raster map

- In the main menu go to Vector Operation ----Segment-----Sub Map. A window will appear where we need to give X and Y values of bottom left and upper right point and give the name of output file. After Pressing enter a new map will be displayed where sub map will be created. In case of creating sub map for polygon map, select Vector Operation then Polygon and then Mask. Here, another polygon map is required which mask out the area from big map. While in case of raster map, Raster Operation---Sub Map. A window will appear where, Input map, Output map and either of coordinates, start point and lines or corners need to be specified.

Attribute Map from Polygon Map

- For creating attribute map, first we need to create attribute table based on domain of polygon map. For this Go to File----Create----Table. A Window will appear where name of table and domain name need to be mentioned. A new Window will appear where for column can be added and some value or other information can be added for each domain elements.
- In next step go to Operation----Vector Operation----Polygon Map ----Attribute map.
- A window will appear where input polygon map, attribute table and name of column and output polygon name need to be mentioned. The output polygon map will be generated which has the value of polygon as we have mentioned in Attribute Table. The table given below specifies some of the important operation and resultant map obtained from that operation.

Table 1: Important operations in ILWIS software

Operation	Vector Operation	Polygon	Attribute Map	Create an attribute polygon map
			Mask Polygon	Selectively copy polygons from polygon map into a new polygon map
			Assign Label	Recode polygons according to label points
			Transform Polygon	Transform polygons to a new coordinate system
Operation	Vector Operation	Segment	Attribute Map	Create an attribute map
			Mask Segment	Selectively copy segments from segment map into a new segment map
			Assign Label	Recode segments according to label points

		Sub Map	Copy a part of a segment map into a new mp
		Glue Maps	Glue multiple segment maps into a new map
		Densify Coordinate	Add more intermediate points into one segment map
		Transform Segment	Transform segment into new coordinate system
		Tunneling	Reduce the number of intermediate points into the segments
Operation	Raster Operation	Map Calculation	Perform calculation with raster maps
		Attribute Map	Create an attribute map from a raster map and attribute table
		Cross	Cross two raster maps and create new cross map and/or table
		Aggregate	Aggregate a raster map
		Distance Calculation	Perform a distance calculation: create a distance map
		Iteration	Perform a map iteration: repeating the same calculation
		Area Numbering	Perform an area numbering and assign distinct code
		Sub Map	Copy a part of a raster map into a new mp
		Glue Maps	Glue two raster maps into a new map
		Mirror/Rotate	Mirror or rotate a raster map
Operation	Rasterize	Polygon to Raster	Rasterize a polygon map
		Segment to Raster	Rasterize a segment map
		Segment Density	Calculate the segment length in every pixel of a Rasterize segment map
		Point to Raster	Rasterize a point map
		Point Density	Count the number of points per pixel and return a raster map
Operation	Density Raster Map		Reduce the pixel size of a raster map interpolation
	Kriging from Raster		Perform an ordinary Kriging on a raster map
	Contour Interpolation		Perform an interpolation on contour lines and return a raster map
Operation	Point Interpolation	Nearest Point	Assign each output pixel the code of the nearest point in output raster map
		Moving Average	Perform moving average interpolation on point map of value and return a raster map
		Trend surface	Perform trend surface interpolation on point map of value and return a raster map
		Moving Surface	Perform moving surface interpolation on point map of value and return a raster map
		Kriging	Perform a kriging estimation on point map of value and return a raster map
		Anisotropic Kriging	Perform an isotropic kriging interpolation on point map of value and return a raster map
		Universal Kriging	Perform universal kriging interpolation on point map of value and return a raster map
		Cokriging	Perform cokriging on point map of value and return a raster map

LECTURE X- CONTOUR MAP, DIGITAL ELEVATION MODEL AND SLOPE MAP

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

In ILWIS, Digital Elevation Model (DEM) can be obtained by interpolation of segments, by an interpolation of points, or by an interpolation of a raster map which contains rasterized value segments and points. The toposheet has contour lines which can be digitized (Fig 1).

Fig.1: Toposheet having contours

From Segments

Digitize the contour lines of a segment map with a value domain. Make sure that contour lines that consist of more than one segment have the same value. Code consistency of segments can be checked in the Segment editor. Then perform a Contour interpolation. Contour interpolation is an operation which first rasterizes the contour lines in a segment map with a value domain, and then calculates values by means of a linear interpolation for pixels that are not covered by segments. For the Contour interpolation operation, you can also use a segment map with a class or ID domain as input and then the segment map must have an attribute table with a value column representing height values.

To create a Digital Elevation Model from Segments, following may be the steps

- Digitize contour lines in a segment map with value domain keeping toposheet in the background. Here we will generate a segment map with Segment name "Contour".
- from the Operations menu in the Main window, choose Interpolation, Contour Interpolation, or in the Operation-tree, open the Interpolation item, and double-click the InterpolSeg operation, or in the Operation-list, double-click the InterpolSeg operation.
- A new window will appear where give input segment map as "contour" and new name for output raster map as "DEM". Create a georeference with radio button.
- The output map "DEM" will have interpolated value of elevation on each pixel.

From Points

Perform a point interpolation on your point map. A point interpolation performs an interpolation on randomly distributed point values and returns regularly distributed point values. This is also known as gridding. In ILWIS, the output values are raster values.

The input map for a point interpolation is a point map where:

- points are values (point map with a value domain), or
- points are identifiers (point map with an ID domain) and for which elevation values are stored in a column in a linked attribute table.

To create a Digital Elevation Model from Points:

- From the Operations menu in the Main window, choose Interpolation, Point Interpolation, Moving Average or Moving Surface, or
- In the Operation-tree, open the Interpolation, Point Interpolation item, and double-click the MovAverage or MovSurface operation, or
- In the Operation-list, double-click the MovAverage or MovSurface operation, or in the Catalog, click a point map with the *right* mouse button, and select Interpolation, Moving Average or Moving Surface.

From Segments with additional Point data

1. Digitize the contour lines of a segment map with a value domain. Rasterize the segment map with the Segments to Raster operation:
   - o From the Operations menu in the Main window, choose Rasterize, Segment to Raster,
   - o In the Operation-tree, open the Rasterize item, and double-click the SegRas operation, or

- In the Operation-list, double-click the SegRas operation, or
- In the Catalog, click a segment map with the *right* mouse button, and select Rasterize, Segment to Raster from the context-sensitive menu.

2. Rasterizing the point data: If you have a point map with a value domain, rasterize the point map with the Points to Raster operation:
   - From the Operations menu in the Main window, choose Rasterize, Point to Raster,
   - In the Operation-tree, open the Rasterize item, and double-click the PntRas operation, or
   - In the Operation-list, double-click the PntRas operation, or
   - In the Catalog, click a point map with the *right* mouse button, and select Rasterize, Point to Raster from the context-sensitive menu.

Use the same georeference for both the rasterized segment and rasterized point map. Then, combine the two raster maps by typing the following MapCalc expression on the command line of the Main window:

pntseg = iff(isundef(*pntras*), *segras*, *pntras*)

where: *pntseg* is the output raster map name of the combined point and segment map

pntras is the name of the rasterized point map

segras is the name of the rasterized segment map

Finally, interpolate the *pntseg* raster map which contains the rasterized segments and the rasterized points. Type on the command line of the Main window:

DEM = mapinterpolcontour(*pntseg*)

Visualize a DEM

To visualize a DEM, you can simply the DEM in a map window or apply the Shadow filter on the DEM and display the filtered map in a map window; you can overlay the contour lines in one color.

Generation of Slope Map

To calculate slope maps in percentages and in degrees following steps are required.

- Create a segment map with a value domain (it is advised to create a value domain Height). Digitize the contour lines and give the contour lines the height value they represent.

- Interpolate the segment map by contour interpolation and give name as DEM
- Calculate height differences in X-direction by selecting Operation ----Image Processing ---Filter. A new window will appear.
- In new window, give the name of input raster map, filter type as Linear Filter dfdx. Call the output map for example DX.
- Calculate height difference in Y-direction by Filter operation again, select the Digital Elevation Model as input map and select linear filter dfdy. Call the output map for example DY.
- To calculate a slope map in percentages from these maps DX and DY, type on the command line of the Main window

SLOPEPCT = 100 * HYP(DX,DY)/ PIXSIZE(DEM)

HYP is an internal Mapcalc/Tabcalc function. Function PIXSIZE returns the pixel size of a raster map; for *DEM*, fill out the name of your DEM created in step 2. SLOPEPCT is the output map name of the slope map in percentages. To convert the percentage values into degrees, type:

SLOPEDEG = RADDEG(ATAN(SLOPEPCT/100))

LECTURE XI- ASSESSMENT OF SOIL LOSS FROM A WATERSHED USING GIS

R.K. Jaiswal
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
E-mail: rkjaiswal_sagar@yahoo.co.in

Introduction

Erosion and sedimentation embody the process of detachment, transportation and deposition of soil particles (ASCE, 1975). Detachment and transport are the basic processes occurring on source areas while transport and deposition take place in sink areas. Recent observations in India have brought to light the alarming fact that reservoir sedimentation, resulting from degradation of the watersheds is on manifold rise compared to the rate that was assumed at the time the projects were designed. According to information published by Ministry of Agriculture (Govt. of India) in 1980, in India as many as 175 M ha (constituting 53 percent of India's geographical area) is subject to environmental degradation. About 150 M ha has been caught in the vicious circle of erosion by water and wind, the vehicles of erosion. It is worth mentioning nature takes about 200 to 400 years to build up 1 cm of topsoil, one estimate puts the loss of top soil by water action at 12,000 M tones every year. This soil loss even at a mere price of Rs. 10 per tonne, works out to a huge loss of Rs. 12,000 crores annually.

Study Area

The Tumri watershed is situated in the Kesli block of Sagar district in Madhya Pradesh with a catchment area of 23.91 sq. km. The watershed is located between latitudes 23^o 23´ 25´´N and 23^o 27´ 05´´ N and longitude 78^o 42´ 30´´E and 78^o 46´ 39´´E and lies in the Sonar basin of the Ken river system. The index map of the study area is given in Fig. 1. River Chamak Dhol which traverses 11.50 km within the watershed is one of the main tributaries of river Sonar and joins it near Berar Veeran. The climate is semi-arid and the average annual rainfall is about 1182 mm; 90% of which occurs during the monsoon period. The topography of the Tumri watershed is highly undulating comprising of steep hills with dense forests on ridges and few barren flat top hillocks. The geology comprises of basaltic formations and boulder strewn plains are found mostly near Tumri. The watershed is degraded and red soils are mostly encountered on the hills and degraded regions whereas black soils are found in the agricultural fields which are mostly located near foot hills, valley and river banks. The watershed is rain-fed and soyabean and gram are the principal kharrif crops whereas wheat is the predominant rabi crop.

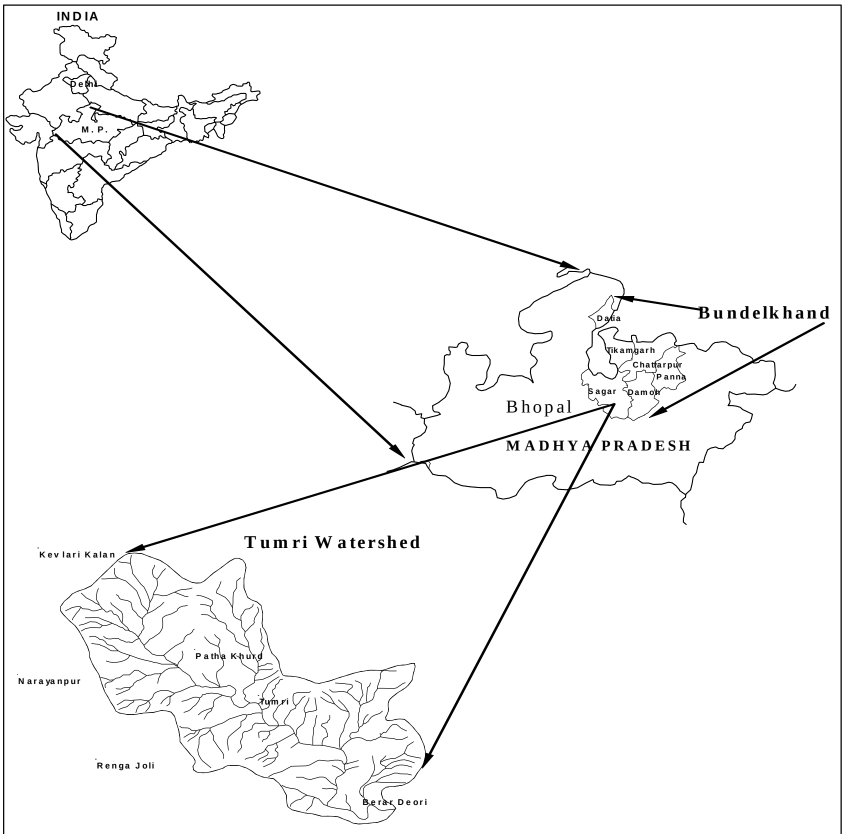


Fig 1: Index map of the Tumri watershed

Methodology

In the present study, the well-known model for soil erosion estimation from a watershed, the Universal Soil Loss Equation (USLE) has been used. The data storage and analysis was done using ILWIS3.0 Geographic Information System (GIS).

The USLE Model

The USLE model was developed by Agriculture Research Services (ARS) scientists W. Wischmeier and D. Smith (1978). The USLE states that the field soil loss in tons per hectare, A, is the product of six causative factors:

$$A = RKLSCP \qquad \ldots\ldots 1$$

where,

R = Rainfall erosivity factor, K = Soil erodibility factor ,

L = Slope length factor , S = Slope factor

C = Cropping-management factor and P = Conservation practice factor

In this equation, the R-term characterizes the level of attacking forces while the remaining terms characterize the level of resisting forces.

Rainfall erosivity factor, R

The rainfall erosivity factor implies a numerical evaluation of rainfall pattern, which describes its capacity to erode soil from an unprotected field. The most useful rainfall erosion index is one whose magnitude represents composite measurements of various rainstorm characteristics, which influence the rate of erosion (Wischmeier and Smith, 1978). In India, simple relationship between erosivity index (R) and annual or seasonal rainfall (X) has been developed by Singh et al, 1981 after analyzing the data collected from 45 stations distributed in different rainfall zones throughout the country. The relationship can be expressed by the following equations.

$$R_a = 79 + 0.363 X_a \qquad \ldots\ldots 2$$

$$R_s = 50 + 0.389 X_s \qquad \ldots\ldots 3$$

where, R_a = annual erosivity index, R_s = seasonal erosivity index

X_a = average annual rainfall (mm) and X_s = average seasonal rainfall (mm)

Soil erodibility factor, K

The soil erodibility factor, as described by Wischmeier and Smith (1965) is a function of complex interaction of a substantial number of its physical and chemical properties. For a particular soil, the erodibility factor (K) is the rate of erosion per unit of erosion index from a standard plot of 22.13 m long under continuous fallow and tilled parallel to the uniform slope of 9 %. The sandy soils are least susceptible to erosion because of its resistant to transport due to bigger particle size, hence greater force is required to entrain them, and they are also highly permeable (Holy, 1980). On the other hand, clay soils with low permeability have high contents of colloidal particles and show a high level of consistency, and due to their cohesiveness character, they are resistant to detachment. The least resistance particles are silts and fine sands.

The topographic factor, LS

Steeper slopes produce higher overland flow velocities. Longer slopes accumulate runoff from larger areas and also result in higher flow velocities. Thus, both result in increased erosion potential, but in a non-linear manner. Slope length factor (L) is the ratio of soil loss from field slope length to that from a 22.13 m long plot on the field in meters and can be expressed as:

$$L = \left(\frac{\lambda}{22.13} \right)^m \qquad \ldots\ldots 4$$

where, λ = Slope length and m = numerical constant depends on slope

The value of m for different slope percentages has been given below.

S.N.	Slope	m
1.	Less than 1%	0.2
2.	1% to 3%	0.3
3.	3% to 4.5%	0.4
4.	4.5% to 10%	0.5
5.	More than 10%	0.6

The slope factor (S) is the ratio of soil loss on actual gradient to that from 9% slope under otherwise identical conditions. The following equation suggested by Wischmeier and Smith (1965) has been used for evaluating the slope gradient factor:

$$S = \frac{\left[0.43 + 0.30s + 0.43s^2\right]}{6.613} \qquad \ldots\ldots 5$$

where, s is the slope gradient in percent.

Cropping-management factor, C

This factor is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. It measures the combined effect of vegetation cover and management variables. The vegetation cover protects the soil surface from direct impact of the falling raindrops. Meszek et al (1975) concluded that the forest with a dense canopy, good undergrowth and undisturbed litter have the most significant effect on the surface runoff and thereby on the intensity and course of erosion. Jaiswal (1982) determined the cropping management factor for different land use patterns in the Gagas sub-watershed of Upper Ramganga catchment.

Conservation practice factor, P

The conservation practice factor, P, in the Universal Soil Loss Equation is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope on agriculture land. Practices included in this term are contouring, strip cropping (alternate crops on a given slope established on the contour) and terracing. As a rule of thumb, contouring reduces to one-half the soil loss caused by up-and-down hill farming, strip cropping to one-half that of contouring, and terracing to one-half that of strip cropping. The value of P ranges from 1.0 for up and down cultivation to 0.25 for contour strip cropping of gentle slope.

Results and Analysis

The Universal Soil Loss Equation for estimation of soil erosion from a catchment area requires data on rainfall, soils, land use and cover, degree and length of slope, cropping pattern, and conservation practices adopted in the agricultural fields.

Base Map

A base map has been generated by digitizing the SOI toposheet as reference map for all other purposes. The watershed is covered by 1:50,000 scale SOI topographic maps No. 55 I/ 11 & 15. The basin boundary is digitized and stored as 'basin' map in vector format. The map was then polygonised and converted into raster format assigning the pixel size of IRS 1 C LISS-III merged with IRS 1D Pan georeferenced satellite data, i.e., 6.036 m.

R Factor

Kesli is the only rain gauge station falls nearby the watershed and data of Kesli were used. The average annual rainfall of Kesli is 1182 mm and hence the annual rainfall factor, R for the watershed is computed as 527.156.

K Factor

The soil maps of Madhya Pradesh published by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Government of India, Nagpur pertaining to the study area along with actual soil information collected from the field observations and soil profiling have been used for identification of soils in the study area. Three categories of soils falling in the study area are clayey loam, fine sandy loam and sandy soil with gravels. The organic matter (O.M.) contents in these soils are reported about 2%. The geographic area under each soil class and its K- factor has been presented in Table-1.

Table-1: Distribution of soil class and 'K' value in Tumri watershed

Soil class	Area (hectare)	Area (%)	K-Factor
Clayey loam	349.91	0.15	0.28
Fine sandy loam	1097.12	0.46	0.12
Sandy soil with gravel	944.27	0.39	0.05
Total	2391.28	100.00	

LS Factor

The contour lines and the spot height of the study area and surrounding have been digitized and a Digital Elevation Model (DEM) has been prepared using interpolation technique. The slope percentage of DEM map is then calculated. For the present study, the slope length was taken same as the pixel size, i.e. 6.036 m for the calculation of 'L' factor. The L factor map was calculated using the Equation 4 by putting the value of the slope length and value of exponent 'm' which varies from 0.20 to 0.60 for varying degree of slope percentages. The topography of the watershed is largely highly undulating with small hillocks and deep valleys at many places only. Average slope of the watershed is 13 percent with maximum value of 46 percent. The S factor map was generated using Equation 5 by putting the value of the degree of slope.

C Factor

The cropping management factor, C is based on the land use class and hence IRS 1-D, LISS-III merged with Pan geo-referenced satellite data, Path 99-Row 55 covers the entire watershed used for identification of various land uses in the study area. Six land use classes have been identified in the sub-basin based on the ground truth survey and digital classification. The land use classes include agriculture, barren, open forest, dense forests, water bodies and built up areas. For Indian conditions, Jaiswal (1982) and Singh et al (1981) suggested the values of 'C' factor based on the field experiments conducted all over the country. The land use map thus classified from satellite data is shown in Figure-2 and spatial distribution of all the six land use classes with 'C' factor is given in Table-2.

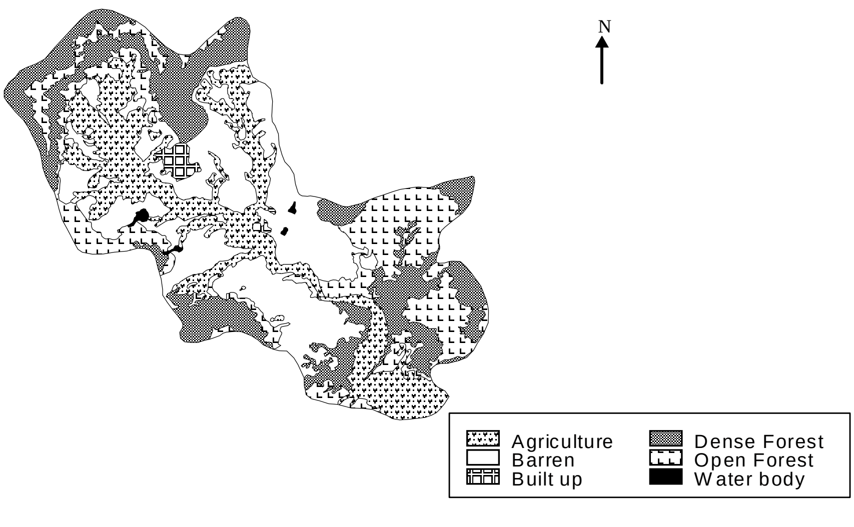


Fig. 2: Land use map of Tumri watershed

Table-2: Land use distribution Tumri watershed and 'C' factor

Land Use Class	Area (hectare)	Area (%)	'C' factor
Agriculture	540.15	22.59	0.42
Barren land	706.14	29.53	1.00
Open forest	521.90	21.83	0.09
Dense forest	587.98	24.59	0.14
Water bodies	7.23	0.30	0.009
Built up areas	27.93	1.17	0.024

P Factor

The cultivators of the study area do not adopt any specific conservation practices, therefore P factor for agriculture, barren land, built up areas and water bodies have been taken as 1.0 and for open and dense forest the value of P factor has been assigned as 0.8.

Estimation of Soil Loss

The expected soil loss in the watershed for various types of land uses is given in Table-3. The soil loss from various areas in the watershed has been classified into four classes i.e. low, moderate, high and very high. The range and area falling in each class have been presented in Table 4. The distribution of various classes in the watershed has been depicted in the Figure-3.

Table-3: Expected soil loss in Tumri watershed from various land use classes

S. No.	Land use	Area (ha)	Average R-factor	Average K-factor	Average L-factor	Average S-factor	Average C-factor	Average P-factor	Erosion (t/ha/yr)
1.	Agriculture	540.13	527.16	0.22	0.61	0.50	0.42	1.00	14.78
2.	Barren	706.12	527.16	0.16	0.56	0.73	1.00	1.00	34.56
3.	Built-up	27.92	527.16	0.26	0.53	0.75	0.02	1.00	1.30
4.	Dense forest	587.83	527.16	0.13	0.50	3.31	0.011	0.80	0.97
5.	Open forest	521.76	527.16	0.12	0.52	1.51	0.09	0.80	3.68
6.	Water bodies	7.23	527.16	0.16	0.53	0.54	0.009	1.00	0.22

Table-4: Expected Soil Loss from Tumri watershed

S. No.	Erosion class	Range (tons/ha/year)	Area (Hectare)	Percent to Total Area
1	Low	< 2.5	892.71	37.33 %
2	Moderate	2.5 – 10.0	432.73	18.10 %
3	High	10.0 – 20.0	514.96	21.53 %
4	Very high	> 20.0	550.88	23.04 %
Total			2391.28	100.00

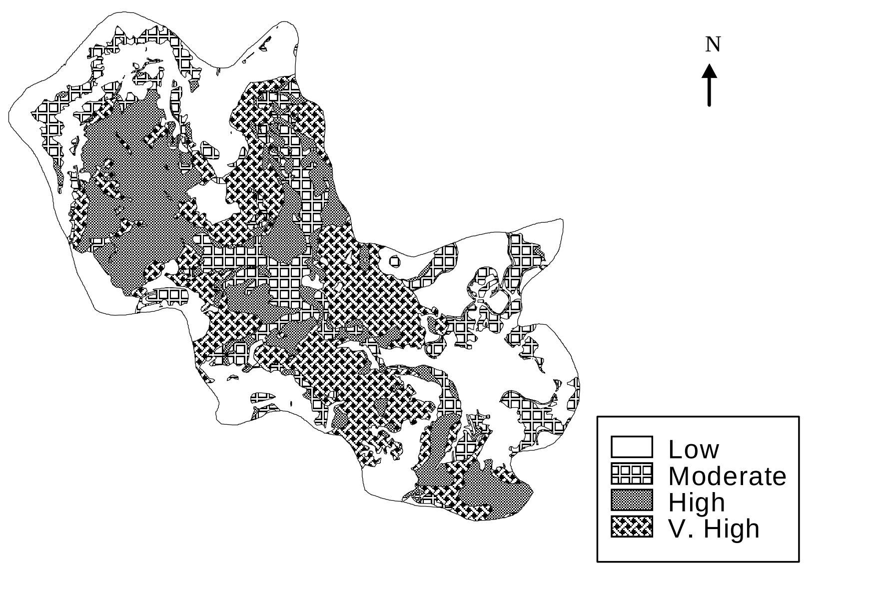


Fig. 3: Soil erosion map of Tumri watershed

Conclusions

Knowledge of degree of soil erosion under alternate management strategies and practices helps in reducing the soil loss from a watershed through better management practices. The Universal Soil Loss Equation (USLE) has been widely accepted and used for land management planning worldwide and according to the International Soil and Water Conservation Society; the USLE is the primary tool of conservationists for planning purposes. With the application of GIS and real time data from remote sensing, various management strategies of soil conservation measures and land use change can be planned and the effect of these changes can be modeled. The following conclusions can be drawn from the soil erosion study of Tumri watershed:

- The average rate of soil erosion calculated by USLE model from the watershed is 14.60 t/ha/yr and the quantity of actual soil erosion comes out to be 34912.69 tones/year.
- The rate of soil erosion from barren areas is 34.56 t/ha/yr, which is maximum among all other classes.
- Nearly half of the watershed area falls under class high and very high erosion. This is indicative of need of immediate soil conservation practices in the watershed.
- The results indicate that the forest plantations in 50 % of the barren land in Tumri watershed would reduce soil erosion from present rate of 14.60 tones/ha/year to 9.53 tones/ha/year.
- Comparison of results of USLE model with Khosla's method indicates that the prediction of soil loss from USLE is comparable with the Khosla's method.

References

- Bundela, D S, R Singh and K Mishra (1995), 'Sediment yield modeling for small watersheds in Barkar river valley', Institution of Engineers (I) Jr, 76: 22-25.
- Chinnamani, S, Sairam Venkata and R Sakthivadivel (1982), 'Applicability of the Universal Soil Loss Equation in mountain watershed in semi-arid and humid regions', Recent Developments in the Explanation and prediction of Erosion and Sediment Yield, IAHS Publ. No. 137.
- Government of India (1972), 'Hydrology and Sedimentation', Central Unit for Soil Conservation, Ministry of Agriculture (GOI), New Delhi.
- Gurmel Singh, G Ram Babu, and Subhash Chandra (1981), 'Soil loss prediction research in India', Bull. No. T-12/D-9, Central Soil and Water Cons. Res. Training Inst., Dehradun, India. 70 pp.
- Indian Council of Agricultural Research (1987), 'Handbook of Agriculture', ICAR, New Delhi.
- Jaiswal, S K (1982), 'Runoff and sediment yield from Gages watershed of Ramganga catchment', Thesis, M.Tech. in Agriculture Engg., G. B. Pant University of Agriculture and Technology, Pantnagar.
- Joglekar, D V (1960), 'Silting of Reservoir', Jour. Inst. Civil Engrs., 40(8).
- Khosla, A. N. (1953), 'Silting of Reservoirs', CBI&P, New Delhi.
- Musgrave, G W (1947), 'The quantitative evaluation of factors in water erosion: A First approximation', Jr. Soil and Water Conserv., 2(3): 133-138.
- Narayana, V. V. Dhruva, and Ram Babu (1983), 'Estimation of soil erosion in India', J. Irrig. And Drainage Eng., ASCE 109(4) : 419-433.
- Narain P., Ram Babu., M. S. Rama Mohan Rao., J. L. Sehgal., R. K. Datta., D. Sarkar & C. J. Thampi (1993), 'Soil erosion map of West Bengal', Indian Journal of Soil Conservation, Vol. 21 (2), pp 6-10.
- Raghuwanshi, N S and K K S Bhatia (1987), 'Study of soil erosion for different land use and vegetal covers using Universal Soil Loss Equation', National Institute of Hydrology, Roorkee, TR-28.
- Ram Babu, K.G. Tejwani, M. C. Agarwal, L. S. Bhushan (1978), 'Distribution of erosion index and iso-erodant map of India', Indian Journal of Soil Conservation, Vol. 6 (1), 1-12.
- Singh, G, Ram Babu and Subhas Chandra (1981), 'Soil Loss Prediction Research in India', Central Soil and Water Conservation Research and Training institute, Dehradun, Bull No. T-12/D-9.
- Wischmeier, W H and D D Smith (1978), 'Predicting rainfall erosion losses from cropland east of Rocky Mountains', Agriculture Handbook No. 282, U. S. Dept. of Agri., Washington, D.C.

LECTURE XII- MIKE BASIN: A GIS BASED TOOL FOR RIVER BASIN MANAGEMENT

Ravi Galkate
Scientist-C, Ganga Plains South Regional Centre Bhopal,
National Institute of Hydrology, WALMI Campus Kolar Road Bhopal (M.P.)
Email: rgakate@yahoo.co.in

Introduction

MIKE BASIN is a multi-purpose, GIS-based river basin simulation package designed for analyzing water sharing problems and environmental issues at international, national and project scale. MIKE BASIN is powerful, yet simple to use, with lots of analysis capabilities for water resources engineering. It is a professional engineering software package developed by Danish Hydraulic Institute (DHI), Denmark.. MIKE BASIN is a simulation model for water allocation representing the hydrology of the basin in space and time. Technically, it is a network model in which the rivers and their main tributaries are represented by a network of branches and nodes. River basin management and planning for a basin may broadly be conceived as an attempt to identify the best possible utilization of the available water resources given certain soil, land, agricultural, engineering, and social constraints. A water resources management tool, such as MIKE BASIN centered on a basin wide representation of the water availability and potential users of water, offers a basis for such a framework.

MIKE BASIN operates on the basis of a digitized river network generated directly on the computer screen in the map view. All information regarding the configuration of the river branch network, location of water users, channels for intakes and outlets to and from water users, reservoirs are also defined by on-screen editing. Basic input to the model consists of time series data of various types. Basically only time series of catchment run-off is required to have a model setup that runs. Additional input files define reservoir characteristics and operation rules of each reservoir, meteorological time series and data pertinent to each water supply or irrigation scheme such as bifurcation requirements and other information describing return flows.

An important feature of the MIKE BASIN Model is the ability to handle users with multiple priorities from any number of different river sources as well and a source with priorities for any number of different users. Often, several users may want to receive water from the same resource (Figure 1). Within the MIKE BASIN network model concept this situation is represented by several user nodes connected to a single supply node. Allocation algorithms determine how water is distributed among several users in case of conflicts. In general, a local priority relationship is applied between a supply node (upstream) and several user nodes (downstream). Dialog boxes for supply nodes (reservoirs, river nodes) allow for the specification of the sequence in which connected user nodes water demands are fulfilled. Alternative water sharing algorithms are also available in MIKE BASIN that are based on fraction of flows or fraction of demands. All dialog boxes use a standard design for specifying these connections. The facility to handle priorities from a user perspective as well as from the resource perspective makes the model extremely flexible in its application. The model is also able to look at and use many different types of institutional arrangements such as fractional allocations and capacity sharing (Water banking) which make it even more useful in terms of different operating criteria which you can manage on a system.

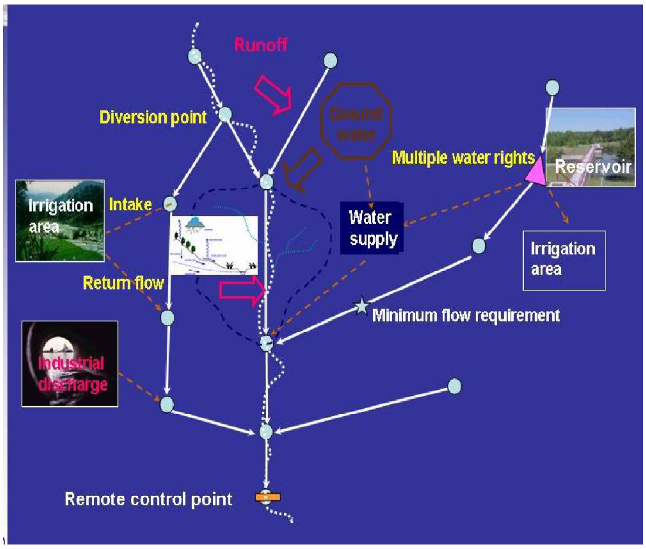


Figure 1: Simplified schematization of the MIKE BASIN model network

MIKE BASIN is also able to handle a large array of different processes, such as rainfall runoff, water quality, groundwater and channel routing on top of the water allocations priorities and water accounting dynamics. It has the ability to allow for flexible time stepping from seconds to months and years enabling the user to run the model at the level of detail and with the processes they require. It can thus easily be used in real time and near real time operational river management, planning and licensing applications.

Typical MIKE BASIN Applications

MIKE BASIN is powerful river basin simulation package designed for analyzing water sharing problems, water allocation, demand deficit, hydrological modeling and with lots of analysis capabilities for water resources engineering. Following are the typical MIKE BASIN applications which can be undertaken for water resources management of the river basin.

- Solve multi-sector water allocation problems
- Improve reservoir and hydropower operations
- Conduct transparent water resources assessments
- Evaluate irrigation scheme performance and crop yield
- Assess nutrient loads from non-point and point sources
- Compare measures for water quality compliance

- Store, analyze and visualize temporal data in GIS

Generic Modeling Concepts

The methodology employed in the setting up of the MIKE BASIN model follows both local and international guidelines as to model formulation and setup. These guidelines ensure a scientifically rigorous approach is followed and that the models are set up at an appropriate level of detail for the project at hand. The process is also designed to ensure that model results can be replicated (with a reasonable degree of accuracy) in that the assumptions, chosen processes and associated temporal and spatial scales are made explicit.

Conceptual Model Formulation

Before setting up a model, it is important to define the appropriate schematization of the river basin and the characteristics to be included. The evaluation of the water resources in large river basins often has to take account of numerous individual demands and features. Typically a large number of small irrigation users are scattered in an area. To incorporate all these entities as individual schemes would in most cases require enormous resources for model set-up. It is therefore important already in the model development phase to define a flexible schematization with the objectives of the modeling effort and the availability of information in mind. Different types of schematizations may be introduced:

- Lumping of smaller rivers into one single branch upstream of an intake point;
- Lumping of small irrigation areas into one single scheme with one intake point;
- Lumping town supply and industrial water supply into one entity.

A model river network is a simplification of the physical system. The schematization should therefore reflect the functions and inter-relations that have been identified in the natural system. It is important to follow a set of guidelines in the model schematization and overall model configuration so as to set a model up at the appropriate spatial and temporal scale, accounting for the appropriate processes. The following process was followed in the initial model configuration and subsequent refinement:

- Project objectives
- Problem formulation
- Model domain
- Conceptual configuration
- Scenario formulation

Project and System Objectives

These are generally defined by the major client of a particular project or the systems intended users. It is important to understand the requirements for a particular model setup prior to setting up the model. The clear definition of objectives and requirements can thus save a lot time and effort in both the short and long term modeling efforts.

Problem formulation: This is similar to the objectives stipulated but forms the requirements for a clear and precise problem statement where the requirements from the user and stakeholder perspective are defined.

Model domain: This needs to be appropriate set up as to satisfy the problem statement. In the case of the MIKE BASIN model the model domain is usually represented by a catchment boundary with the catchment being modeled in its entirety.

Conceptual configuration: This step generally defines the full setup of the model in terms of processes which need to be modeled, the main users on the system and how they are lumped together, aspects that will be taken into account in the catchment delimitation process, time step of the modeling configuration, information sources and requirements, major role players and stakeholders who need to be consulted, system objectives and problem formulation

Scenario formulation: This step needs to be consultative where major stakeholders are consulted as to which aspects they believe should be taken into account and the present and future scenarios in terms of development option and management options need to be discussed.

ArcGIS User Interface

MIKE BASIN is an ArcGIS extension and the model setup is carried out within the ArcMAP environment. The MIKE BASIN model of Wainganga basin of Madhya Pradesh is shown in Figure 2.

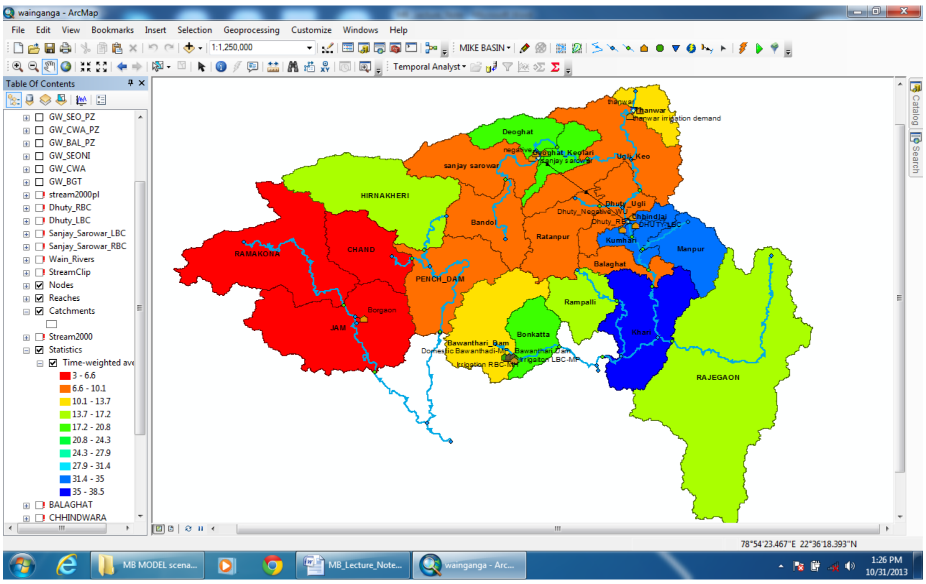


Figure 2: ArcGIS User Interface for MIKE BASIN Model of Wainganga basin

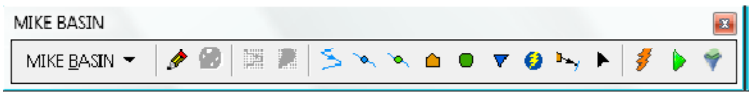


Figure 3: MIKE BASIN Toolbar

Various features of MIKE BASIN model has a capability of creating a river network, adding a diversion, adding a water user, adding a reservoir, creating a model using a DEM, assigning priorities, creating a model using pseudo DEM, importing time series associated with each feature, simulation, getting results, etc.

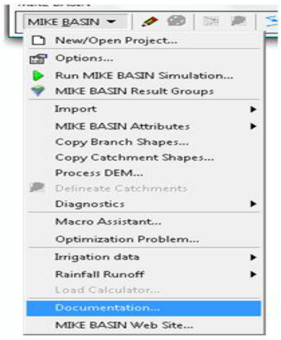


Figure 4: MIKE BASIN Drop down menu

Water Use and Supply Priorities in MIKE BASIN

MIKE BASIN can handle priorities from both the water use and water supply perspective. This means that the user has the ability to choose a number of different water source or supply options and prioritize them in order of importance (Figure 5).

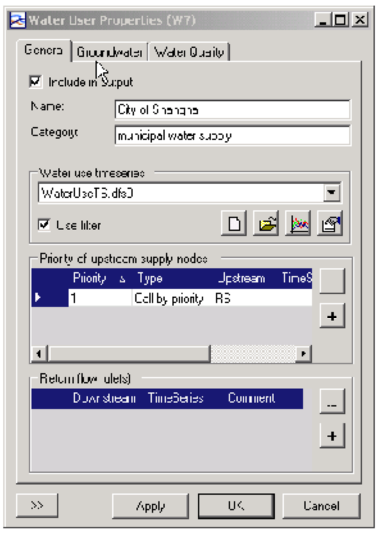


Figure 5: Assigning priority to the user

Extraction rules: Two types of rules are available:

Call by priority. Water is extracted from upstream nodes to satisfy the demand in the order of priority beginning with nodes having the lowest priority number.

Call by fraction of demand. Water is extracted from each upstream node based on the fraction of the demand required from each node. If an upstream node cannot fulfil its fraction there is no attempt to extract water from another upstream node.

Reservoir Modeling

The MIKE BASIN has a capability for reservoir modeling. There are several methods of operation for reservoirs in MIKE BASIN. The most common operating rule is what we refer to as the rule curves. This mode of operation generally requires that users are curtailed according to different dam levels. The other method is referred to as the allocation pool reservoir mode of operation and in this mode different users have access to different pieces of the reservoir supply. The rule curve methodology essentially splits the reservoir into several operating zones as shown in figure 6. There are three standard operating zones:

- The flood control zone: water is released if the water goes above this level as it represents a danger due to dam wall failure
- The conservation or minimum operating zone: The conservation zone is the zone where water must be left for environmental or social reasons
- The dead storage zone: This is the zone that cannot be accessed in the reservoir due to physical infrastructural constraints

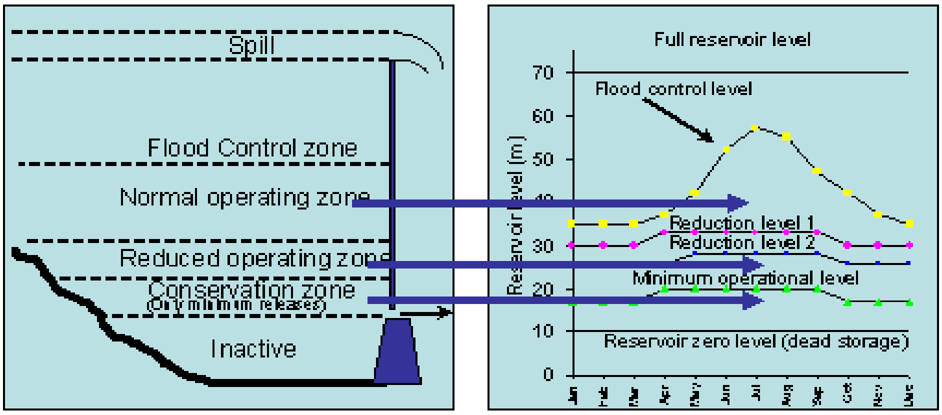


Figure 6: Rule Curve Zones

Groundwater Modeling in MIKE BASIN

MIKE BASIN has the ability to model groundwater processes. Groundwater discharge is a hydraulic response and computed within MIKE BASIN. The underlying conceptual hydraulic model is the linear reservoir model as shown in Figure 7.

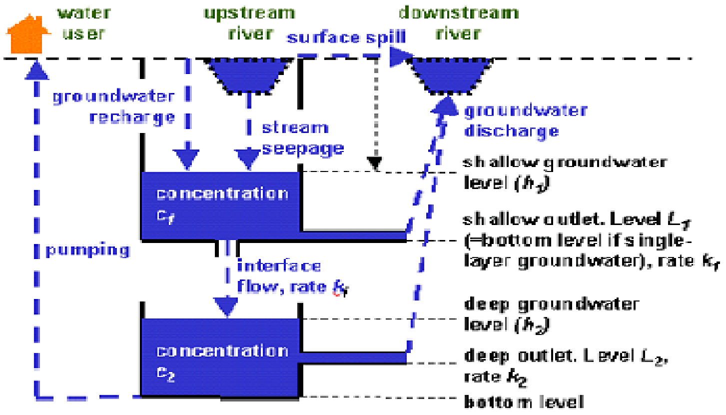


Figure 7: Conceptual Organization of Groundwater in MIKE BASIN

A groundwater aquifer interacts with the surface water system via the following fluxes:

- Stream seepage to aquifer (river to aquifer)
- Groundwater recharge (catchment to aquifer)
- Pumping if any (aquifer to water user)
- Groundwater discharge (aquifer to river)

River Routing

The choice as to whether routing is important or not in a particular simulation depends to a large extent on the required accuracy and should also be evaluated in the context of time step and the distances between the nodes used or required. There are four methods of routing which the user can specify in MIKE BASIN.

- Muskingum routing
- Linear reservoir routing
- Wave translation
- No routing

Irrigation Scheduling

The MIKE BASIN has a capability to develop irrigation model. It requires climatological data such as rainfall, temperature, humidity, wind speed, sunshine hour, crop type, crop area, variety, etc. It has a capability develop irrigation scheduling scenario of the command area. The irrigation model can be integrated with reservoir model so that it can simulate the whole irrigation operation scenario of the command area.

Water Quality Modeling

MIKE BASIN has the ability to simulate water quality in both surface water and groundwater resources, with solute inputs from non-point and/or point sources. Combined with the ArcGIS interface and the Temporal Analyst extension you have a very powerful tool at your disposal as you have a visual picture of where pollutants are moving through our system as well as the approximate concentrations of these pollutant loads. MIKE BASIN can simulate water quality in surface and groundwater, with solute inputs from non-point and/or point sources.

Rainfall-Runoff Modeling

Rainfall runoff modeling can be handled in a number of ways in the MIKE BASIN model. Firstly an external rainfall runoff model could be used. The information from these models can then be fed into MIKE BASIN either as a specific runoff (Runoff per unit area) file or absolute runoff (actual volume) file. The second method would be to use the inbuilt rainfall runoff model in MIKE BASIN which is referred to as the NAM model.

Temporal Analyst

In MIKE BASIN, Temporal Analyst is a GIS extension which when added to the ArcGIS which can be used for managing, viewing, querying, analyzing and editing time-series data from within ArcMap. The most important thing to realize is that it adds functionality on a temporal scale to the existing spatial functionality already available to us in the ArcGIS framework. That is, it enables the storage, management and visualization of time-related data in a spatial context. This is an exceptionally powerful tool especially when it is used for water resource analysis.

References

Blackie, J.R. and Eles, C.W.O. 1985. Lumped Catchment Models, M.G. Anderson and T.P. Burts (eds), Hydrologic Forecasting, Wiley, New York.

Cai, X. 2008. Implementation of holistic water resources-economic optimization models for river basin management-reflective experiences. Environmental Modelling & Software. Volume 23, Issue 1 January, 2008: 2-18.

DHI. 2003. MIKE Basin Reference Manual, Danish Hydraulic Institute, Copenhagen,Denmark.

DHI. 2003. MIKE Basin: Rainfall-Runoff Modeling Reference Manual, Danish Hydraulic Institute, Copenhagen, Denmark.

Wubet, F.D., Seleshi, B.A. and Moges, S.A. 2009. Analysis of water use on large river basin using MIKE BASIN model – A case study of the Abbay river basin, Ethiopia. International Result Dissemination Workshop, Feb. 5-6, 2009, Addis Ababa, Ethiopia.