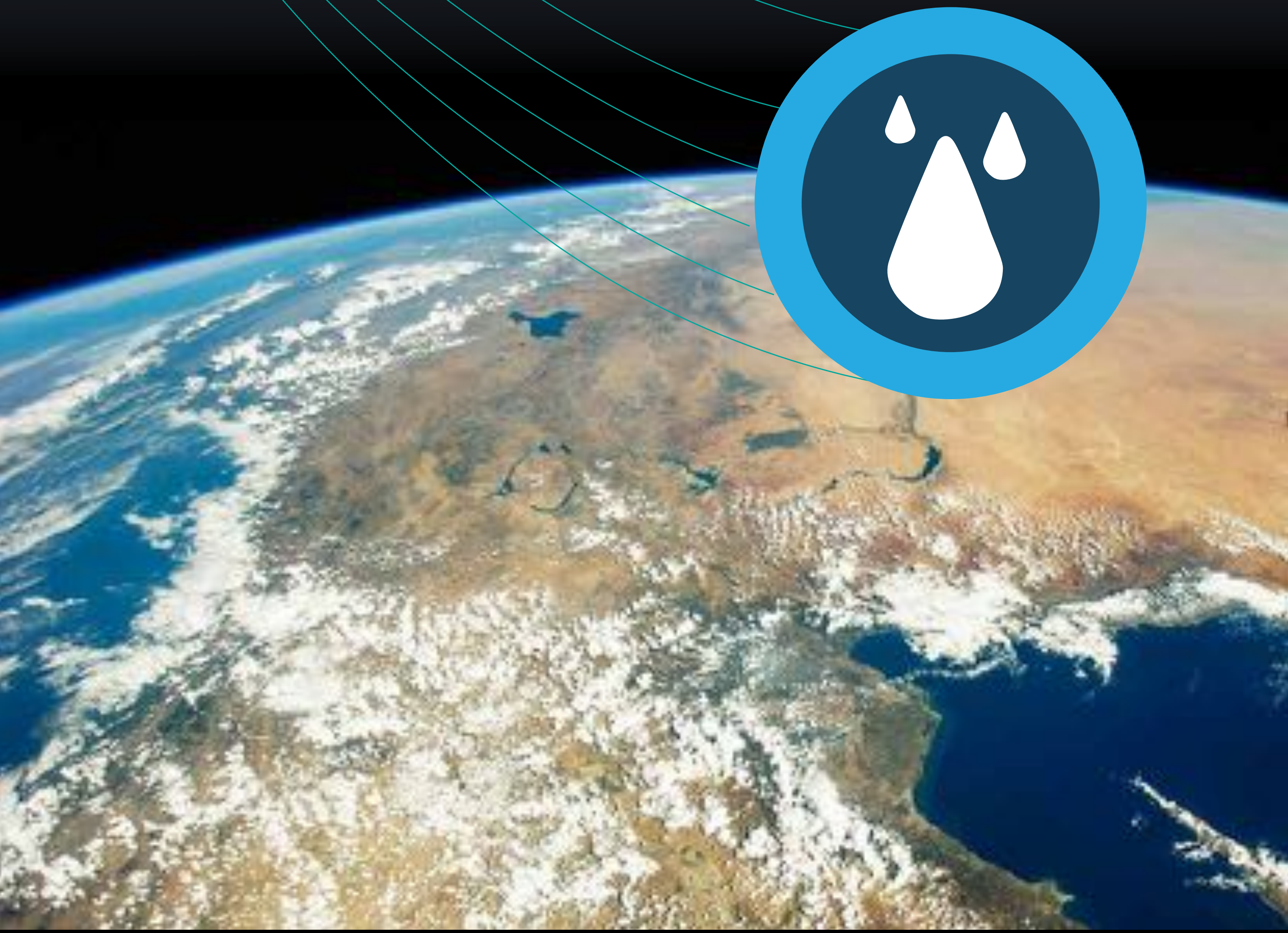
Integrated Water Resources Management and

Earth Observation



Cap-Net Training Manual

INTEGRATED WATER RESOURCES MANAGEMENT AND EARTH OBSERVATION

FOREWORD

Integrated Water Resource Management (IWRM) is a process that promotes the interconnected organization of water, land and other resources in an effort to maximize economic and social welfare without compromising environmental sustainability.

Hydrological processes are by nature interrelated – water left in a river to protect fisheries reduces the availability of water for agriculture; polluted water from agriculture reduces water quality and increases cost to provide clean drinking water to cities and towns; contaminated wastewater from municipalities damages ecosystems. Globally, water policy and management are beginning to reflect these connections rather than the sector-by-sector, top-down management style that dominated in the past. This interconnected view requires a deeper understanding and better monitoring of the linkages between the various components of water resource management. As these linkages often cross political boundaries and are spatially extensive understanding them requires international cooperation, wider data collection and analysis and better information management.

To assist in these challenges earth observation (EO) tools such as high resolution satellite imagery, geographic information systems (GIS), rainfall monitoring, drought and flood mapping have emerged as low-cost, effective methods of evaluating and monitoring water resources. The last two decades have seen vast improvements in the availability of low-cost, high resolution global satellite imagery. Several major depositories of satellite imagery such Landsat 5 Thematic Mapper and EO-1 Advanced Land Imager are now freely available for download while the cost of other databases is steadily decreasing.

Coupling an integrated approach to water management with increased availability of earth observation tools can only be maximized if training of water resource personnel keeps pace with the technological advances. Many organizations are still using outdated, limited techniques due to lack of training.

The objective of this training manual is to enhance the capacity of water sector professionals and managers on the use of earth observation satellite data and products in support of IWRM. The training manual will address technical skills required to access and select appropriate satellite imageries and products relevant to IWRM projects; approaches to satellite imagery processing and feature extraction; design of IWRM-related applications using EO tools; review the use of EO in the following thematic areas: watershed characterization, flood mapping, rainfall monitoring, drought assessment, groundwater assessment, and water quality management.

This training manual is an initiative of Cap-Net UNDP and ITC and strives to address this by developing international training materials for the use of earth observation tools for IWRM. The manual is presently in its first draft and through a series of training of trainers it is envisaged to be further refined and tested to reflect real needs and applications on the ground particularly these training materials.

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Director, Cap-Net UNDP
December 2012

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Cap-Net UNDP would like to acknowledge the various contributions mentioned above as well as the feedback and input from participants of the first training courses that served to improve the materials significantly. Any omission or error is the responsibility of Cap-Net UNDP.

Other materials are available from Cap-Net UNDP that cover more specific issues like climate change adaptation, hydro-climatic disasters, urban flood management and community management of floods, river basin organizations.

Training materials and tools developed by the Cap-Net global network

a. Conflict resolution and negotiation skills for IWRM
b. Course book on water safety plans
c. Economics in sustainable water management
d. Groundwater management in IWRM
e. Hydro-climatic disasters in water resources management
f. Integrated urban flood management
g. Integrated water resource management for river basin organisations
h. Integrated water resources management plans
i. IWRM as a tool for adaptation to climate change
j. IWRM tutorial
k. Network management tools
l. Online and offline self-learning tutorial - IWRM as a tool for adaptation to climate change
m. Streams of law: water legislation and legal reform for IWRM
n. Sustainable sanitation and water management toolbox
o. Water integrity and accountability
p. Why gender matters: a tutorial for water managers

These materials are freely available for use, adaptation and translation as desired and can be downloaded from the Cap-Net web site or requested on CD together with all of the resource materials and PowerPoint slides. When using the materials please give appropriate acknowledgement to the source.

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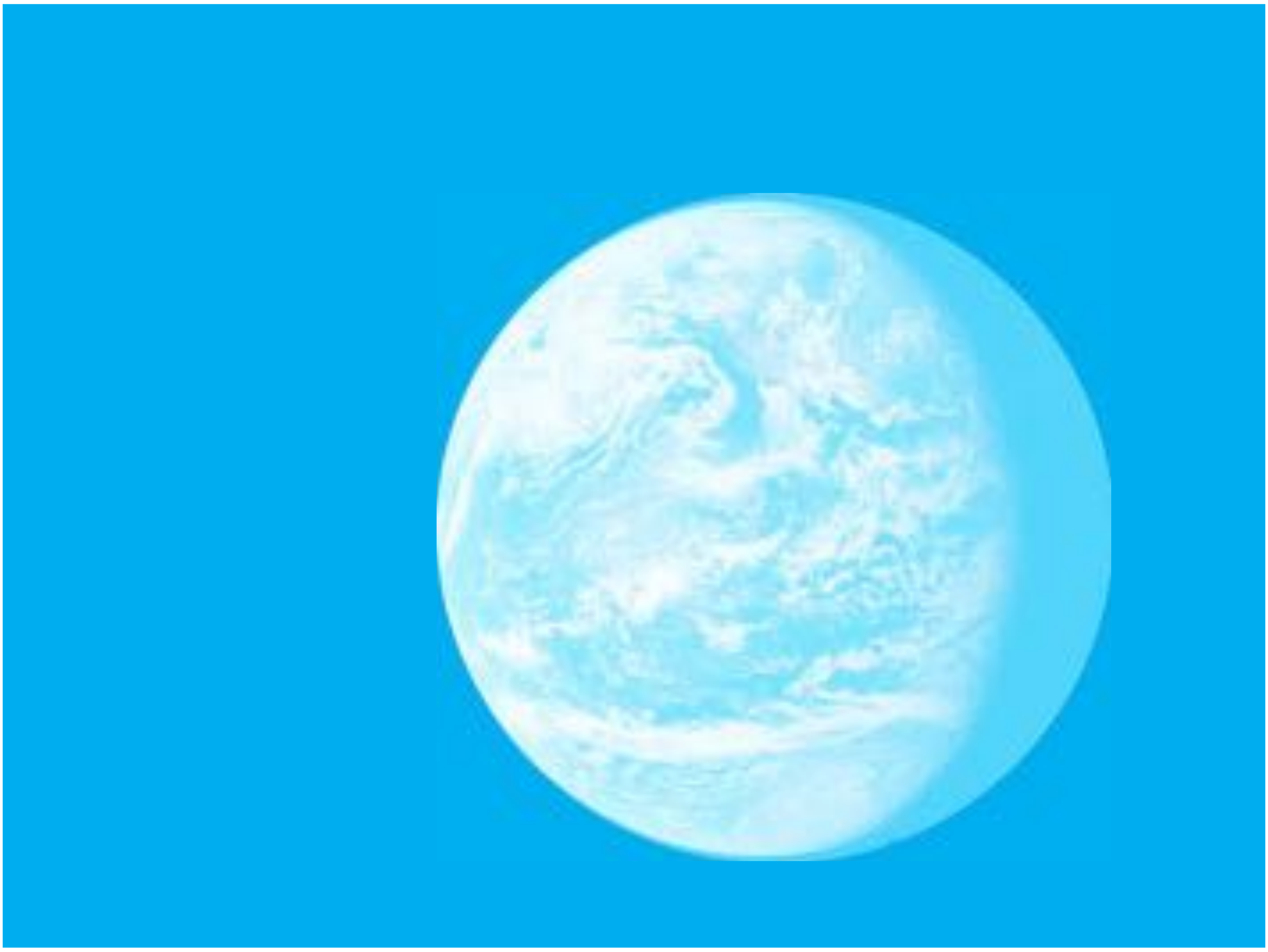

Chapter 1

Introduction to Integrated Water Resources Management and Earth Observation

Learning Objectives

- To learn the concept of integrated water resources management (IWRM) and its principles,
- To provide an overview of the use of earth observation tools in implementing IWRM.

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1.1 INTRODUCTION

Water sustains life. It is therefore a basic human need and right without which human beings cannot survive. However, the world's freshwater resources face increasing demands from population growth, economic activity and, in some countries, improved standards of living. It is also becoming clear that sustainable development includes maintaining healthy ecosystems and biodiversity, which require sufficient water. Competing demands and conflicts over rights of access occur amidst the fact that many people still do not have equal access to water and this has been described as an impending water crisis. According to the United Nations, access to safe drinking water and basic sanitation is essential for the achievement of the Sustainable Development Goals (SDGs) (UNDP, 2013) It is a fundamental requirement for effective primary health care and a precondition for success in fighting poverty, hunger, child mortality, gender inequality and environmental damage.

Basic Principles on IWRM (Cap-Net, 2005a) notes that:

- Water resources are increasingly under pressure from population growth, economic activities and intensifying competition among users.
- Water withdrawals have increased more than twice as fast as population growth, and currently one third of the world's population lives in countries that experience medium to high water stress.
- Pollution is further aggravating water scarcity by reducing water usability downstream.
- Shortcomings in the management of water, a focus on developing new sources rather than managing existing ones better, and top-down sector approaches to water management result in uncoordinated development and management of the resource.
- More and more development means greater impacts on the environment.
- Current concerns about climate variability and climate change demand improved management of water resources to cope with more intense floods and droughts, as well as changes in seasonality.

According to the UN world water development report (UNESCO, WWAP and UN Water, 2012);

- By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two thirds of the world's population could be living under water stressed conditions.
- In scenario of climate change, almost half of the world's population will be living in areas of high water stress by 2030.

This impending water crisis presents challenges to the water sector, many of which are multifaceted in that they must address questions such as:

- How can people access water and sanitation?
- How can competition among various users be addressed without undermining economic growth objectives?
- How can the protection of vital ecosystems be ensured?

Failure to address these complex challenges pushes societies further away from meeting the goal of sustainable development in general, and sustainable management and development of water resources in particular. There is growing support for the ability of IWRM to meet these challenges.

1.2 WHAT IS INTEGRATED WATER RESOURCES MANAGEMENT (IWRM)?

IWRM is the sustainable development, allocation and monitoring of water, land and related resource use in the context of social, economic and environmental objectives (Cap-Net, 2005a). It is cross-sectoral and therefore in stark contrast to the traditional sectoral approach that has been adopted in the past by many countries. It has been further broadened to incorporate participatory decision-making of all stakeholders.

IWRM is a paradigm shift. It departs from traditional approaches in three ways:

- The multiple goals and objectives are cross-cutting so that IWRM departs from the traditional sectoral approach.
- The spatial focus is on the river basin instead of on single water courses.

- It entails a departure from narrow professional and political boundaries and perspectives, broadening them to incorporate participatory decision-making among all stakeholders (i.e. inclusion versus exclusion)

The basis of IWRM is that there is a variety of uses of water resources that are interdependent. The failure to recognize interdependency, coupled with unregulated use, can lead to water wastage and the unsustainability of water resources in the long term.

Identify and discuss examples from your own country where this interdependency of water uses exists.

Integrated management does not segregate water users or take a sectoral approach as is done in many countries. Rather, water allocation and management decisions consider the impact of each use on the others. In doing so, the cross-cutting goals of social, economic and environmental sustainability are considered collectively, and cross-sectoral policies are examined to shape more coherent, coordinated policies. In short, IWRM recognises that water is a scarce natural resource, subject to many interdependencies in conveyance and use.

The basic IWRM concept has been extended to incorporate participatory decision-making and will be discussed in more detail in Section 1.4, which deals with water management principles.

Different user groups (farmers, communities, environmentalists and others) may influence strategies for water resource development and management. That brings additional benefits, as informed users apply local self-regulation in relation to issues such as water conservation and protection of catchments far more effectively than central regulation and surveillance can achieve.

The term 'management' is used in its broadest sense, in that it highlights the need to not only focus on the development of water resources, but also to consciously manage water development that ensures sustainable use for future generations (Cap-Net, 2005a).

1.3 THE WATER MANAGEMENT FRAMEWORK

IWRM occurs in a holistic framework, dealing with:

- All water (spatial);
- All interests (social);
- All stakeholders (participatory);
- All levels (administrative);
- All relevant disciplines (organizational); and
- Sustainability (in all senses: environmental, political, social, cultural, economic, financial and legal). (Jaspers, 2001)

The framework is so broad, that the aim of IWRM is to discard sector approaches and to create environmental, institutional, social, technical and financial sustainability through the creation of a platform for government and stakeholders for planning and implementation, and to deal with conflicts of interests.

At the core of the water management framework is the treatment of water as an economic good as well as a social good, combined with decentralized management and delivery structures, greater reliance on pricing and fuller participation by stakeholders (World Bank, 1993). All of these principles and issues will be discussed in more detail in the following section (1.4).

What will a water management framework do?

i. Provide a framework for analysing policies and options that will guide decisions about managing water resources in relation to:

- Water scarcity;
- Service efficiency;
- Water allocation; and
- Environmental protection.

ii. Facilitate consideration of relationships between the ecosystem and socio-economic activities in river basins.

The analysis should take account of social, environmental and economic objectives; evaluate the status of water resources within each basin; and assess the level and composition of projected demand. Special attention should be given to the views of all stakeholders, which should take place through activities designed to facilitate participation.

Stakeholder participation essentially involves four steps:

1. Identifying the key stakeholders from the large array of groups and individuals that could potentially affect, or be affected by, changes in water management;

2. Assessing stakeholder interests and the potential impact of the IWRM planning on these interests;

3. Assessing the influence and importance of the identified stakeholders; and

4. Outlining a stakeholder participation strategy (a plan to involve the stakeholders in different stages of the plan preparation).

The results of the analyses at a river basin level would become part of the national strategy for water resources management. The analytical framework would provide the underpinnings for formulating public policies on regulations, incentives, public investment plans, environmental management, and the linkages among them. A supportive legal framework and adequate regulatory capacity are required, as well as a system of water charges to endow water entities with operational autonomy and some financial autonomy for efficient and sustainable service delivery.

1.4 WATER MANAGEMENT PRINCIPLES

Two decades ago (at the International Conference on Water and the Environment, convened in Dublin, Ireland, in 1992), four main principles of water emerged that have become the cornerstones of subsequent water sector reform.

Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

This principle highlights that water is critical to sustaining life. However, freshwater is a finite resource because the hydrological cycle on average yields a fixed quantity of water per period, and the quantity of water resources cannot be adjusted significantly by human actions. Furthermore, as a resource, water is paradoxically both essential to development and vulnerable to its effects. Effective management of water resources – which seeks to ensure that the services that are in demand can be provided and sustained over time – requires a holistic approach that links social and economic development with the protection of natural ecosystems. Effective management does not dichotomize land and water uses but sees the integration of these uses across the whole of a catchment area or river basin.

The integrated approach to management of water resources demands a coordination of the range of human activities that create the demand for water, determine land uses, and generate waterborne waste products. Principle 1 also recognises the catchment area or river basin as the logical unit for water resources management.

Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.

Where water is concerned, everyone is a stakeholder. Accordingly, water development and management should be based on a participatory approach that draws on the principle of democratizing decision-making and gives recognition to the input of multiple stakeholders, including users, planners and policy makers at all levels.

Real participation only takes place when stakeholders are part of the decision-making process. This can occur directly when local communities come together to make water supply, water management and water use choices. Participation also occurs if democratically elected or otherwise accountable agencies or spokespersons can represent stakeholder groups; but even in this situation, access to information, consultation processes and opportunities to participate should also exist.

Benefits of participation:

- Participation emphasizes involvement in decision-making at the most feasible level (subsidiarity), with full public consultation and input from users in the planning and implementation of water projects. This leads to more successful projects in terms of scale design, operation and maintenance.
- Participation also helps to ensure that environmental resources are protected and that cultural values and human rights are respected.
- Participation can help coordinate interests and increase transparency and accountability in decision-making.
- Greater participation can also improve cost recovery, which is key to generating revenue and financing IWRM.

In your country, are all stakeholders involved in decision-making on water supply, management and investment decisions?

Principle 3: Women play a central part in the provision, management and safeguarding of water.

It is widely acknowledged that women play a key role in the collection and safeguarding of water for domestic use and, in many countries, for agricultural use. However, women are less instrumental than men in key areas such as management, problem analysis and the decision-making processes related to water resources. Often the marginalized role of women in water resources management can be traced to social and cultural traditions, which also vary between societies.

There is strong evidence that water managers must consider that there is an urgent need to mainstream gender in IWRM to achieve the goal of sustainable water use. Cap-Net and the Gender and Water Alliance (GWA) developed a tutorial for water managers entitled 'Why Gender Matters'. Some parts of the tutorial are covered in this section, but the manual users are advised to review the tutorial for a more complete understanding of the importance of having a gender-balanced approach in IWRM.

Basic linkages between gender and IWRM

There are three basic linkages between gender and IWRM issues:

1. **Gender and environmental sustainability linkages**

- Women and men affect on environmental sustainability in different proportions and by different means, as they have different access, control and interests.
- Flood and drought events weigh heaviest on women because they lack the means to cope with disasters.

2. **Gender and economic efficiency linkages**

- In many societies, women pay for drinking water but have mobility restrictions and payment constraints. Allowing users to pay smaller amounts more frequently and nearer to home makes water more affordable for them. (Water supply)

- Technology choice affects affordability. Consulting female and male users may result in a more acceptable, user-friendly and sustainable service. (Water supply)

- Lack of access to finance for poor people and for women farmers prevent them from developing more prosperous and water-efficient agricultural enterprises, and limit their participation in agriculture to that of a subsistence activity. (Agriculture)

3. **Gender and social equity linkages**

- Powerful groups of society, usually male-dominated, can exploit resources more systematically and on a large scale and can also drive industrial transformation of the environment; therefore, their potential to create damage is higher. (Environment)

- When water is not supplied by a piped system, the burden of water collection falls on women and children, who must expend considerable time and energy on this activity. (Water supply)

- Women rarely have equal access to water for productive use and are the first to be affected in times of water shortage. (Agriculture)

- Women and children are the most susceptible to waterborne disease due to their roles in water collection, clothes washing and other domestic activities. (Sanitation)

In your country, is a gender sensitive approach being used in managing water resources? If not, why has this approach not been adopted?

Little girls cross a rice field after heavy rains carrying water in plastic containers. Vemasse, Timor-Leste, December 2008. UN Photo/Martine Perret

Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good as well as a social good.

Many past failures in IWRM are attributable to ignoring the full value of water. The maximum benefits from water resources cannot be derived if misperceptions about the value of water persist.

Value versus charges

Value and charges are two distinct concepts. The value of water in alternative uses is important for the rational allocation of water as a scarce resource, whether by regulatory or economic means. Conversely, charging for water means applying an economic instrument to achieve multiple objectives, as follows:

- To support disadvantaged groups;

- To influence behaviour towards conservation and efficient water usage;
- To provide incentives for demand management;
- To ensure cost recovery; and
- To signal consumer willingness to pay for additional investments in water services.

When is water appropriate as an economic good?

Treating water as an economic good is imperative for logical decision-making on water allocation between competing water sectors, especially in an environment of water resource scarcity. It becomes necessary when extending the supply is no longer a feasible option. In IWRM, the economic value of alternative water uses helps guide decision makers in prioritizing investments. In countries where there is an abundance of water resources, it is less likely to be treated as an economic good since the need to ration water usage is not as urgent as in water-scarce countries.

Why is water a social good?

Although water is an economic good, it is also a social good. It is particularly important to view water allocation as a means of meeting the social goals of equity, poverty alleviation and safeguarding health. In countries where there is an abundance of water resources, there is more of a tendency to treat water as a social good to fulfil equity, poverty alleviation and health objectives over economic objectives. Environmental security and protection are also part of the consideration of water as a social good. Aesthetic and religious functions of water are often neglected or at least not sufficiently considered in water management.

Applying the concepts

In the real world, in a situation of water scarcity, should water be provided to a steel-manufacturing plant because the manufacturer has the ability to pay more for water than thousands of poor people who have no access to safe water? Can you find any similar examples from the ground level in your country? How was such a situation solved?

1.5 IMPLEMENTING IWRM

As demonstrated earlier in this chapter, IWRM offers various tools and instruments that deal with access to water and protecting the integrity of the ecosystem, thus safeguarding water quality for future generations.

Key water resources management functions are:

- Water allocation;
- Pollution control;
- Monitoring;
- Financial management;
- Flood and drought management;
- Information management;
- Basin planning; and
- Stakeholder participation.

In brief, IWRM makes it easier to respond to changes in water availability. Risks can be better identified and mitigated in the process of basin planning. When action is needed, stakeholder participation helps to mobilize communities and generate action. Water users can be stimulated to use the resource sustainably in the face of changing water conditions.

While there has been progress in a general understanding the meaning of IWRM, its importance in the context of scarcity, an acknowledgement of the main (Dublin) principles and a growing recognition of the need to use the right mix of economic and financial instruments, the actual implementation of IWRM is a challenging process.

There are several roadblocks to implementing IWRM, starting with entrenched sectoral interests, professional insecurities and socio-cultural myths. These challenges are nevertheless not insurmountable. Overcoming the barriers to the implementation of IWRM requires an incremental approach to negotiating differences, cross-sectoral integration and instituting reforms (including policy and legal reforms).

Conflicts among professionals working in the various sectors, combined with a sense of vulnerability in adopting alternative approaches to water development and management that permeates professional groupings, calls for skills in negotiating win-win solutions and providing platforms for very different stakeholders to develop collaboration in implementing IWRM. These processes take time and require patience.

IWRM can only be successfully implemented if, among other reforms, there is a concerted effort to integrate perspectives and divergent interests of various water users in the management framework. Formal mechanisms and means of cooperation and information exchange should be established at different levels to achieve cross-sectoral integration. Past informal attempts have not been successful, and a formalized set of mechanisms should have the effect of ensuring commitment at the various levels. Uncertainties are part of a shift in the management paradigm and the process of implementation considers dealing with them (see Chapter 5).

Existing institutional and legislative frameworks have not been entirely responsive to the demands and requirements for implementing IWRM. Implementing IWRM will therefore require reform at most stages in the water planning and management cycle.

Although there is an urgent need for reform, these changes can only take place incrementally – some occurring immediately and others taking several years of planning and capacity building. It will involve creating an enabling environment, and developing an institutional framework and management instruments for sustainable IWRM.

1.6 EARTH OBSERVATION EXPLAINED

The single location where we can learn the most about our planet is found nowhere on Earth but high up above it. Meteosat-1 was launched on a Delta rocket from Cape Canaveral and moved to its nominal operational location over the equator at 0 Longitude. The check-out of all systems was followed within a month by the start of routine image acquisition and distribution. This immediately became part of the operational system for weather forecasting across many countries in Europe (See Figure 1.1).

The ability to fly satellites into space has changed human lives in many ways, but the single greatest innovation has been the availability of new ways of seeing the world that satellites leave behind. Early pictures of the Earth seen from space became icons of the Space Age, and encouraged an increased awareness of the precious nature of the common home. Today, images of the planet from orbit are acquired continuously; they have become powerful scientific tools to enable better understanding and improved management of the Earth and its environment. Earth observation images show the world through a wide-enough frame so that complete large-scale phenomena can be observed to an accuracy and entirety it would take an army of ground-level observers to match.

The single location where we can learn the most about our planet is found nowhere on Earth but high up above it.

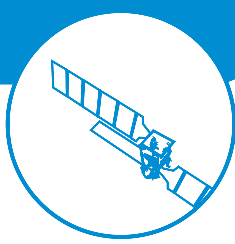


Figure 1.1: Meteosat-1 9 Dec 1977 Credits: ESA

Launched in 2002, Envisat is a truly advanced earth observation satellite with a unique combination of sensors that vastly improve the range and accuracy of scientific measurements of the atmosphere, oceans, land surface and ice. Its total range of capabilities far exceeds those of any previous or planned earth observation satellite (See Figure 1.2).

Depending on their orbit and intended function, different earth observation satellite instruments have differing spatial resolutions, which mean the minimum size of detail observable in an image. Low spatial resolution instruments are best for the study of regional vegetation coverage or wide-area weather and cloud patterns. Intermediate resolution sensors are typically used for agriculture and resource mapping as well as assessing the impact of disasters, while the highest resolution sensors can show individual roads, buildings or even cars.

However, the higher the resolution of an earth observation instrument the lower the overall area – termed the swath – covered, which generally means a longer revisit time for a given area as the satellite orbits the globe. But some earth observation instruments have changeable resolutions or steerable sensors in order to reduce the revisit time to as low a wait as possible. While satellite acquisitions are most often presented in the form of pictures, they are actually digital data. So the same raw data can be processed with computer software in many different ways to extract whatever information the particular end user requires.

Earth observation is an inherently multipurpose tool. Just as a single picture is said to be worth a thousand words, so many different types of information can be extracted from a single satellite image or data sample and put to a large number of diverse uses.

This means there is no typical earth observation user: it might be anyone who requires detailed characterisation of any given segment of the planet, across a wide variety of scales from a single city block to a country, region, or continent, right up to coverage of the entire globe. Acquiring the most reliable, detailed and up-to-date information available is a basic requirement of good business and effective government. Earth observation provides a whole new dimension of information, and for this reason is already employed by many thousands of users worldwide (see Box 1.1).

Box 1.1: GMES: Improved intelligence gathering

ESA is also supporting a suite of operational earth observation-based services. These services have been established under the umbrella of the Global Monitoring for Environment and Security (GMES) initiative. A joint endeavour by ESA and the European Commission, GMES is meant to address perceived deficiencies in European information gathering. It works to bring together information providers and users and establish an independent capacity to gather timely, accurate global data to help carry out European environment and security policies.

As well as improving and co-ordinating the function of ground-based monitoring resources, making GMES happen also means optimising use of existing and future Earth Observation systems.

The set of earth observation-based services currently backed by ESA represent a first step in GMES, and are collectively known as the GMES Services Element. Data yielded from GSE supports the work of a range of scientists, policy makers and implementers within government agencies, non-governmental organisations and key international scientific bodies. The needs of GSE users are also influencing the design of future European satellite systems http://www.esa.int/esaEO/index.html

It should be noted that GMES is no longer being used. It has been replaced by the European Earth Observation Programme Copernicus (the Sentinels satellites). Users interested in data coming directly from the Copernicus space component can access them through the Sentinel Online portal operated by the European Space Agency https://sentinel.esa.int/web/sentinel/home

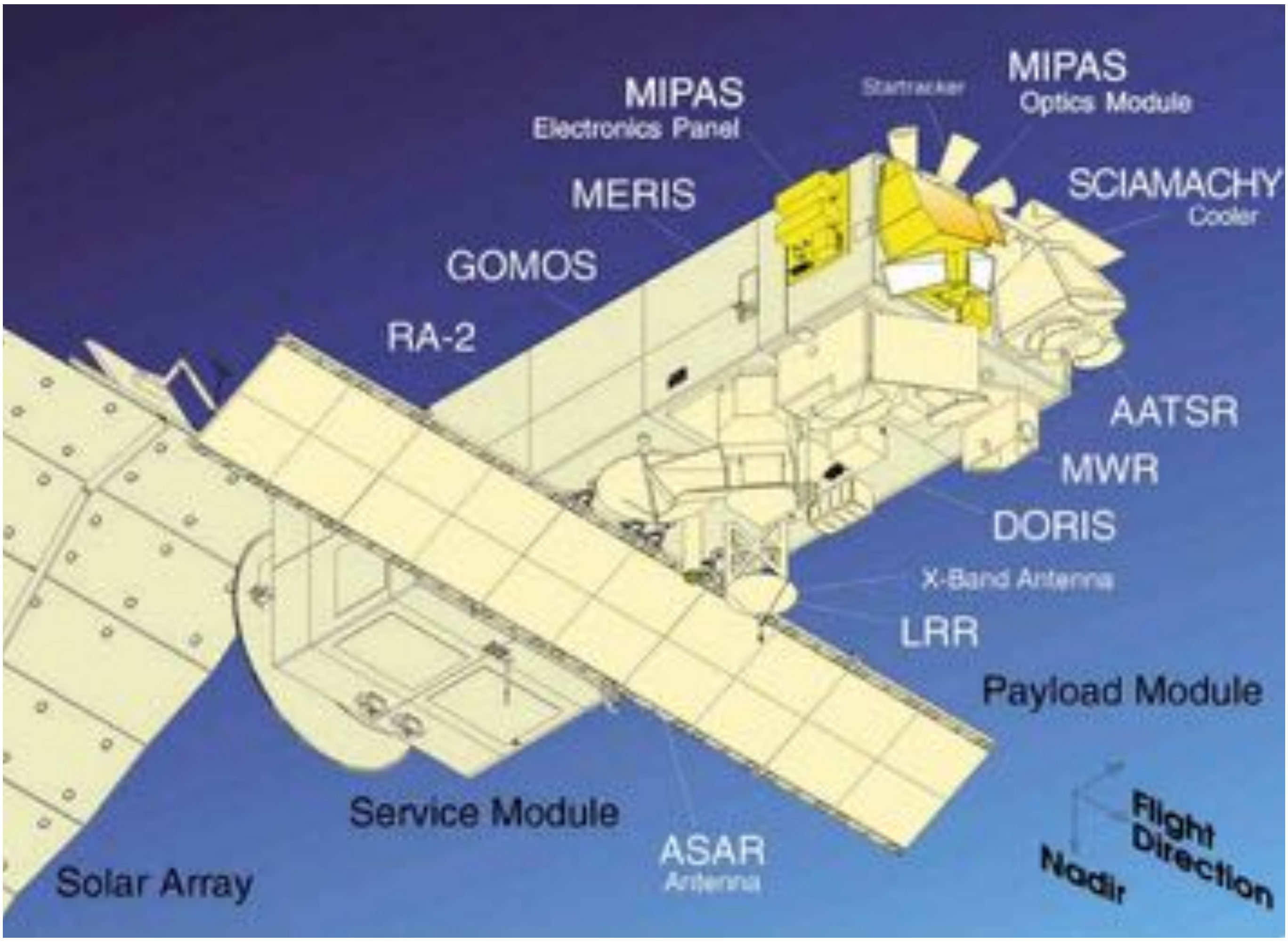


Figure 1.2: Envisat Instruments Credits: ESA

Earth observation data produced by satellites are so many and the available thematic data could, to a certain extent, complete the necessity of such associated with water resources management. So far the utilisation of these data is still very limited and there exists a large gap between the products of EO and the utilisation of the same for water resources management in planning/operational stages. This gap lies on the ability which is lacking to transform the data into "user friendly" information for decision makers. Therefore, besides providing the data, it is also important to provide coupled interface facility to transform the data into useful (and easily operable) information for effective use by various operating levels.

The utilisation of remote sensing/satellite data alone would not satisfy the requirements in solving the related issues and hence the integration between remote sensing and the conventional in-situ data need to be streamlined. For instance, in the case of drought monitoring in-situ measurements on terrain variables should complement remote sensing data. Not only the data but also the water related issues in some aspects need to be solved by taking an integral approach. Also it is necessary to address the associated issues on available data are sometimes inaccessible and not interoperable systems.

1.7 EARTH OBSERVATION TECHNIQUES APPLIED TO IWRM

The lack of water relevant information in many countries hinders the deep knowledge of its water cycle at continental and basin levels. This represents a critical drawback for these governments to completely understand the current status of the water resources, to identify the impacts of climate change in water availability and to set up adaptation and mitigation measurements to cope with future potential threats. To predict the future evolution of the water resources, variations due the complex interaction between climate system, land use and the hydrological cycle first need to be understood.

Water resource issues are often very complex and frequently require large amounts of diverse data. Effective management of water resources can be greatly aided by methods which allow for timely and accurate data collection. Collection of data by traditional means (e.g. field work) can be quite difficult at times, especially in remote areas, as well as costly and resource intensive. The use of Earth Observation (EO) technologies such as satellite based monitoring can be very useful as it can provide a cost-effective means of replacing or complimenting field data collection. Some of the main benefits of EO data are that it can provide coverage over large and remote areas with systematic, repetitive data captures (EURAC Research, 2010). EO data can also be integrated with field or remotely collected data (i.e. real-time) to produce effective up-to-date predictive and analytical products.

Applications of EO in understanding the hydrologic cycle and management of water at river basin or catchment scale include the following:

Rainfall estimation: Utilising satellite data and development of an integrated flood analysis system for poorly-gauged stations, identifying scale-interactions among diurnal, synoptic, intra-seasonal and seasonal variability of precipitation. Increasing usefulness of satellite information has been understood, particularly of the Global Precipitation Measurement (GPM) for flood forecasting, and developing and managing the early warning system.

River flow monitoring: River flow quantity estimation and prediction useful particularly in ungauged basins (see Box 1.2)

Box 1.2: Prediction in ungauged basins

PUB, Predictions in Ungauged Basins, was introduced as an IAHS initiative for decade 2003-2012. Accordingly it related its commitment to the reduction of the predictive uncertainty in hydrological science and practice mainly through channels of knowledge sharing and technology transfer http://www.pub.iwmi.org

Land cover and land use mapping: Use of EO in determination of rainfall-runoff models, comparing land cover change over time with water quantity and quality trends. Using imagery to detect the amount of impervious surfaces in watersheds, to assess runoff potential.

Climate change adaptation: Applying EO products and technology to monitor the impacts of climate change and assist in developing adaptation strategies; quantify the impacts that climatic variability have on the components of the cryosphere and the consequences of these impacts for the climate system.

Cooperation and disclosure: Use of EO improves international cooperation on water management through ease in sharing information and disclosure especially in contested river basins based on the fact that the data-sets are the same.

Research: EO provides researchers in the water sector and users access to in-situ data, satellite data and model output data from, data analysis and visualisation, real world themes, for instance, tropical mixed coastal and urban zones, meteorology imaging, disaster warning systems, and data collection platforms

Energy and water balance monitoring system: Use of EO in monitoring and validation of rainfall and energy balance, and flow and flood forecasting. Determination of evapo-transpiration using energy balance processing and mapping of relative evapo-transpiration.

Drought prediction and forecasting: EO is useful drought prediction e.g. drought-related EI Nino and computation of available rainfall and refining warning and response systems

Flood forecasting and risk mapping: EO products have been very helpful in the area of flood forecasting and mapping. For example, in flood risk studies air photos and high resolution imagery and Flood GIS can be used to map land cover for flood modelling and used as maps themselves to provide current views of land use in flood prone areas (Figure 1.3).

Digital elevation models and slope stability mapping: Digital Elevation Models (DEMs) are often created using remote sensing techniques and are an important tool for water resource studies. The use of DEMs in conjunction with Geographic Information System (GIS) offers important computational and visualisation capabilities. Slope mapping has also been an important element of natural hazard mapping (e.g. landslides).

Wetland mapping: Mapping of particular features of interest is another potential use of EO. High resolution satellite imagery enables the creation of detailed wetlands inventory for regions under high development pressures. Improved mapping of wetlands allow better protection of wetlands which serve important ecological functions, such as providing wildlife habitat or attenuating flood

Figure 1.3: Flood GIS displaying Flood Zones, Credit: ESA

waters. It also aid in monitoring the cumulative impact of development activities on small wetlands.

Water quality monitoring: The power of EO analysis can be enhanced when used in conjunction with field observations or real-time data collection. Verifying and calibrating EO analysis techniques with in-situ data allows for the creation of more accurate and informative products. For example, ESA's TIGER project to monitor water quality in several lakes in Egypt using MERIS and MODIS imagery and real-time water quality data sensors

Pollution source detection: EO can also be used to monitor pollution sources and points of discharge into water bodies. EO can be used to determine the effectiveness of various types of satellite imagery in detecting point discharges from sewage and industrial outfalls as well as monitoring sedimentation in water bodies caused by industrial activity

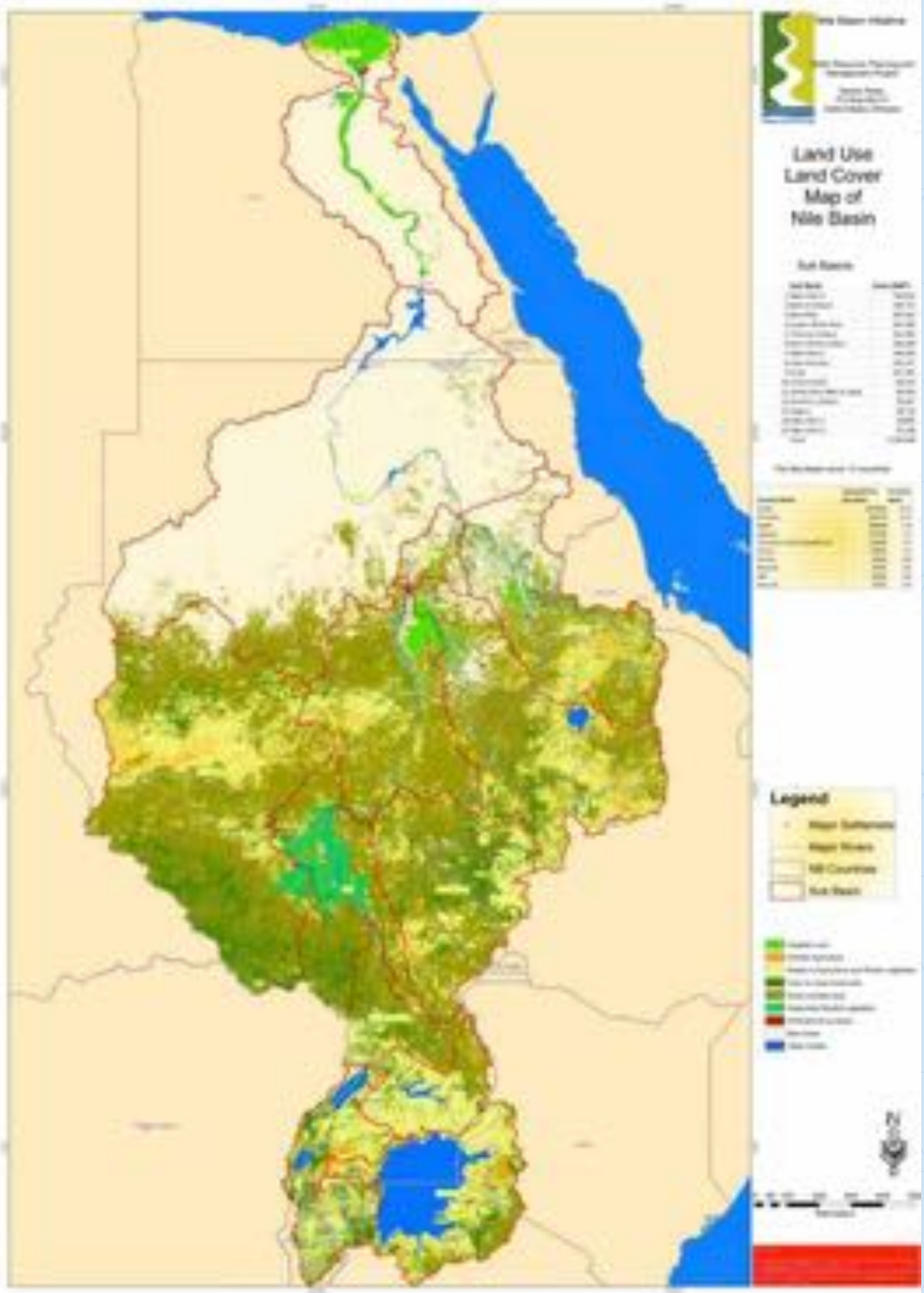
Ground water assessment and monitoring: Applying EO methodologies to assess groundwater conditions and investigating the groundwater potential (see Box 1.2, 1.3 and 1.4).

Box 1.3: Global groundwater information system

Measurements from GRACE satellites were used to quantify underground water-storage – a key development towards detecting water-cycle acceleration under a changing climate. A number of tools were refined for global groundwater assessment, such as the Global groundwater information system; http://www.earthobservations.org/index.shtml.

Identify and discuss examples from your own country where EO has been applied in water resources management?

Copyright: NASA



TIGER's Aquifer project was highlighted as a major success story. Aquifer was developed in collaboration with the Sahara and Sahel Observatory (OSS) to use satellites for managing trans-boundary groundwater aquifers, which are the main source of freshwater in the region. The results led to the African Water Facility of the African Development Bank investing in the technology, culminating in the OSS being selected as the winner of the King Hassan II Great World Water Prize.

Box 1.4: TIGER initiative in Africa (http://www.tiger.esa.int/)

Satellite observations are indispensable for monitoring our water resources. For example the Terrestrial Initiative in Global Environment Research (TIGER) initiative is supporting Africa in monitoring precious water assets by exploiting satellite information. Satellite observations of the planet are widely acknowledged as an indispensable tool for collecting information on available water resources. This is especially true for areas like trans-boundary river basins, such as the Nile basin and its 11 countries. Responding to this need for information on water, European Space Agency (ESA) TIGER initiative is running projects and developing capacity to use space technology for managing water resources in direct partnership with several African and international organisations, such as the African Ministers' Council on Water, UNESCO-IHP, African Water Facility, UN-ECA and the Canadian Space Agency.

1.8 SUMMARY

The demand for water is growing inexorably. Access to water is vital – not only for drinking, but also for agriculture, energy and sanitation. In certain regions of the world, water scarcity is caused by population growth, climate conditions and increasing climate variability, economic development or urbanisation

IWRM has come up as the internationally and locally accepted management system to ensure sufficient water resources of adequate quality, not only for today but also for generations to come. The four principles of IWRM are:

- Freshwater is a finite and vulnerable resource.
- Water development and management should be based on a participatory approach.
- Women play a central role.
- Water has an economic and a social value.

Improving water resource management through better understanding of the water cycle in the IWRM context has many societal, economic and political benefits. Sustainable water management means sharing timely, quality, long-term information on water quantity and quality, and their variation as a basis for sound national and regional decision making. This may require the construction of a comprehensive, coordinated and sustained observational system or systems, such as prediction systems and decision support capabilities and developing capacity (human and institutional) for making maximum use of globally integrated data and information for local purposes as well as for observation and collecting data. Managing our water resources from space is possible and is complimentary to the efforts on the ground.

Global earth observation systems seek to track these variables by filling in existing information gaps about water resources, integrating data sets from various monitoring systems, developing better forecasting models, and disseminating the results to a wider range of decision makers. A key step is to combine water-level data from satellite-based radar altimeters with data from ground-level, in-situ monitors. This will improve the ability of water managers to map the water cycles of major rivers. There is also a need for standardising metadata and improving the accuracy of data and predictions and move from global prediction models to national-level models and river-basin or catchment-level models. These models will eventually become interoperable, creating a "system of systems" that will facilitate the global exchange of observation data and forecasting information.

Successful and sustainable development and application of earth observation in IWRM requires dedicated capacity development and training of scientists and water authorities to exploit current and future satellite observations. This course manual is aimed at exchanging information and knowledge transfer on the best practices and available tools for applications of earth observations for water resources management in low and medium income countries.

In order to utilise the emerging earth observation data and associated techniques from different sources, capacity development programmes in different modules and at different stakeholder levels need to be devised and implemented. Earth observation providers/space agencies also need to prioritise their action plan in such a manner to cater to the urgent needs of the society which would eliminate the associated risk.

1.9 SUGGESTED READING

Cap-Net (2005) Tutorial on basic principles of integrated water resources management.

United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations World Water Assessment Programme (WWAP), UN-Water (2012) United Nations World Water Development Report 4. Accessed online March 2012. http://www.un.org/waterforlifedecade/scarcity.shtml

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Global Water Partnership (2000) TAC Background Paper No. 4: Integrated Water Resources Management. GWP: Stockholm, Sweden.

http://unesdoc.unesco.org/images/0018/001880/188045m.pdf

http://www.a-a-r-s.org/ws-eowm/index.php

http://www.earthobservations.org/index.shtml

http://www.esa.int/esaEO/index.html

United Nations (2009) Water in a Changing World. http://www.unesco.org/water/wwap/wwdr/wwdr3/pdf/WWDR3_Water_in_a_Changing_World.pdf

http://www.hydrology.nl/mainnews/1-latest-news/497-earth-

Chapter 2

Earth Observation Systems

Based on Textbook: Stein et al (2011): GI Science and Earth Observation: a process-based approach, ITC, Enschede, The Netherlands. 2nd edition.

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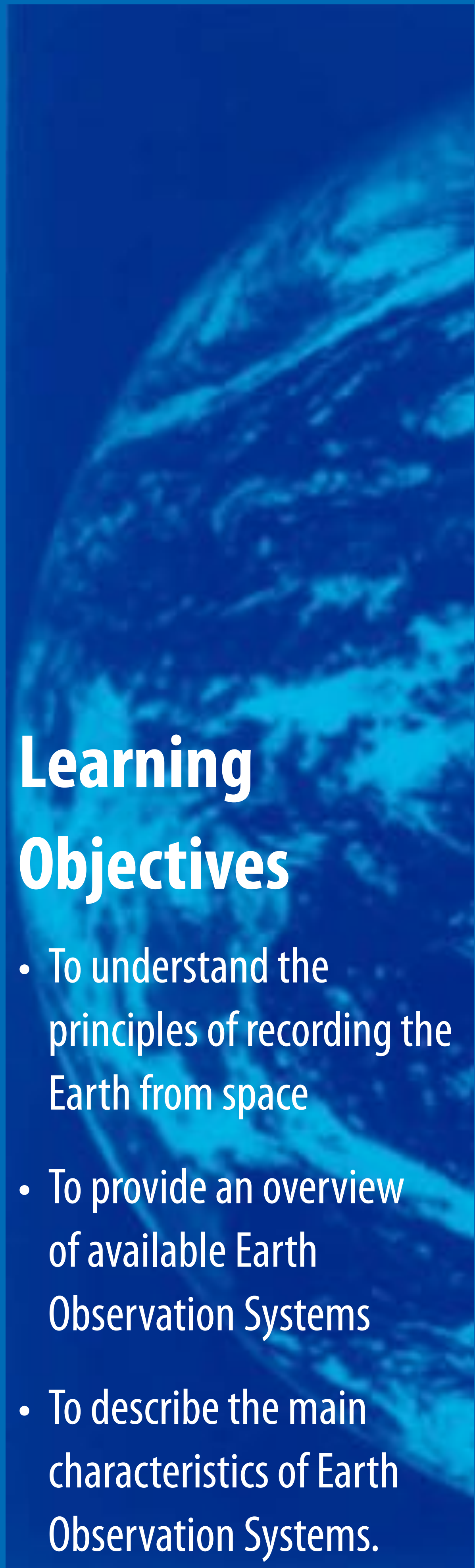


Learning Objectives

- To understand the principles of recording the Earth from space
- To provide an overview of available Earth Observation Systems
- To describe the main characteristics of Earth Observation Systems.

2.1 INTRODUCTION

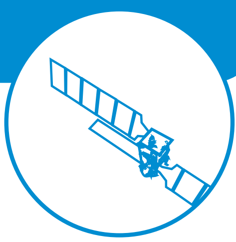
With the launching of satellite into space a new era of observation of the earth started. Aerial photography was commonly used for cartographic and detailed reconnaissance studies. High quality photographs were produced of relatively small areas. The scale of the observations was large, providing a detailed view of the earth. The instability of the recoding platform caused by the turbulence and the spectral characteristics of the sensor limited in many cases the usefulness of the recordings. Aerial survey missions were not done on a regular base so seasonal or let alone daily changes of the earths' surface could not be monitored.

Satellites provided a stable platform and with sophisticated sensors on board, the earth can be observed as never was done before. Nowadays with fast internet, cheap storage capacity of computers and tremendous developments of processing speed and dedicated software the use of satellite images for assessment of water resources and monitoring of water related phenomena has become relatively easy and accessible for the water resources manager.

In this section an overview of Earth Observations Systems will be given, attention will be paid to their main characteristics of the systems and how the systems can be categorized.

2.2 CATEGORIZATION OF SENSOR SYSTEMS

A remote sensor is a device that detects EM energy, quantifies it, and usually records it, in an analogue or digital way.



It may also transmit recorded data to a receiving station on the ground from where it can be processed and/or broadcasted to the users. Sensors record intensity levels, which correspond to radiances of reflected or emitted EM energy of the target area. An electronic sensor "measures intensity" by detecting photons, converting those to electrons and the collected charge to an electrical signal. The analogue electrical signal is sampled and converted to a digital number (DN).

We refer to the different portions of the spectrum by name: gamma rays, X-rays, UV radiation, visible radiation (light), infrared radiation, microwaves, and radio waves. Each of these named portions represents a range of wavelengths, not one specific wavelength. The EM spectrum is continuous and does not have any clear-cut class boundaries.

There are many ways to categorize the sensor systems. One way is to separate active and passive sensors. Passive sensors depend on an external source of energy; in particular the Sun. Active sensors have their own source of energy which is emitted from the sensor. Another way is to separate the sensors on the basis of the wavelengths they can 'sense'. Figure 2.1 shows the available sensor systems depending on wave length and energy source.

In the paragraphs below first the active and passive microwave systems will be described, follows by a description of the commonly used imaging spectrometers in the visible and thermal domain.

2.2.1 Active and Passive Microwave Sensors

Sensors which observe in the spectrum beyond the 1 cm wavelength are the microwave sensors. They can be grouped in Active and Passive Sensors. Active microwave remote sensing uses electromagnetic waves with wavelengths between 1 cm and 1m. These relatively long wavelengths have the advantage that they can penetrate clouds and are independent of atmospheric scattering. In active systems the antenna transmits microwave signals from an antenna to the Earth's surface where they are backscattered. The reflected EM energy is detected by the sensor. There are several advantages to the use of active sensors, which have their own energy source: the radar signal can penetrate through clouds and the emitted signal can be controlled. Depending on the application, the direction, polarization and energy

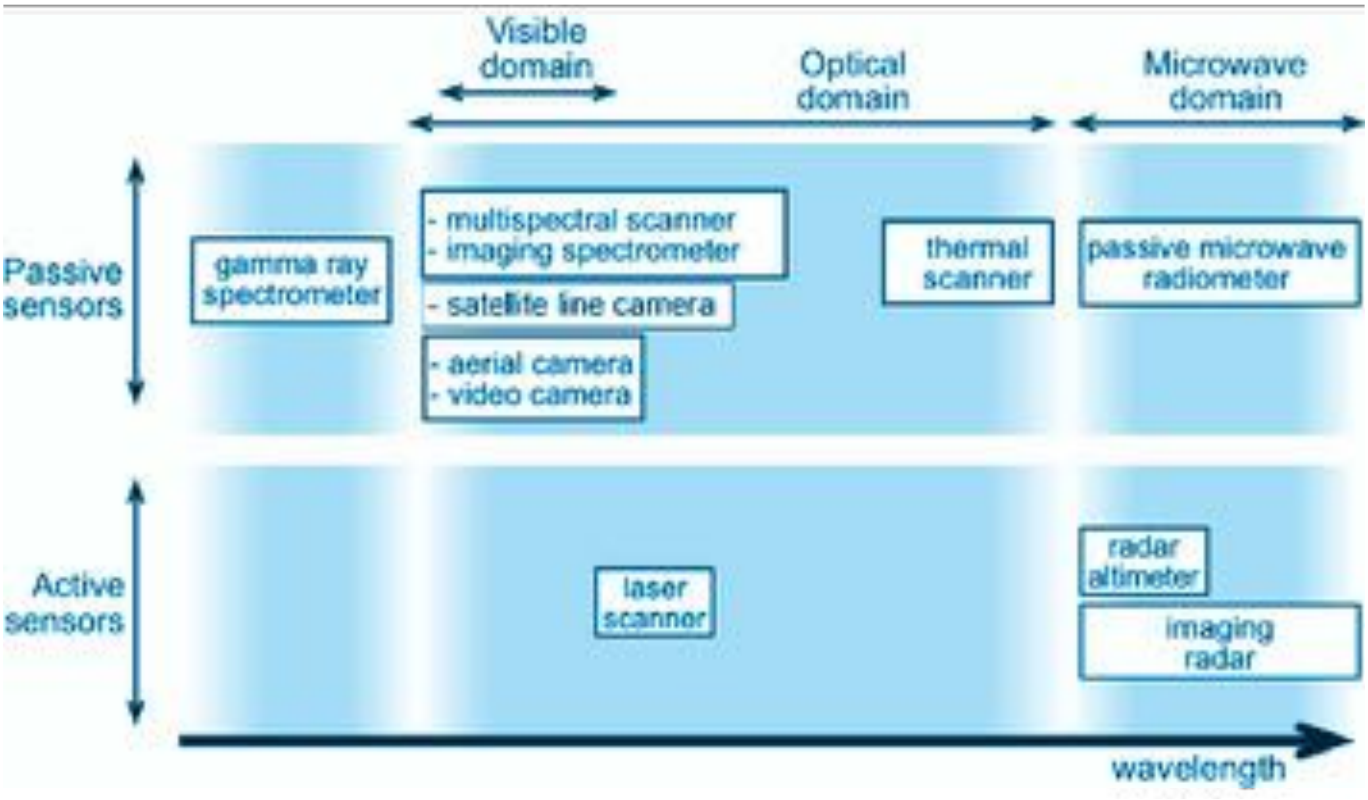


Figure 2.1: Overview of sensors

level of the radar-signal can be set inside the sensing system.

Frequently used radar systems are Advanced Synthetic Aperture Radar (ASAR) on board of the ENVISAT satellite (a follow-up of the Synthetic Aperture Radar on board of the ERS satellites).

Passive microwave radiometers detect emitted radiation of the Earth's surface in the 10 to 1000 mm wavelength range. The emitted radiowaves can be correlated to the moisture level of the top 1-3 cm of the soil. Until recently the Advanced Microwave Scanning Radiometer - EOS (AMSR-E) aboard the Aqua satellite recorded provided soil moisture products (see Figure 2.2). The SMOS - Soil Moisture and Ocean Salinity platform has a Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) on board. The Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) is a passive microwave sensor designed to provide quantitative rainfall information over a wide swath under the TRMM satellite. By carefully measuring the very small amounts of microwave energy emitted by the Earth and its atmosphere, TMI is able to quantify the water vapour, the cloud water, and the rainfall intensity in the atmosphere.

2.2.2 Microwave Sensors Applications

Active radar sensors are often used for the mapping of areas that are under permanent cloud cover. They are primarily used in meteorology, hydrology and oceanography. Since radar backscatter is sensitive to surface roughness, it helps to discriminate between ice and debris, thus making it potentially suitable for glaciers monitoring studies. Radar also allows the measurement of elevation and change in elevation by a technique called Interferometric SAR (INSAR). Radar data is also used for oil-slick monitoring and environmental protection. Passive microwave sensors are mainly used for climate related observations such as soil moisture, wind speed, rain rates and ice coverage.

2.2.3 Multi-spectral scanners

The satellite systems which are most commonly used for water resources monitoring and assessment purposed are the so-called Multi-Spectral Scanners Sensors. They operate in the visible and/or thermal domain and use an electro-optical remote sensor with a scanning

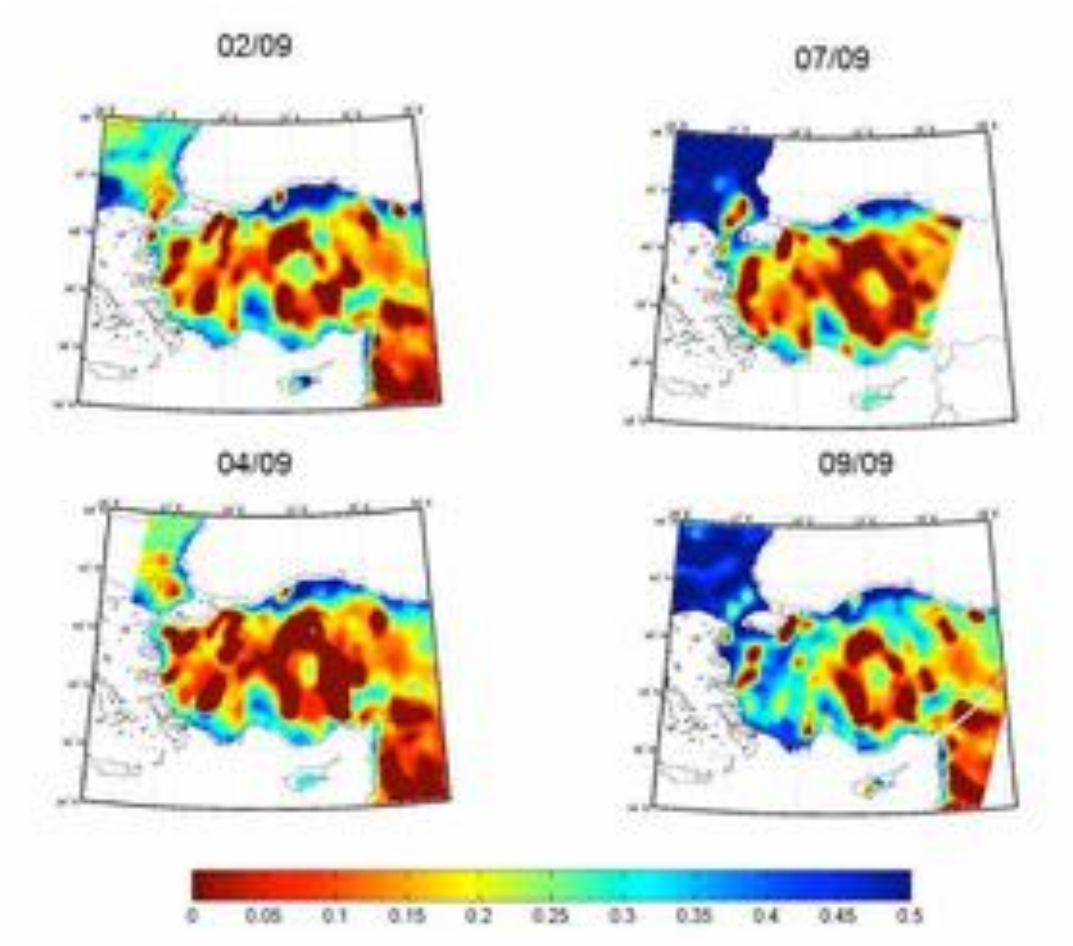


Figure 2.2: Soil moisture dynamics over Turkey based on AMSR-E

device, which is in most cases a mechanical component. The sensor has a very narrow field of view (called the instantaneous field of view (IFOV)) of 2.5 milliradians or less. The sensing device has to scan the ground across the track while the aircraft or space craft is moving. The most commonly-used scanning device is a moving mirror, which can be an oscillating mirror, a rotating mirror (the whisk-broom scanner). Another method to scan the earth is it through a line camera. A line camera builds up a digital image of an area line by line. A line of CCD (Charged Coupled Devices) records the reflectance while the satellites move over the area. In older literature, therefore, it is also referred to as 'pushbroom scanner'; this opposed to a 'whiskbroom scanner', which actually scans across the track of the moving platform. Fig 2.3 and 2.4 shows the principles of both scanning systems. The radiometric quality of scanners (whiskbroom sensors) is usually less than that of comparable line cameras.

Since 1970's multi-spectral scanners on board of satellite record on a regular basis the earths' surface in the visual and thermal domain. Some scanners observe the earth every 15 minutes; others pass over the same area every 14 days depending on the orbit the satellite is in. Same scanners have a high spatial resolution resulting in a < 1 meter pixel size, others produce coarse image with a resolution of > 1000m. To determine the monitoring capabilities and related spatial and temporal resolution of a satellite sensor one have to know the orbit of the satellite.

In the section below the orbit characteristics are described.

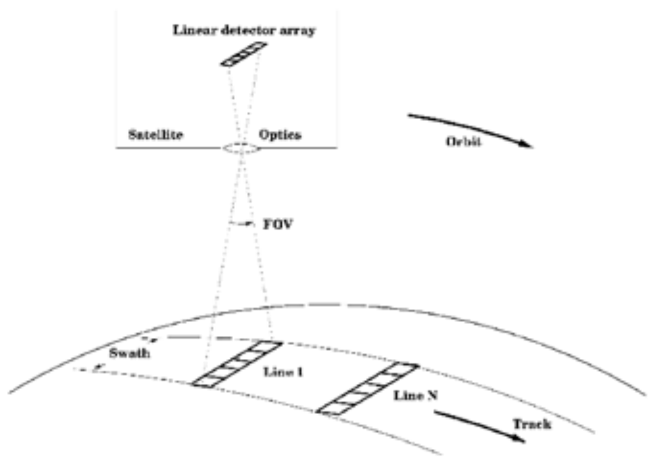


Figure 2.3: Principle of imaging by a line-camera on a space-craft (pushbroom)

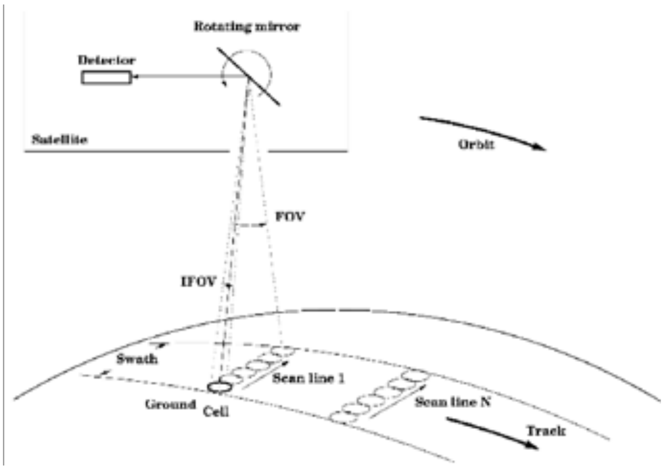
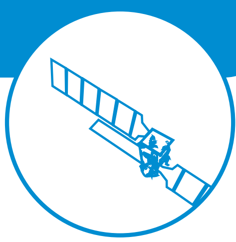


Figure 2.4: Principle of an across-track scanner (whiskbroom)

2.3 ORBIT CHARACTERISTICS

> The monitoring capabilities of a satellite sensor are to a large extent determined by the parameters of the satellite's orbit. An orbit is a circular or elliptical path described by the satellite in its movement round the Earth.



Different types of orbits are required to achieve continuous monitoring (meteorology), global mapping (land cover mapping), or selective imaging (urban areas). For earth observation purposes, the following orbit characteristics are relevant.

a. Orbital altitude is the distance (in km) from the satellite to the surface of the Earth. It influences to a large extent the area that can be viewed (ie, the 'spatial coverage') and the details that can be observed (ie, the 'spatial resolution'). In general, the higher the altitude the larger is the spatial coverage but the lower the spatial resolution.

b. Orbital inclination angle is the angle (in degrees) between the orbital plane and the equatorial plane. The inclination angle of the orbit determines, together with the field of view (FOV) of the sensor, the latitudes up to which the Earth can be observed. If the inclination is 60, then the satellite flies over the Earth between the latitudes 60 north and 60 south. If the satellite is in a low-earth orbit with an inclination of 60, it cannot be used for observations of the polar regions of the Earth.

c. Orbital period is the time (in minutes) required to complete one full orbit. For instance, if a polar satellite orbits at 806 km mean altitude, then it has an orbital period of 101 minutes. The speed of the platform has implications on the type of images that can be acquired. A camera on a low-earth orbit satellite would need a very short exposure time to avoid motion blur due to the high speed. Short exposure time, however, requires high intensity of incident radiation, which is a problem in space because of atmospheric absorption. It may be obvious that the contradicting demands on high spatial resolution, no motion blur, high temporal resolution, long satellite lifetime and thus lower cost represent a serious challenge to satellite-sensor designers.

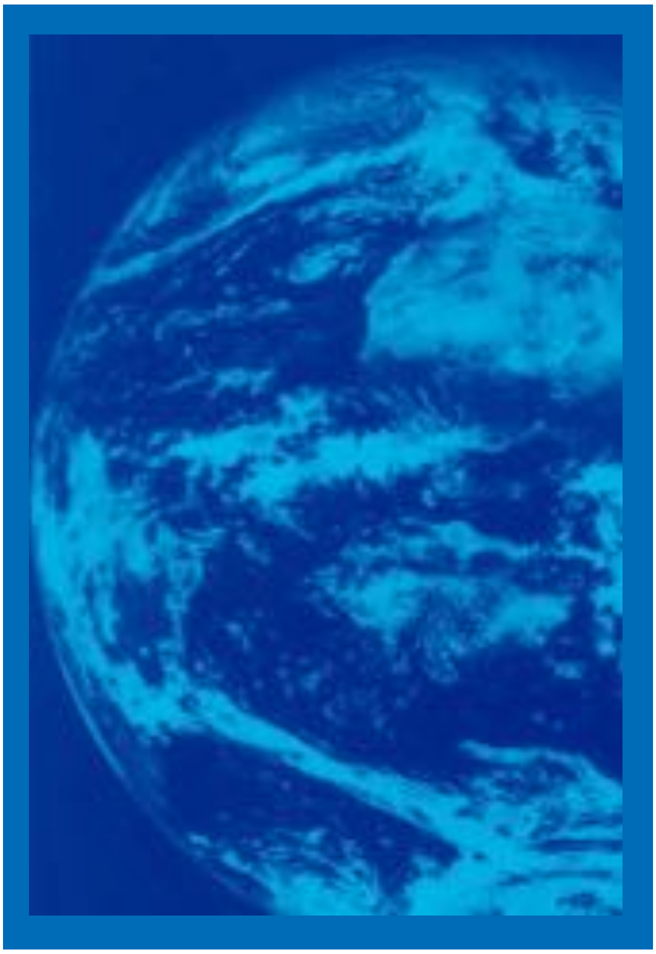
d. Repeat cycle is the time (in days) between two successive identical orbits. The revisit time (i.e., the time between two subsequent images of the same area) is determined by the repeat cycle together with the pointing capability of the sensor. Pointing capability refers to the possibility of the sensor–platform combination to look to the side, or forward, or backward, not only vertically down. Many of the modern satellites have such a capability. We can make use of the pointing capability to reduce the time between successive observations of the same area, to image an area that is not covered by clouds at that moment, and to produce stereo images.

The following orbit types are most common for remote sensing missions:

a. Polar orbit. Polar orbit is an orbit with an inclination angle between 80 and 100. An orbit having an inclination larger than 90 means that the satellite's motion is in the westward direction. Launching a satellite in eastward direction requires less energy, because of the eastward rotation of the Earth. Such a polar orbit enables observation of the whole globe, also near the poles. The satellite is typically placed in orbit at 600 km to 1000 km altitude. NOAA and MetOp are satellites in this orbit.

b. Sun-synchronous orbit. This is a near-polar orbit chosen in such a way that the satellite always passes overhead at the same time. Most sun-synchronous orbits cross the equator at mid-morning at around 10:30 hour local solar time. At that moment the Sun angle is low and the resultant shadows reveal terrain relief. In addition to day-time images, a sun-synchronous orbit also allows the satellite to record night-time images (thermal or radar) during the ascending phase of the orbit at the dark side of the Earth. Examples of polar orbiting, sun-synchronous satellites are Landsat, SPOT, CBERS and IRS.

c. Geostationary orbit. This refers to orbits where the satellite is placed above the equator (inclination angle: 0) at an altitude of approximately 36,000 km. At this distance, the orbital period of the satellite is equal to the rotational period of the Earth, exactly one sidereal day. The result is that the satellite is at a fixed position relative to the Earth. Geostationary orbits are used for meteorological and telecommunication satellites.



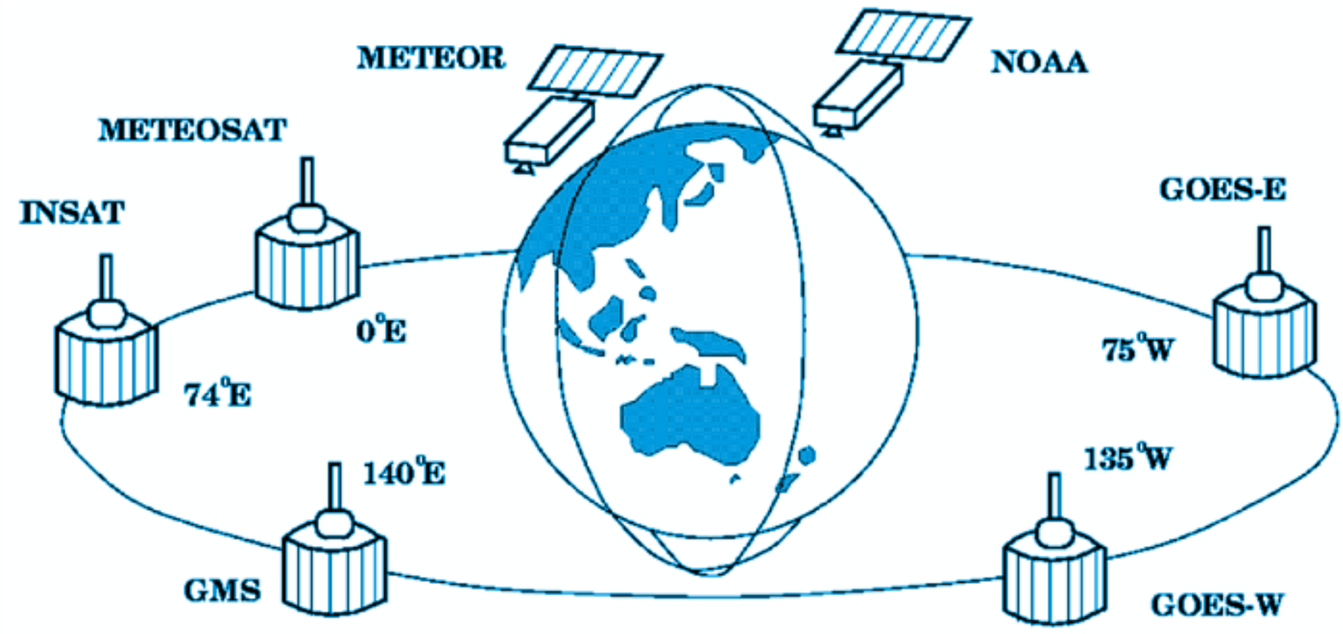


Figure 2.5: Meteorological observation by Polar and Geo-stationary satellites.

Chapter 3

Quick Introduction to ILWIS 3.1

Learning Objectives

- To introduce ILWIS 3.1 specifically the user interface and some key concepts of ILWIS based on the chapters 1 and 2 of the ILWIS 3.0 User's Guide.

Since the publication of this manual, ILWIS 3.1 has been upgraded with ILWIS Academic 3.3. Users may use the latest version. The basic principles and concepts still remain the same.

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3.1 ILWIS MAIN WINDOW

To start ILWIS 3.1, double-click the ILWIS icon on the desktop. After the logo, you see the ILWIS Main window (see Figure 3.1). From this window you can manage your data and start all operations and select all data.

Before continuing with the exercises you first need to change to the subdirectory that stores the data files for this exercise. Ask your supervisor where you can find the dataset.

Use the Navigator Pane to browse to the correct directory.

If you have browsed to the correct directory you will see in the Main window a list of ILWIS objects. This part of the Main window, in which maps, tables and other ILWIS objects in the working directory are displayed each with its own type of icon, is called a Catalog (see Figure 3.2).

To get more information on the ILWIS Main window, press the F1-key or open the Help menu and select Help on this Window. Go to section 1.1 of the ILWIS 3.0 User's Guide if you wish to practice some more xwith the individual parts of the Main window.

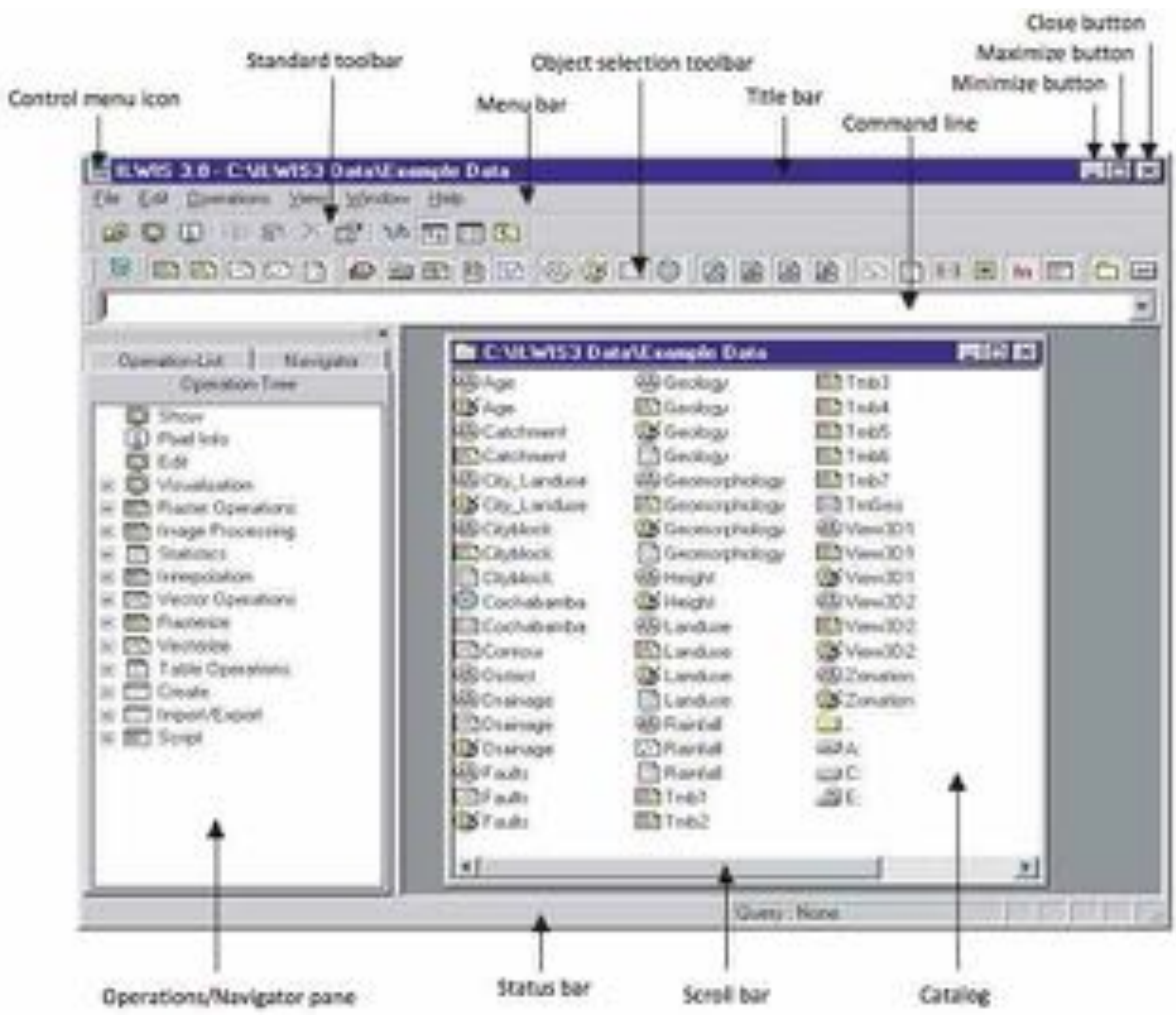


Figure 3.1: The ILWIS Main Window

Figure 3.2: Example of a Catalog of the ILWIS Main window

ILWIS objects commonly used are:

- Raster maps (for example Tmb1)
- Polygon maps (for example Cityblock)
- Segment maps (for example Contour)
- Point maps (for example Rainfall)
- Tables (for example Rainfall)
- Domains (for example Cityblock)
- Representations (for example Landuse)
- Coordinate systems (for example Cochabamba)
- Georeferences (for example Tmgeo)

The first five objects are called data objects. They contain the actual data. The other objects are service objects; they contain accessories that data objects need besides the data itself.

For a complete list of ILWIS objects and their icons, see the ILWIS Help topic Basic concepts, ILWIS objects and icons.

Position the mouse pointer on polygon map Landuse. A description of this map will appear on the Status bar.

The Status bar also gives short information when you move the mouse pointer to a menu command, to a button in the Toolbar to an operation in the Operation-Tree or Operation_List.

Click in the Catalog with the right mouse button on polygon map Landuse to get a context-sensitive menu.

A context-sensitive menu is a menu, which gives only those menu commands that are applicable to the moment you use the right mouse button; thus you will only get the operations which can be applied on polygon map Landuse.

3.2 KEY ELEMENTS IN ILWIS

ILWIS dialog boxes

A dialog box allows the use to enter the information required by ILWIS to carry out an operation. Dialog boxes differ depending on the application you are performing.

Double-click polygon map Landuse in the Catalog. The Display Options – Polygon Map dialog box (see Figure 3.3) is opened.

Figure 3.3: Example of a Display Options - Polygon Map dialog box.

Read pages 14 and 15 of the ILWIS 3.0 User's Guide or click the Help button to get more detailed information about the Display Options – Polygon Map dialog box.

A Map Window

A map window has many similar features as the Main window of ILWIS, which we have seen before.

Accept the defaults by clicking OK. Polygon map Landuse is displayed in a map window (see Figure 3.4).

To get more information on a map window, press the F1-key or open the Help menu and select Help on this Window.

Press the left mouse button on different units in the map to find out what they represent. Find the land use class around the location X=801830 and Y=8089283.

Domain

As you can see, the units of the Landuse map are described by classes, with names such as Forest, Grassland, Bare rock, Lake, etc. The list of all class names that can occur in a map is called in ILWIS a domain. A domain defines the possible contents of a map, a table, or a column. In other words, what do the items in a map, table or column mean? Are they classes (such as land use classes), or values or something else? All ILWIS data objects have a domain. The four most important types of domains are:

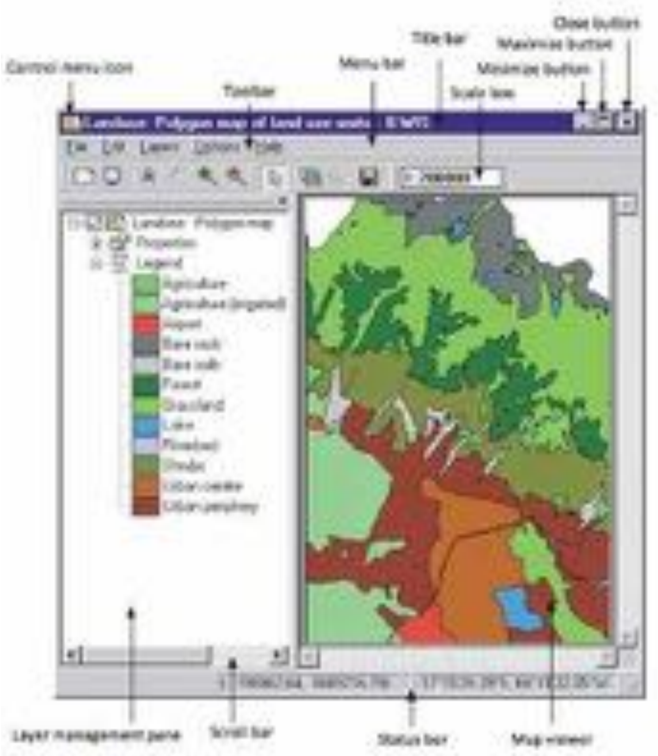


Figure 3.4: An ILWIS map window

- Class domains for data objects that contain classes (e.g. land use units, geomorphological units);
- ID domains for data objects that contain unique identifiers (e.g. city block 102, rainfall station Laguna);
- Value domains for data objects that contain measured, calculated or interpolated values (e.g. height, concentration);
- The Image domain for satellite images or scanned aerial photographs containing values between 0 and 255.

The domain concept is very essential in ILWIS. See the ILWIS Help topic ILWIS Objects, Domains for more detail.

Double-click with the left mouse button on a unit in the polygon map Landuse.

Now you will see a small window appearing with the title Attributes. Inside the window you will see two lines. The first line contains the land use class name of the unit you clicked, and the second line contains the word Landvalue followed by a number, which is the average monetary value of this land use type. The line with Landvalue information is a line from an attribute table Landuse, which is linked to the map.

A Table Window

Close the Attributes window and double-click table Landuse in the Catalog.

The table Landuse is now displayed in a table window (see Figure 3.5). As you can see from Figure 3.5, a table window contains many of the features we have already seen in the Main window and in the map window. The table contains two columns. The left column, in gray color, has no header. If you look closely to the names in this left column you will remember that those are the

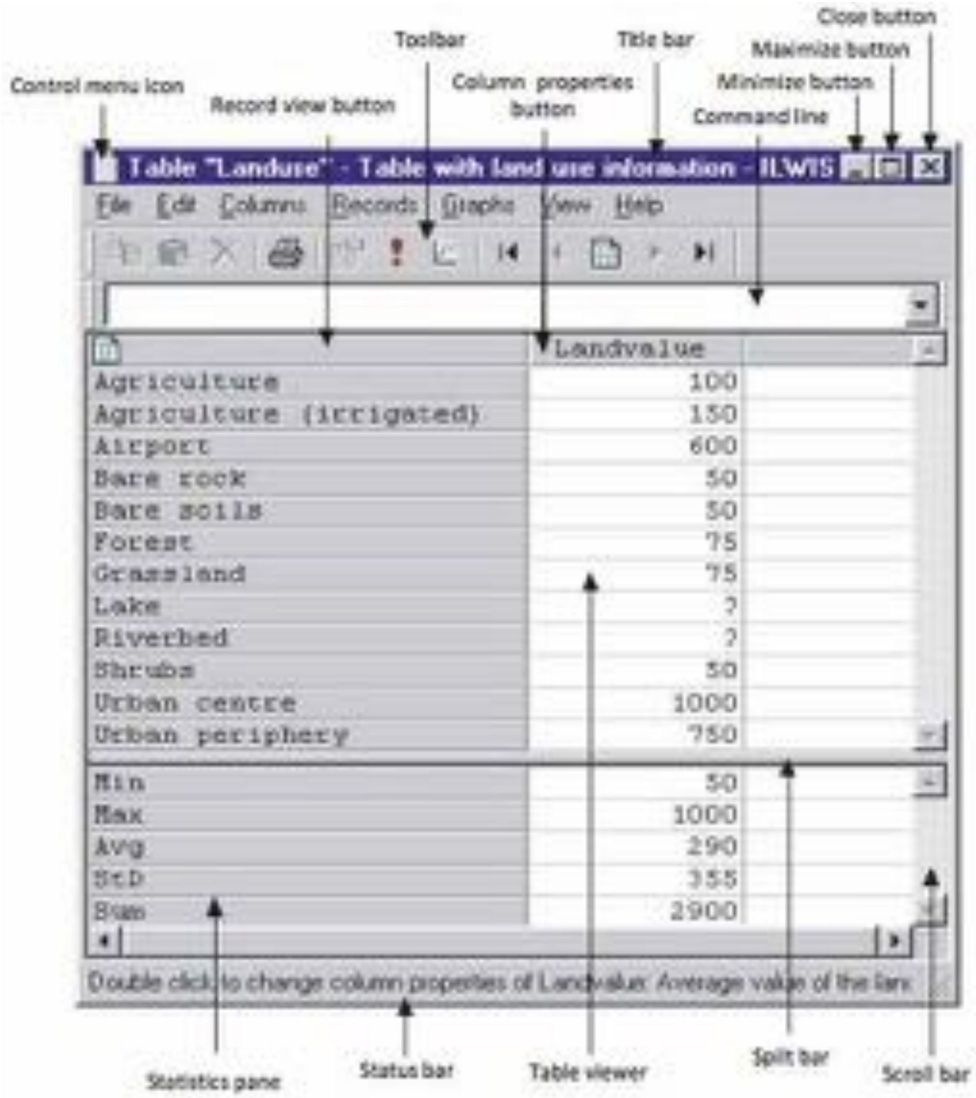


Figure 3.5: An ILWIS table window

names that you have seen in the map Landuse. This is the domain of the table. A domain can thus define the contents of a map as well as the contents of a table. Next to the left gray column containing the domain items, the table has one more column, called Landvalue. This column is an attribute column that contains the average value of the land in fictive monetary values. This column uses a Value domain.

To get more information on a table window, press the F1-key or open the Help menu and select Help on this Window or read pages 14 and 15 of the ILWIS 3.0 User's Guide.

Double-click the Column header with the name Landvalue on it. The Column Properties dialog box (Figure 3.6) appears.

The dialog box contains information on column Landvalue.

Click the Help button to get more detailed information about the Column Properties dialog box.

Click the Cancel button to close the Column Properties dialog box.

In section 1.2 of the ILWIS 3.0 User's Guide many more options of the table window are treated. For now, close table Landuse.

Open raster map Landuse in another map window and drag and successively resize both windows so that they are next to each other.

The first impression is that the polygon map and the raster map are the same. They are similar with respect to the information they contain. You can check this by

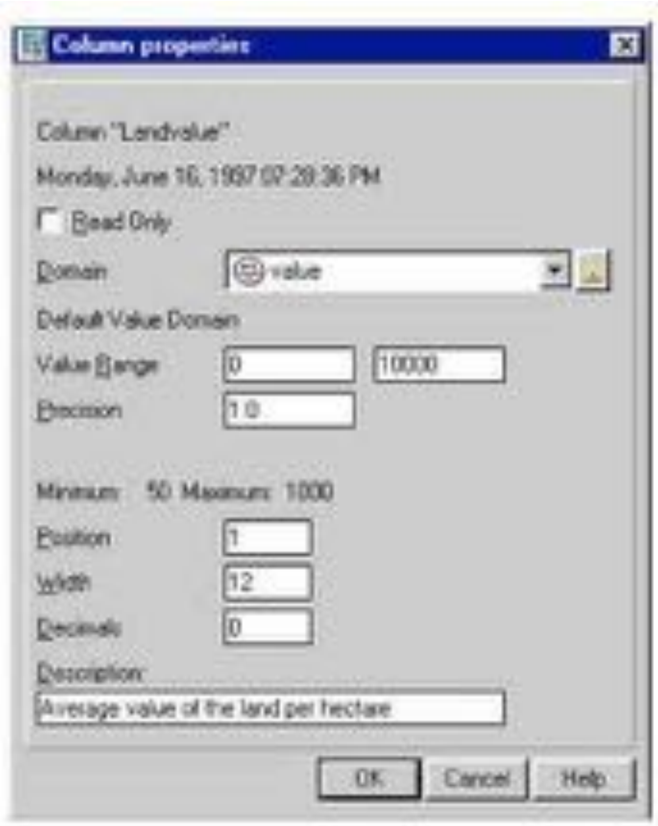


Figure 3.6: Example of a Column Properties dialog box.

clicking the same unit in both maps. The units of both maps are also displayed in the same colors. The difference, however, is in the way the information is stored in both maps; one in vector format and the other in raster format. The best way to evaluate this is by zooming in on both maps.

Click the Zoom In button  in the Toolbar of the polygon map. Position the mouse pointer in a section of the map near the boundary of several units (for example near the lake). Press the left mouse button, hold it down, and drag it to define a small area to zoom in on. Repeat this procedure for the raster map. Zoom in on the same area.

Now you can see quite some differences between the two maps. The polygon map displays smooth boundaries between the units, whereas the raster map has a blocky appearance.

Close the map window that displays raster map Landuse. In the Catalog select satellite image Tmb1 and drag it to the map window that displays the polygon map. The Display Options - Raster Map dialog box is opened. Accept the defaults and click OK. Raster map Tmb1 is now added to the map window.

In the map window, polygon map Landuse is displayed on top of raster map Tmb1. Each of the maps displayed in a map window is called a data layer.

Layer Management

In the Layer Management pane, drag and drop the Landuse polygon data layer below the Tmb1 data layer. Now raster map Tmb1 is displayed on top of polygon map Landuse.

Press the Normal button in the Toolbar of the map window to go back from the Zoom In mode to the Normal mode, and subsequently click individual pixels with the left mouse button. The values that can be read from the map are the values of raster map Tmb1.

Double-click Tmb1 in the Layer Management pane. The Display Options – Raster Map dialog box of raster map Tmb1 appears. In the Display Options – Raster Map dialog box clear the Info check box. This means that you will not see the values of the pixels anymore when clicking in the map.

Accept all other defaults and click OK. Note that in the Layer Management pane in front of the Tmb1 check box has disappeared.

Move again with the mouse pointer through the map while keeping the left mouse button pressed. The classes that can be read from the map viewer are the class names of polygon map Landuse.

Pixel Information Window

ILWIS has a special tool with which you can examine multiple maps and linked tables simultaneously: the pixel information window.

In the map window, open the File menu and select Open Pixel Information. The pixel information window (Figure 3.7) is opened.

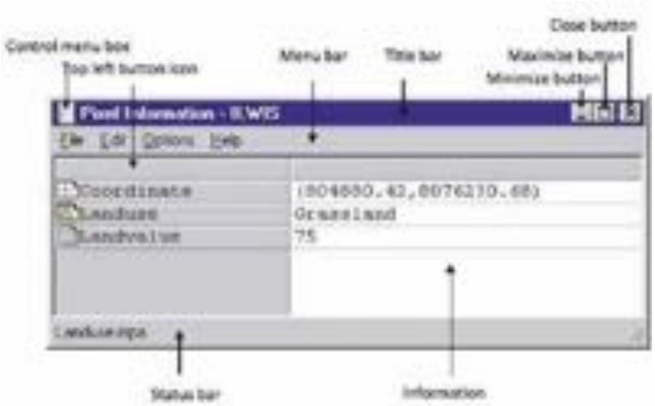


Figure 3.7: An ILWIS pixel information window

> To get more information on a pixel information window, press the F1-key or open the Help menu and select Help on this Window.

Position both windows next to each other and move the mouse pointer over the map. In the pixel information window, you can read the information of map Tmb1 and of map Landuse at the same location. Close the pixel information window by double-clicking the Control menu icon.

In the Layer Management pane expand the Properties tree of polygon map Landuse and double-click Landuse – Domain Class to open the Domain Class editor (see Figure 3.8).

As you can see, domain Landuse lists all possible class names of polygon map Landuse. It is simply a list of all land use types, which can occur in the map.

Domain Class Editor

Figure 3.8: The Domain Class Editor

> To get more information on the Domain Class editor, press the F1-key or open the Help menu and select Help on this Window.
>
> Go to section 2.3 of the ILWIS 3.0 User's Guide if you want to practice some more with different types of domains.

Close the Domain Class editor.

The Layer Management pane shows the Legend of the Landuse map, which is in fact representation Landuse. Double-click the word Legend in the Layer Management pane. The Representation

Class editor is opened in the polygon mode (see Figure 3.9).

Representation Class Editor

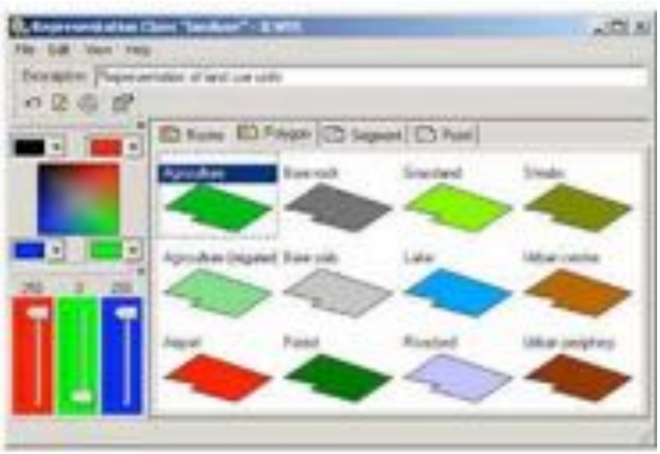


Figure 3.9: The Domain Class Editor

To get more information on the Representation Class editor, press the F1-key or open the Help menu and select Help on this Window.

As a domain determines what items can be stored in a map (or a table or a column), a representation defines how these items should be represented on a screen or a printout (e.g. color). Colors can be edited by clicking on an item, and then changing the Red/Green/Blue amount, by dragging the slide bars in the Color Slider, by selecting a color in the Color Selector or by double-clicking an item in the Representation editor.

Practice with changing colors as explained above. Have a look at the other menu items, try some and close the Representation Class editor. After that go to the Layer Management pane, select polygon map Landuse and click the Remove Layer button in the Toolbar of the map window. The Remove Layer box appears with the question Remove Polygon Map "Landuse" Are you sure? Answer this question with Yes.

Polygon map

We will now look at polygon map Cityblock, which contains the city blocks of a part of the city of Cochabamba.

Add polygon map Cityblock to the map window, zoom in and click the different city blocks to know the content.

You will see that each city block is identified by a number. These IDs are usually just numbers without a certain meaning. Additional information from each individual block can be obtained from the attribute table that is connected to the map.

In the Layer Management pane double-click polygon map Cityblock to open the Display Options – Polygon Map dialog box. Select the Attribute check box, choose attribute column LandUse with Representation City_Landuse and click OK. Polygon map Cityblock shows the prevailing land use type within a city block.

Segment map

Let us now add another data layer to the map window: a segment map containing digitized contour lines.

Click the Entire Map button and add segment map Contour. In the Display Options-Segment Map dialog box, select the Info check box, accept all other defaults and click OK. Segment map Contour is now added to the map window. Click the contour lines and read their meaning.

The contour lines are all coded according to their elevation. In this case the contents cannot be represented as classes, but as values. The map Contour therefore has a value domain.

Open the domain Height.

A value domain looks quite different from a class or ID domain. It is not a list of names or codes, but it is a definition of certain values that should be used in a map or a column. For the Cochabamba area, height values range from 2500 to 4600 meters.

Close the Height domain. In the Catalog, click domain Height with the right mouse button, and select the Properties command from the context-sensitive menu. The Properties sheet is opened. As you can see, domain Height has a representation value called Height. Close the Properties sheet and open representation Height. The Representation Value editor is opened. Have a look at representation Height.

A representation for a value domain is defined on the basis of a number of limiting values between which the color changes from one color to another in a number of user-defined steps.

> To get more information on the Representation Value editor, press the F1- key or open the Help menu and select Help on this Window.

Point Map

Finally, let us have a look at point map Rainfall containing fictive locations of rainfall stations in the Cochabamba area.

Close the Representation Value editor and drag and drop point map Rainfall to the map window. The Display Options - Point Map dialog box appears. Please note that point map Rainfall also uses an ID domain since each name is only valid for one rainfall station only.

Select the check box Text. Some extra text options appear. Click the Font button to open the Font dialog box. In the Font dialog box, select Font: Arial, Font Style: Regular and Size: 8 and click OK.

In the Display Options – Point Map dialog box, select Text Color: Yellow and click the Symbol button.

In the Symbol dialog box select Symbol Type: Simple, Symbol: Square, Size: 5, Fill Color: Yellow, Line Width: 1, and Color: Red. Click OK in the Symbol dialog box. Click OK in the Display Options - Points dialog box. The point map is now added to the map window. Close the map window when you have finished the exercise.

Object properties

As shown in preceding sections, different data and service objects are required to form a map in ILWIS. The properties of an object show which service objects are used for a data object or another service object. A vector map needs a coordinate system, a domain and a representation. These service objects are also needed for raster maps, together with another type of service object: a georeference. In Figures 2.4 and 2.5 of the ILWIS 3.0 User's Guide, a schematic representation is shown of the properties of vector and raster maps. To understand these figures it is good to look at the properties of domain Landuse.

Inspect the Figures 2.4 and 2.5 of the ILWIS 3.0 User's Guide. Click in the Catalog with the right mouse button on class domain Landuse, and select Properties from the context-sensitive menu. The Properties sheet is opened. Click the Use By tab.

You see a list of objects that are using this domain Landuse: raster map Landuse, polygon map Landuse, table Landuse and representation Landuse.

Compare the result with Figure 2.4 and close the Properties sheet afterwards.

Dependencies

When maps are used to create other maps, for instance by performing an operation or executing an expression, then this operation or expression and the input map name(s) are stored inside the new map. This is what ILWIS calls dependency. Output maps thus know how they are created and on which input maps, tables or columns they depend. Such output maps are called dependent data objects. The same applies for tables and columns. The operation or expression stored inside the dependent data object is called the definition. Let us look at an example. Polygon map Landuse was used in combination with the georeference Cochabamba to generate a raster map Landuse. This is shown schematically in Figure 3.10.

The dependent raster map, which is the result of the Polygon to Raster operation (i.e. the Rasterize Polygon Map operation), contains information on the source objects from which it was created. In this case a polygon map and a georeference. Let us check this example in the data set.

Click in the Catalog with the right mouse button on raster map Landuse and select Properties from the context-sensitive menu. The Properties sheet with the title 'Properties of Dependent Raster Map "Landuse"' is opened (Figure 3.11).

The Raster Map tab gives you information on the service objects of this map and information on how the map was made (i.e. the Definition).

> Click the Help button to get more detailed information about the Raster Map Properties dialog box.

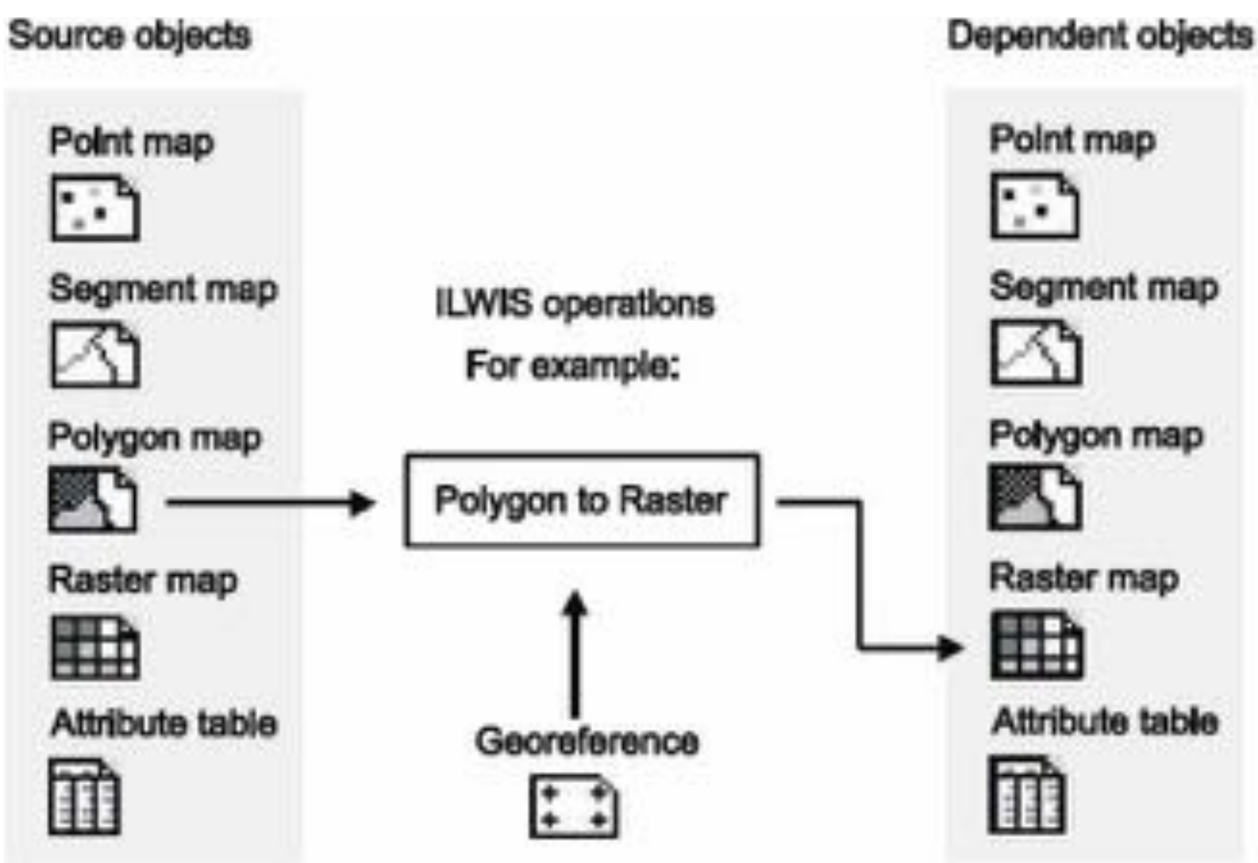


Figure 3.10: The dependency link between objects. The output raster map is made from a polygon map and a georeference, using the Polygon to Raster operation.

Figure 3.11: Example of a Properties Sheet

Click on the Dependency tab. Note that the line below the expression Map Rasterize Polygon (Landuse.mpa, Cochabamba.grf) says: Object is up-to-date.

This means that none of the source objects (i.e. polygon map Landuse and georeference Cochabamba) have been updated since the dependent raster map was generated.

Close the Properties sheet of raster map Landuse. In the Main window click the Details button  in the Standard toolbar. The Catalog, which is currently active, changes from a List View into a Details View. Check the columns D, C, U and Modified. You will see that all the maps are modified on the same date and time and that raster map Landuse is Dependent (D),Calculated(C) and Up-to-Date(U).

Now we are going to update the source polygon map Landuse.

In the Catalog click with the right mouse button on polygon map Landuse and select Edit from the context-sensitive menu. In the Polygon editor change for example the polygon Lake, near the Urban centre, into Urban periphery and close the window afterwards.

The polygon map is updated now. In the Catalog of the Main window you can see that the polygon map Landuse has been modified and that raster map Landuse is now Dependent (D), Calculated (C) and Not Up-to-Date (N).

Open the Properties sheet of raster map Landuse. On the Dependency tab you see: Object is not up-to-date: Landuse.mpa (day date time).

It is important to keep in mind that dependent maps are not automatically updated. ILWIS does keep track of the dates and times at which the source objects were modified. Only when you click the button Make Up-to-Date on the Dependency tab of the Properties sheet, ILWIS will ask you if you want to recalculate the map.

Click the Make Up-to-Date button. A Check Up-to-date message appears with the question Dependent raster map “Landuse” is not up-to-date. Recalculate it to make it up-to- date? Answer Yes to this question to recalculate the map.

Open the Properties sheet of raster map Landuse. On the Dependency tab you see that the Object is up-to-date again. Click the button Release Disk Space. The Release Disk Space dialog box appears.

Click Yes in the Release Disk Space dialog box. The Properties sheet closes.

Now the actual data file of the raster map is deleted. Only the definition of the map remains, so the map can always be recalculated. In the Catalog of the Main window you see that the raster map Landuse is now Dependent (D), Not Calculated (N) and Not Up-to-Date (N). We will recalculate the data file of the raster map below.

Open the Properties sheet of raster map Landuse. On the Dependency tab, click the Calculate button.

A so-called tranquilizer is displayed, showing the progress of the calculation of the map. When it stops, the raster map Landuse is again Dependent (D), Calculated (C) and Up-to-Date (U).

It is also possible to convert a map (or a table, or a column) from being a dependent object to a source object. In that case you will break the dependency link. After that, the map cannot be updated anymore from the Properties sheet. You actually need to do the operation again.

Open the Properties sheet of raster map Landuse. On the Dependency tab, click the button Break Dependency Link. A Break Dependency Link message appears. Confirm the question with Yes. The Properties sheet is closed. Open the Properties sheet again and note the difference.

Chapter 4

Concepts of Digital Image Classification

Learning Objectives

- To learn on digital image classification and practically doing it step by step
- To understand different classification systems and procedures

GO BACK TO TABLE OF CONTENTS

4.1 INTRODUCTION TO DIGITAL IMAGE CLASSIFICATION

Multi-spectral sensors in earth observation satellites measure the amount of sunlight that is reflected by the earth surface. Different parts of the electro-magnetic spectrum (spectral channels or bands, such as infrared, red, green) are measured separately, but at the same time. The number of bands and their locations in the spectrum (expressed as wavelengths or wavelength intervals) specify the spectral resolution of a sensor. The measured reflection values depend on the local characteristics of the earth surface; in other words there is a relationship between land cover and measurement values. In order to extract information from the image data, we must find out this relationship. This will enable us to decide about land cover classes based on satellite images.

When we are able to make these decisions for an entire image, or for a part of it that has our interest, we can make a land cover map of that area. Multi-spectral Image Classification can be an important step in the production of thematic maps from satellite images. The aim is to make this process as "automatic" as possible by using suitable image processing and image analysis software. Therefore, such a process can be seen as a substitute for visual image interpretation. The place of multi spectral image classification in the context of spatial data acquisition and image processing is given in Figure 4.1 and list.

4.2 PRIMARY DATA ACQUISITION

- **Pre-processing**
    - Image restoration, Radiometric corrections, Geometric corrections
- **Image Enhancement**
    - Contrast enhancement, Noise reduction, spatial filtering (Sharpness)
- **Image Fusion**
    - Multi-temporal, Multi-resolution, Mosaicking
- **Feature Extraction, quantitative**
    - Spectral (NDVI), Spatial (lines, edges), Statistical (PCA)

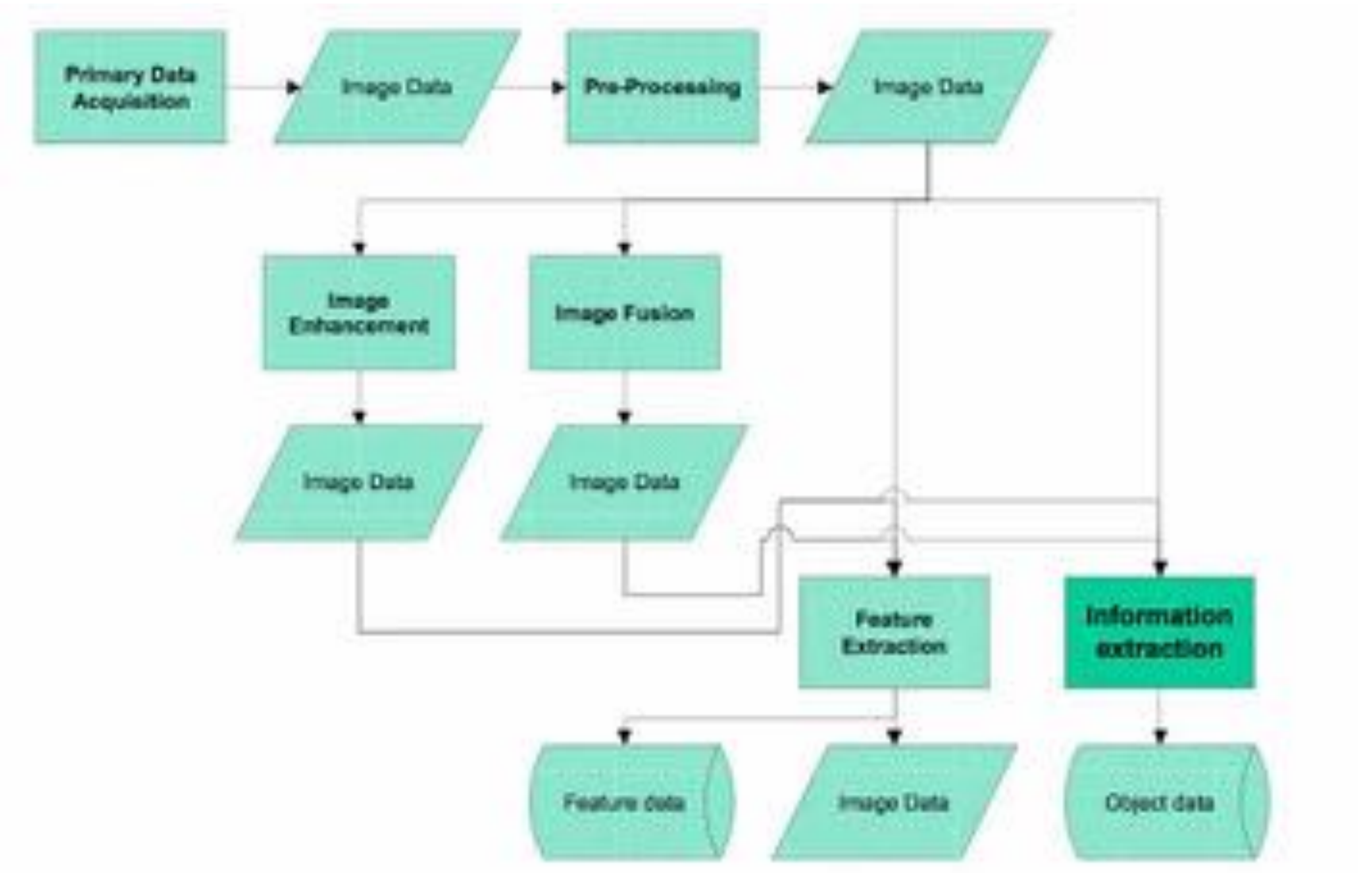


Figure 4.1: Multi-spectral Image Classification

- **Information extraction, qualitative**
    - Classification, classified pixels
- **Supervised**
- **Unsupervised**
    - Segmentation, spatial objects
    - Visual Interpretation

4.3 SLICING

We can derive a histogram of images. Of each intensity value, or pixel value, the frequency of appear-ance is counted and plotted in a diagram. If the histogram of a single layer/band shows a number of distinct peaks (maxima) and valleys (minima) then we can assume, based on our knowledge of visual interpretation of aerial photos, that the distinctive parts with high frequencies have a spectral property in common and correspond to different landcovers (grass, bare soil, forest, water etc.). These different landcovers are called classes, so class grass or class forest etc.

On this basis we can subdivide the horizontal axis of the histogram diagram into slices. These slices start and end at a valley or minimum. The slice boundaries are given by the intensity values belonging to the minima.

On the horizontal axis a number of slices can be detected.

Clear distinction between slices

In the easiest situation, we can link one slice to one interval or class. The minima are zero, so there will be distinct boundaries between the slices (See Figure 4.2). Without any additional information we do not know which landcover classes exist in the image and which slice belongs to which class. We only dissect the histogram into slices. This method is called an unsupervised classification, because we are not using any supervised knowledge to take decisions. If the slices are labelled (giving them a number, code or colour) and these labels are assigned to the corresponding pixels in the image layer, then the results is a sort of classified image. It only gives the information, to which slice a pixel belongs it does not tell what landcover is associated with it.

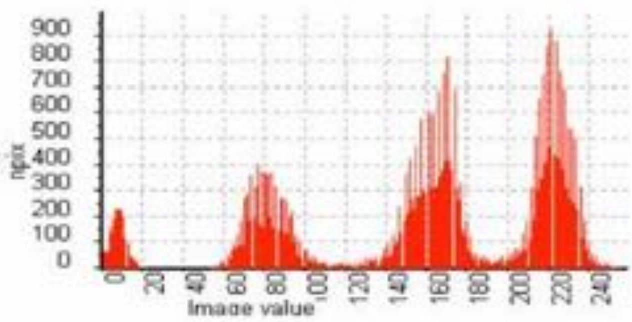


Figure 4.2: The distinct boundaries between the slices of the histogram

No clear distinction between slices

If the minima in the histogram are not equal to zero, thus there are no distinct boundaries detectable for the intervals (See figure 4.3), then we can assume that there is an overlap between two or more classes. This means that a pixel value in the image layer can belong to different classes and a clear slicing is not any more straightforward. Several methods are developed to support the slicing in this case, although these techniques are outside the scope of this lecture.

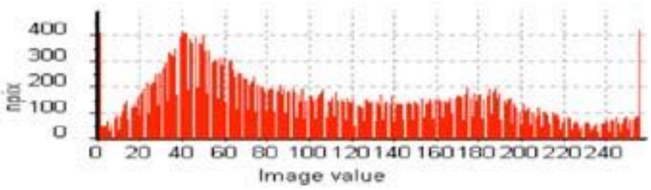


Figure 4.3: No distinct boundaries detectable in the histogram

4.4 SCATTERGRAM

A plot of values of 1 band and their frequency is called a histogram. A plot of the values in two bands of all pixels is called scattergram or 2-dimensional histogram or alternatively a 2-dimensional feature space plot.

A scattergram can be considered a histogram of two-bands-at-the-same-time. For each combination of DN-values, the frequency of occurrence is calculated. Different intensities (or different colours) are used to represent those frequencies. In the figure below the feature vectors (or combinations) band 3 between 50 and 65 AND Band 4 between 50 and 60 have highest frequency and occur most (red). E.g. there are many pixels with the value combination [60,55]. A feature vector of [55,150] has low frequency (purple); there are only few pixels with that combination. See Figure 4.4 and 4.5.

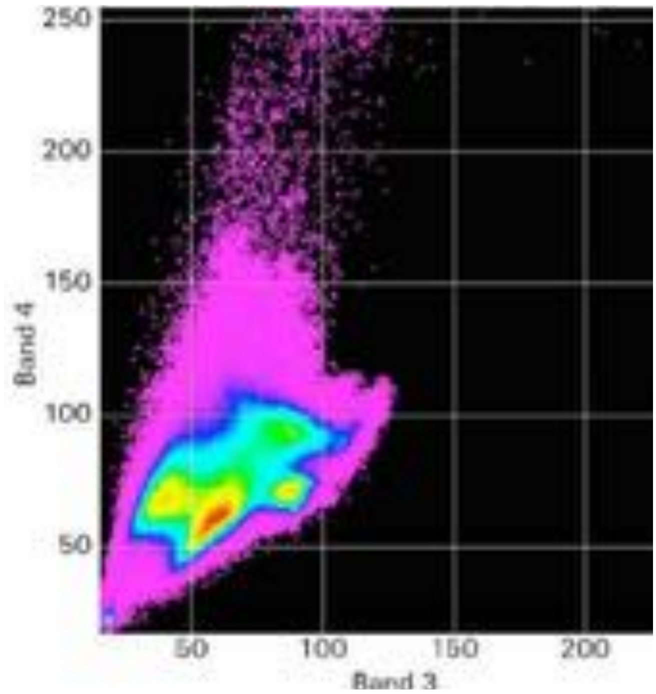


Figure 4.4: Scattergram 2-dimensional

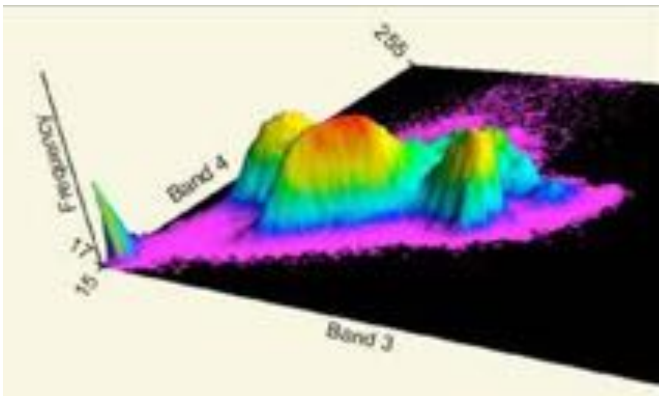


Figure 4.5: Scattergram 3-dimensional

4.5 MULTI-DIMENSIONAL FEATURE SPACE

A pixel in a multi-spectral image (n-bands) consists of a vector of reflection measurements: one measurement per spectral band. This vector is called a n-dimensional feature vector. It can be plotted in an n-dimensional feature space.

When we look at a certain image pixel in n bands simultaneously, we observe n values at the same time. In the example of multi-spectral SPOT-1, where n = 3, we have for each pixel three reflection values, in the green, red and infrared parts of the electro-magnetic spectrum, respectively. For instance, we get (34, 25, 117) in one pixel. In another pixel, we might get (34, 24, 119) and in a third (11, 77, 51).

You can already recognise that the first two patterns are quite similar and that the third is different from the other two. The first two probably belong to the same landcover class and the third belongs to another one.

The Figure 4.6 shows a 2-dimensional and a 3-dimensional feature space with a feature vector. Feature spaces may have more than three dimensions, but then they are difficult to visualise.

We can plot all pixels of a multi-spectral image in a so called multi-dimensional feature space. A plot of a

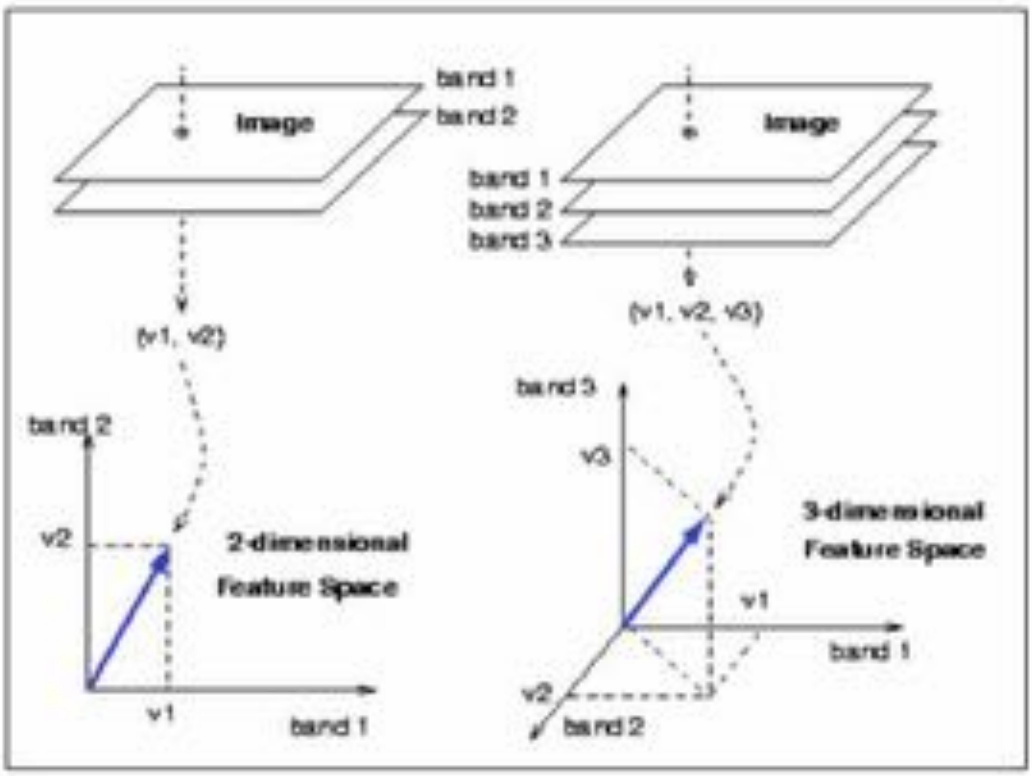


Figure 4.6: Illustration of 2-dimensional and 3-dimensional plotting of a multi spectral image

selection of two elements from each feature vector, or a feature space projection[1], the result is called scattergram.

4.6 TRAINING SAMPLES

Like with a histogram, it can be decided that isolated or clearly distinct clusters in the feature space are caused by clearly distinct and separate classes. To define such clusters in an n-dimensional feature space, and to define which landcover class to associate with each cluster we need training samples. The procedure is then called a supervised classification since we provide additional information to the software to define the clusters (class boundaries).

During the training phase of supervised classification we must feed some "knowledge" about the relationship between classes and feature vectors into the computer.

The Figure 4.7 shows a scattergram, made from the training samples: a few image pixels of which the class is known. The class determines the colour of those pixels in the feature space.

1 Given the fact that we can actually consider the feature space as a geometric space containing feature vectors, vector geometry theory is applicable; a plot of 2 bands from a n-dimensional feature space is a projection from the n-dimensional feature space onto the two dimensions.

The point of the whole story is obviously that pixels, belonging to the same (land cover) class have similar spectral characteristics, and end up near to each other in the feature space. All pixels belonging to a certain class will (hopefully) form a separable cluster in the feature space.

Theoretically, the relationship between classes and feature vectors could be stored in a data base. It is tempting to assume that in the past enough images of each kind of sensor have been analysed as to know the spectral characteristics of all relevant classes. This would mean, for example, that a pixel with feature vector (44, 32, 81) in a multi-spectral SPOT image always means: grass, whereas (12, 56, 49) is always a town pixel. This would mean that training is not necessary but these relationships could be used over and over again.

4.7 WHY TRAINING?

Usually the observed feature vectors in a particular image are influenced by a large number of other factors than land cover, such as: atmospheric conditions, sun angle (as a function of latitude/time of day/date and

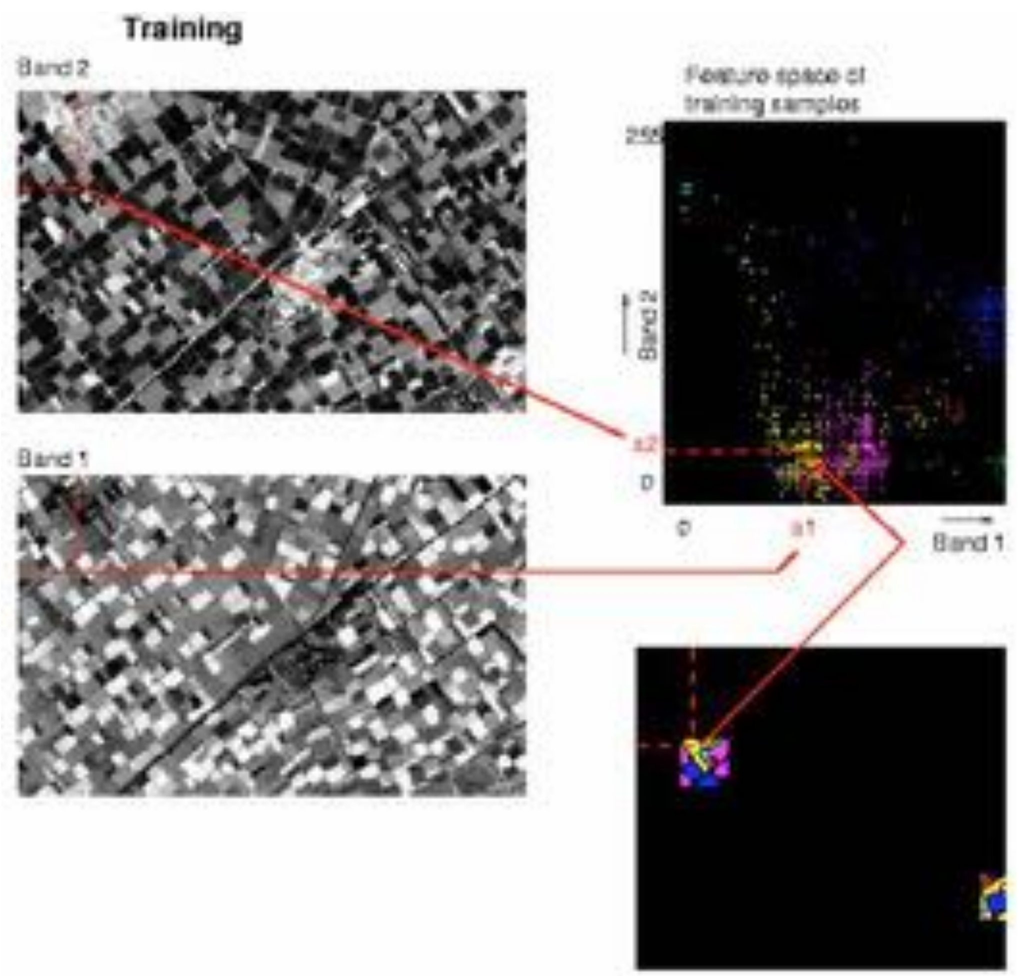


Figure 4.7: Training samples

as function of terrain relief), soil type, soil humidity, growing stage (vegetation), wind (affecting orientation of leafs), etc.

The problems we meet when trying to take all these influences into account vary from 'quite easy' to 'practically impossible'; at least, vast amounts of reliable additional data (DEM's, soil maps etc.) would be required. See Figure 4.8

Much more widely used are, therefore, classification methods where the process is divided into two major phases: a training phase, where the user "trains" the computer by telling for a limited number of pixels to what classes they belong in this particular image, followed by the decision making phase, where the computer assigns a class label to all (other) image pixels, by looking for each pixel to which of the trained classes this pixel is most similar.

During the training phase, we must first decide and describe which classes to use. This step is often not taken seriously. However a good unique description of classes highlights problems like overlap, gaps, confusion especially when working in teams. About each class we need some reference data: a number of places in the image area that are known to belong to that class. This knowledge must have been acquired, for instance during fieldwork, or from an existing map or higher resolution image/photo (assuming that in some areas the class membership has not changed since the map was produced or the image taken).

Then, we need suitable training software, which allows us to put the image on the computer screen such that we can orient ourselves properly and find the places where our reference data is collected. The software should allow us to indicate training samples (small areas or individual pixels) in the image and to enter the corresponding class names. It helps if meanwhile we are able to inspect the feature space, where our training samples are plotted using distinct colours for the different classes. This enables us to judge whether our classes are really spectrally distinguishable, whether each class corresponds to only one spectral cluster (if not, it is advisable to create subclasses, which must be joined after the classification is finished) etc.

4.8 CLASSIFICATION PROCEDURE

To perform a supervised classification of an image thus the following steps have to be executed (See Figure 4.9).

- Define the different (landcover) classes in which you are interested. This means that not all classes really will appear in that area. On the other hand it may happen that more classes exist then you define.

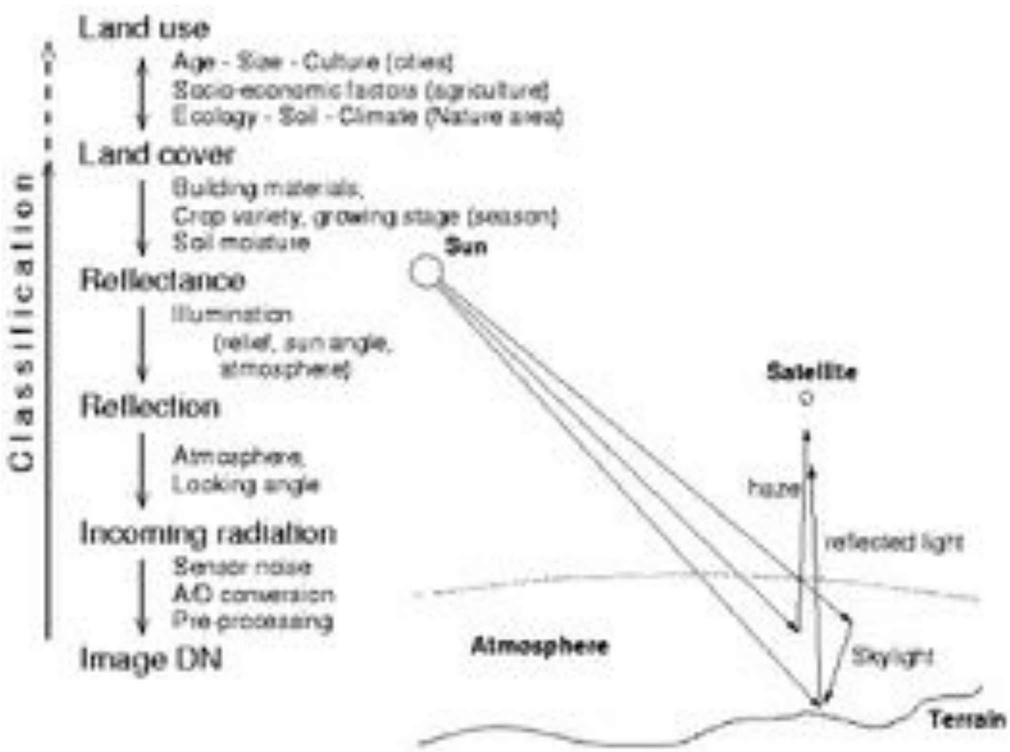


Figure 4.8: Factors influenced a satellite image

- Collect reference data
  - Collect by fieldwork or analysis of other data sources. Indicate where you can find the different classes on a map or a printed image. Identify of each class more locations to enable separate training of the classifier and accuracy assessment of the final classification.
- Create a sample/training set
- Choose a classifier/decision rule
  - Analyse statistics
  - Analyse feature space
  - Analyse sample set
- Classify the image data
- Assess the quality by accuracy assessment

Sample set creation

For each class a number of pixels (samples of ground truth) is selected in the image of which we know that they belong to that class. The intensity values of these pixels are used to extract the spectral characteristics of the classes. All samples together form the training set that is used to train the classifier. All pixels that belong to the training set are used to create a feature space plot. In the feature space plot some of the classes will overlap since some classes include pixels with the same spectral reflection, e.g. forest and grass. We will use a one dimensional example depicted by a histogram. See Figure 4.10.

The number of required representative samples for a classification is influenced by:

- Sampling strategy
  - E.g. gridded sampling requires more field data to be collected to be representative than stratified sampling
- Statistical rules
  - E.g. when the # samples is less than 4 x the number of classes the estimation error is high
- Accuracy assessment
  - If accuracy assessment is required, one actually needs two reference data sets; one for training and classification and one for the accuracy assessment

Some rule of thumbs does exist:

- 50-100 samples per class (Lillesand & Kiefer, Congalton & Green) for training and for accuracy assessment
- 10-100 samples x number of bands
- 1 % of image area (McCloy)

Figure 4.9: Flow chart of classification procedure

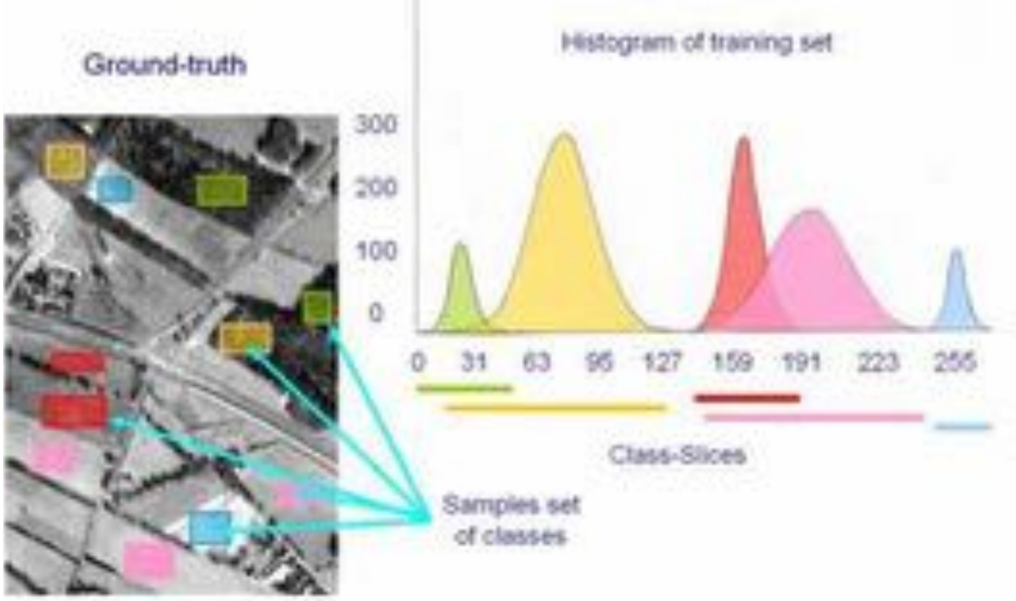


Figure 4.10: Creation of samples

Statistics

Some class statistics (minima, maximums, sizes, mean and standard deviation) are obtained from labelled feature vectors to assist in decision taking.

In case of a multi dimensional feature space, the mean vectors are computed. They consist of the means of the individual components of the vectors in the corresponding class sample set.

To derive a descriptive "shape" of a cluster in a feature space in all directions, we can use the standard deviations within the cluster. These standard deviations are computed with the variance/covariance matrices of the classes (See Figure 4.11).

Whether mean and standard deviation are applicable to describe the location and shape of a cluster depends on the class and on the sample selection.

Feature Space portioning

It is the task of the decision making algorithm to make (in one way or another) a partitioning of the feature space, according to our training samples. For every possible feature vector in the feature space (at least for those that actually occur in the image), the program must decide to which of the sets of training pixels this feature vector is most similar. After that (or in parallel, but this is an implementation detail), the program makes an output map where each image pixel is assigned a class label (usually the class number), according to the feature space partitioning.

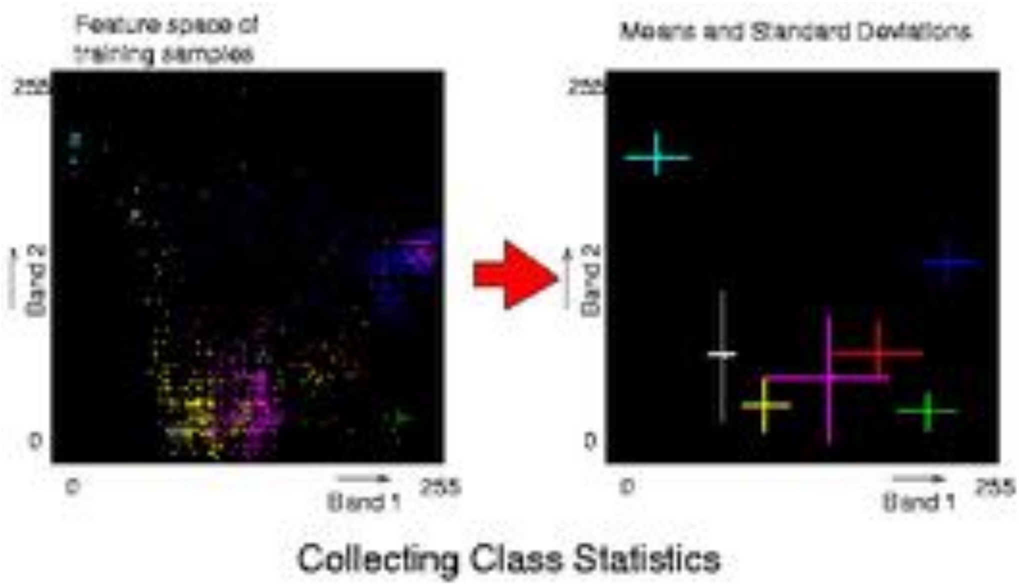


Figure 4.11: Collecting class statistics

Based upon the selected decision rule and class statistics, the feature space is partitioned.

To find the relationship between classes and (untrained) feature vectors is not as trivial as it may seem. Therefore, various decision making algorithms are being used; they are different in the way they partition the feature space.

Some algorithms are able to decide that feature vectors in certain parts of the feature space are not similar to any of the trained classes. They assign to those image pixels the class label unknown. In case the area indeed contains classes that were not included in the training phase, the result unknown is probably more realistic than to make a "wild" guess and assign another trained class label to it.

4.9 SUPERVISED CLASSIFICATION ALGORITHMS

To classify the image, the horizontal histogram axis is divided into a number of intervals. These intervals belong to the different classes. In those parts of the histogram where the samples of the different classes are overlapping a decision has to be taken which class will get the priority for these pixels. Several methods (decision rules) are developed to define these priorities. The following decision rules in classification methods for this one-dimensional case are treated. For n-dimensional feature space similar algorithms exist.

Priority to the class with:

1. the class interval (smallest slice-length, box/ parallelepiped)
2. the shortest distance to the class mean
3. the highest probability

Class interval

After the creation of the histogram, the maximum and minimum spectral value for each class sample are computed (See Figure 4.12). These two values are the boundaries of the interval per band. Pixel values inside this interval belong to the class that is assigned to this sample. If two or more samples overlap in the histogram, then pixels in these overlapping ranges will be assigned to the class that belongs to the smallest interval. If the samples of the class grass cover the interval from 42 to 83 and the class forest the interval 70 to 90 then a pixel with a value 72 will be classified as forest since the interval for forest is 20 and the interval for grass is 41.

Figure 4.12: Classification based on class-intervals using the histogram of training

In multi dimensions this decision rule is also referred to as Box-classifier or parallelepiped classifier.

Box classifier

The box classifier is the "easiest" one for n-dimensional feature spaces: In 2-D, rectangles are created around the training feature vectors for each class; in 3-D they are really boxes (blocks). The positions and sizes of the boxes can be "exactly including" the training feature vectors (Min-Max method), or according to the mean vector (this will be at the centre of a box) and the standard deviations of the feature vector, calculated separately per feature (this determines the size of the box in that dimension). In both cases, the user is sometimes allowed to change the sizes by entering a "multiplication factor". In parts of the feature space where boxes overlap, it is possible to give priority to the smallest box. Feature vectors in the image that fall outside all boxes will be unknown. See Figure 4.13.

Shortest distance to the class mean

After the creation of the histogram, the mean value for each class sample is computed. These values are about the midpoint of the interval in case the number of pixels in the samples is sufficient large (e.g. more than 100) and the class has a normal/Gaussian distribution. The midpoint between class means determine the class boundaries. Pixel values inside this interval belong to the class that is assigned to this sample.

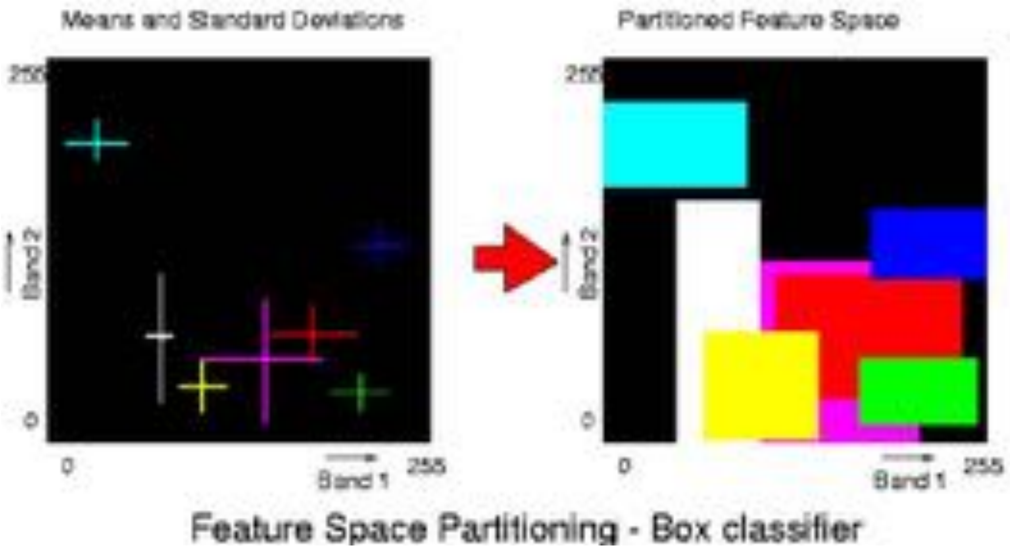


Figure 4.13: Using "Box Classifier"

Even if two or more samples overlap in the histogram, pixels with values in these overlapping ranges will be assigned to the class of which the distance from that value to the mean of the class is shortest.

If the sample of the class grass cover the interval from 42 to 83, with a mean 62.4 and the class forest the interval 70 to 90 with a mean 84.7, then a pixel with a value 72 will be classified as grass since the distance to the grass mean is 9.6 and the distance to the forest mean is 12.7.

In multi-dimensional feature space this algorithm is also called Minimum Distance to Mean classifier (See Figure 4:14).

Figure 4.14: Classification using closest distance to the class mean

Minimum distance to mean

The minimum distance-to-mean classifier first calculates for each class the mean vector of the training feature vectors. Then, the feature space is partitioned by giving to each feature vector the class label of the nearest mean vector, according to Euclidean metric. Usually it is possible to specify a maximum distance threshold: if the nearest mean is still further away than that threshold, is assumed that none of the classes is similar enough and the result will be unknown. See Figure 4.15.

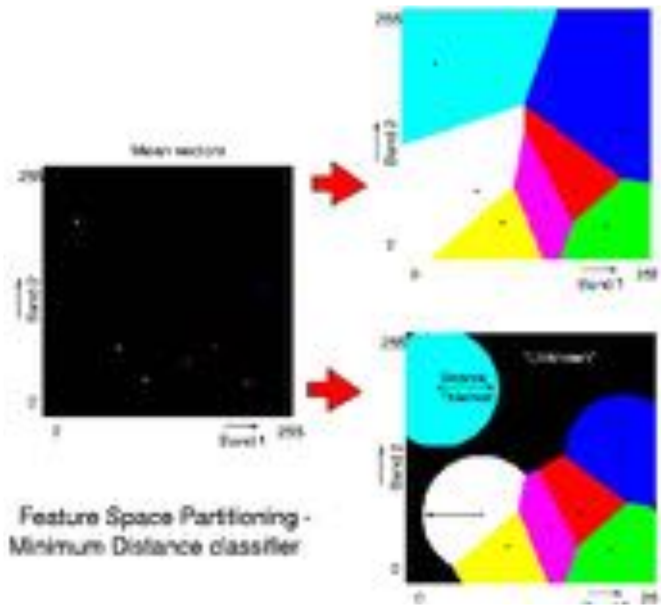


Figure 4.15: Using "Minimum Distance to Mean Classifier"

Highest probability

After the creation of the histogram, the mean value and the standard deviation for each class sample is computed. With these parameters, the probability that a pixel value x belongs to a class c is calculated assuming a normal distribution.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(x-\mu)^2/\sigma^2}$$

Where

μ : the mean value of class c

σ : the standard deviation of class c

π : 3.14159.... (Pi)

e : 2.71828....

Pixels will be assigned to the class of which the probability is the highest one.

Let the sample of the class grass cover the interval from 42 to 83, and the class forest the interval 74 to 90. If the probability of a pixel with a value 80 to be forest is 0.2 and to be grass is 0.17 then the pixels with a value 80 will be classified as forest. See Figure 4.16

Another name for this algorithm is Maximum Likelihood classifier (Figure 4.17).

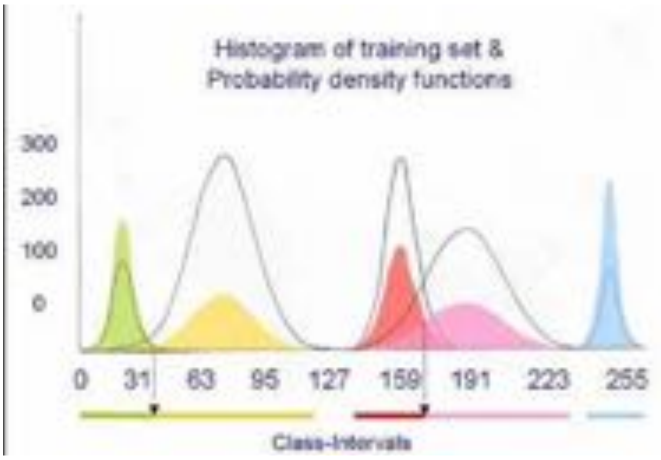


Figure 4.16: Classification using highest probability

Maximum likelihood

The maximum likelihood methods for satellite image classification aim at assigning a "most likely" class label Ci, from a set of N classes C1, ….., CN, to any feature vector x in the image. A feature vector x is the vector (x1, x2,…,xM). The vector components are pixel values in M features (for instance spectral bands). Some methods are able to assign unknown instead of one of the classes Ci, to those feature vectors for which none of the class labels seems likely enough.

The "most likely" class label Ci for a given feature vector x is the one with the highest posterior probability P(Ci | x). So, all P(Ci | x), i =[1..N], are calculated, and the Ci with the highest value is selected. The following explanation using formulas is included to show that in practise the complex calculation of probabilities is usually replaced by a simpler distance calculation in feature space which is tuned by the class variability.

The calculation of P(Ci | x) is usually based on Bayes formula, which states:

$$P(C_i\,|\,x) = \frac{P(x\,|\,C_i) \times P(C_i)}{P(x)}$$

Gaussian maximum likelihood classifiers assume that the feature vectors of each class are (statistically) distributed according to a "multivariate normal probability density function".

From the training data, for each class Ci the sample mean vector and the sample variance-covariance matrix are obtained, and they are used as (estimates for) the class mean vector mi and the class variance-covariance matrix Vi. This gives the class probability density function for class Ci:

$$P(x\,|\,C_i) = (2\pi 2^{-M/2}\ |V_i|^{-1/2}\ e^{-1/2\,(y^T V_i^{-1} y)}$$

Where:

M : the number of features

Vi : the M ×M variance-covariance matrix of class Ci

|Vi| : the determinant of Vi

Vi-1 : the inverse of Vi

y : x - mi (mi is the class mean vector), as a column vector with M components

yT : the transposed of y (a row vector).

We still want to find the largest of these (for different Ci), if we don't take prior probabilities into account. We can simplify the formula for easier and faster calculation. The first one of the three factors (2π2-M/2) at the right-hand side has no influence on the result of comparisons and is omitted. Of the remainder, we take the logarithm, which also doesn't change the result of the comparisons:

$$\ln(P(x\,|\,C_i)) + \text{constant} = -\frac{1}{2}\ln|V_i| - \frac{1}{2}(y^T V_i^{-1} y)$$

Finally, we multiply by -2 and get an expression, which we call Di, that now must be minimised instead of maximised:

$$D_i(x) = \ln|V_i| - \frac{1}{2}(y^T V_i^{-1} y)$$

Di is a function of x and can be regarded as a measure of the dissimilarity between a feature vector x and a class mean mi (because of yT and y) in the feature space. It is weighted by Vi-1 and compensated by ln|Vi| according to the within-class variability.

The second term of Di, $(y^T V_i^{-1} y)$ is commonly referred to as Mahalanobis distance.

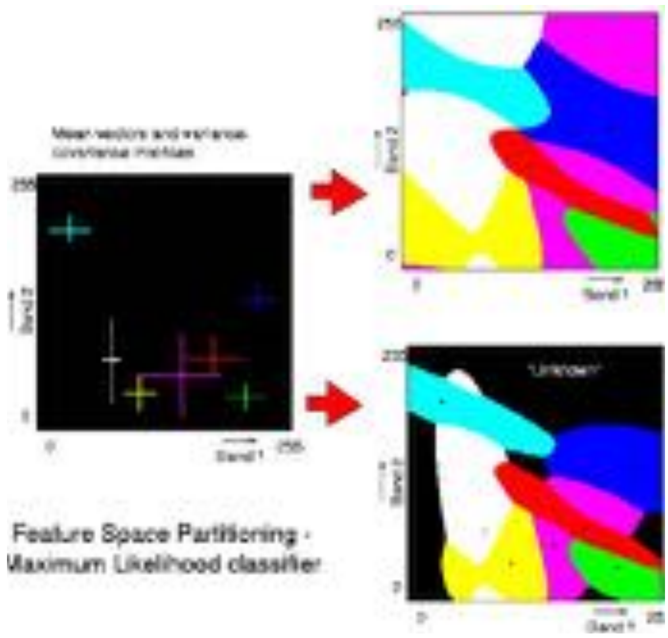


Figure 4.17: Maximum Likelihood Classifier

Note that the whole exercise must be carried out for every image pixel. The variance-covariance matrices Vi, and therefore ln|Vi| and Vi-1, are different for each class, but they are independent of x. Therefore, the N values of ln|Vi|, as well as the N inverse matrices Vi-1 are calculated once at the beginning of the classification, and can be used at every pixel. This is exactly what most maximum likelihood classifier do: Minimize on Di. The "Threshold for Distance" refers to it: if all Dis are larger than this threshold value, a pixel is classified unknown.

4.10 CLASSIFICATION

Classify the image

The feature space partitioning tells how to classify each feature vector and, therefore, each image pixel. When a feature space partitioning has been established, the generation of the output map becomes a 'piece of cake': for each pixel the feature vector determines the class label.

The boundaries between the different partitions in the feature space are the places where the decision changes from one class to another. They are called decision boundaries.

We saw that classification attempts to assign a class label to each pixel of an image. The feature vector of a pixel determines which class is selected, the one with the cluster in the feature space to which the pixel's feature vector is the most similar.

If a pixel is not similar to any cluster, the class unknown may be selected: The pixel belongs to a class that is not in the training set.

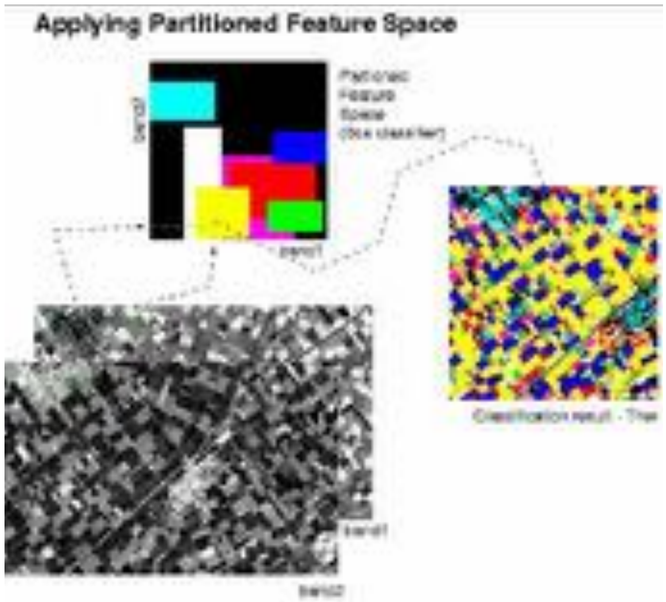


Figure 4.18: Applying partitioned feature space

Classification Problems

- Only Spectral: Unlike human interpreters, classification only takes "spectral" characteristics into account. It doesn't consider shape, size patterns and other interpretation elements. For example, the fact that a lot of pixels are arranged in a long linear fashion does not help in classifying.
- Class definition
- 'Mixed Pixels'; single pixels covering more than one class
- Multi-modal classes; class having several distinct spectral properties (grass can have many different spectral properties)
- Spectral overlap: The whole method relies on spectral separability of classes. When a pixels feature vector falls in an overlapping area of two classes (for instance grass and potatoes) in the feature space, this means that probably there are in the image some pixels with this feature vector belonging to grass and others, with the same feature vector, belonging to potatoes. The classifier will treat all of them in the same way and classify them as one class, either grass or potatoes. Similar problems occur with heterogeneous classes, such as town: a mixture of roads, roofs, trees, gardens, ponds etc. If all town pixels are to be classified as town, then elsewhere a lot of forest, grass etc. pixels may get classified incorrectly.

- Heterogeneous classes; often related to land use classes in which several spectral classes are combined (build up area consists of grass, trees, brick, tarmac, roof tiles)

- Scale and Resolution issues

All these items are related to each other and can interfere.

Class definition

A distinction should be made between land cover and land use.

Land cover is a physical characteristic of the earth surface. What material covers the land at a certain place? Examples of land cover are: grass, building, pavement, trees, wheat and bare soil.

Land use describes people's activities at a certain position: What is the function of this piece of land? Examples of land use are: Residential, recreational, industrial, educational, agricultural, nature reserve, vacant.

Reflections, as measured by satellites, are stronger related to land cover than to land use although the relationship between reflection and land cover may also be complex.

The relationship between land cover and land use is many-to-many. Certain land use classes consist of a spatial complex of land covers, whereas the same complex (possibly with different proportions) may be found in other land use classes, as well.

Therefore, land cover classification is `easier', but land use classification may be preferred by the end-user.

Very often we find a mixture of land use and land cover classes in a single classification. A consequence may be that different classes have (partially) overlapping meanings, such as potatoes and agriculture, or grass and rural, or grass and recreational (not to mention all this at the same time . . .). One should be very careful when mixing land use and land cover classes. Note that the Bayesian theory (the basis for maximum likelihood) requires that the classes Ci (I   [1 . . . N]) are spectrally disjoint.

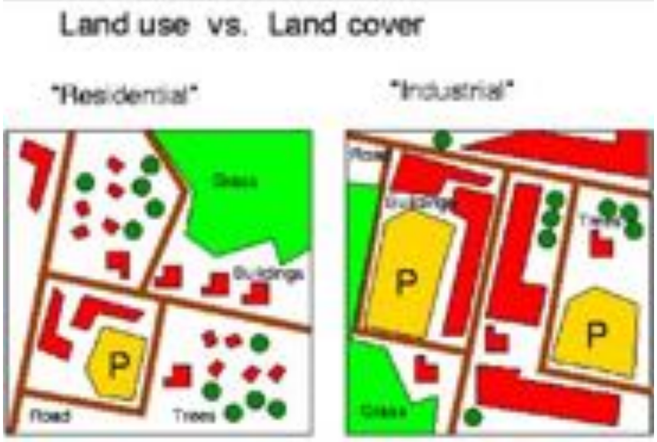


Figure 4.19: Land use vs. Land cover classifications

Mixed pixels

- Small objects - Objects smaller than one pixel appear as 'noise'

- Narrow objects - Elongated terrain objects, such as roads, having a width less than the image resolution, usually influence the pixels ("scene elements") that they intersect enough to make them visible in the image. However, all these pixels are "mixed"; they are also influenced by the surrounding landscape. Therefore, such classes are difficult to classify. Classification is mainly suitable for classes of objects that form areas in the terrain.

- Boundaries between (sufficiently large) areas - At boundaries between two distinct classes in the terrain we find pixels in the image where the reflection measurement is influenced by both classes. The feature vector of such a pixel may be outside both clusters (somewhere in-between them in the feature space).

Such a "mixed" pixel will become unclassified, or (worse!) be classified as something completely different. See Figure 4.20

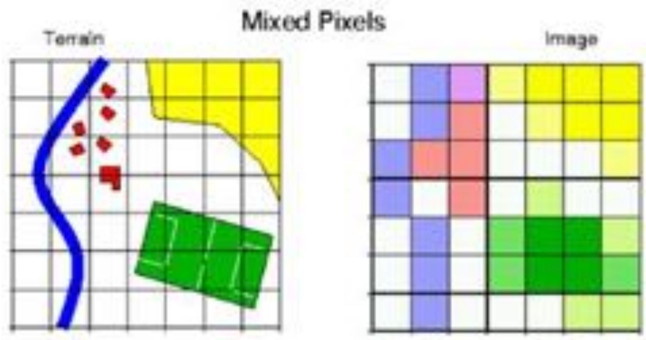


Figure 4.20: Classification of Mixed Pixels

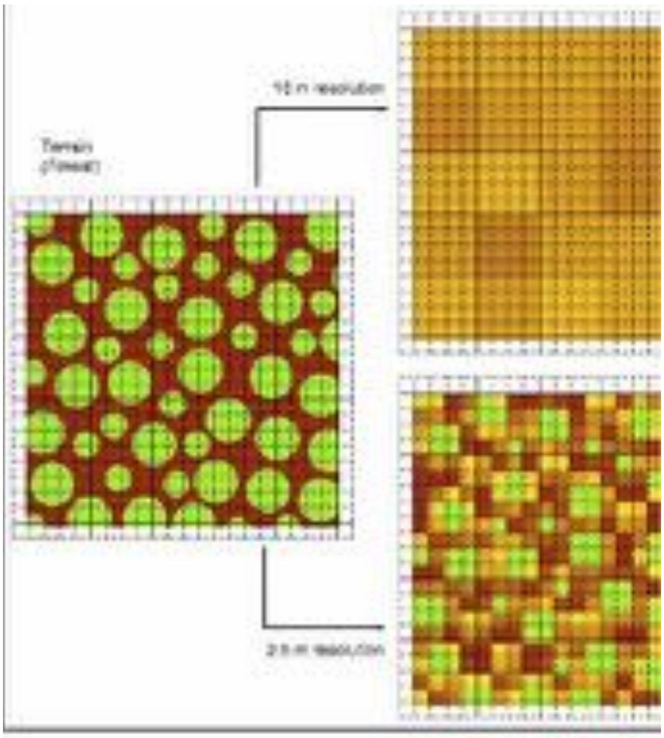


Figure 4:21: Difficulties in classifications with higher and lower spatial resolution

Accuracy Assessment

In order to assess the accuracy of a classification, it is common practice to create a confusion matrix which contains a comparison between some (additional) reference data and the classification result (See Figure 4.22).

You should not use the same sample sets for both the classification and the accuracy assessment, because this will produce too optimistic figures. In fact at that moment you are assessing the separability of the samples set classes, not the accuracy of the classification.

For each pixel in the reference data set you assess what class has been assigned by the classifier. The result can be represented in an accuracy matrix/table (as shown below).

Every column (A…D) in the matrix corresponds to a class in the reference map; every row corresponds to a class in the classification result. So at the diagonal you find per class the number of pixels that were classified correctly. The off-diagonal elements contain the classification errors.

The producer accuracy calculates the percentage of pixels of the reference that were correctly classified, sometimes referred to as the accuracy of each class. E.g. of the reference set A, 66% percent is classified as A. The complement is the error of omission; the percentage of reference samples that should have been classified as A.

The user accuracy calculates the percentage of classified pixels that are actually correct; it is referred to as the reliability of the class and of course a very interesting parameter for someone who will be using the classification map. E.g. Of all pixels that were classified as C, probably 60% are correct. The complement is the error of commission; the percentage of samples that are classified as A but should have been something else.
The overall accuracy is the fraction of all reference/ ground truth pixels that were classified correctly, so it does take reference class sizes into account.

Quality considerations

Depending on the algorithm some general considerations that influence the outcome and accuracy can be mentioned.

		Reference Class				Total		Error of Commision	User Accuracy
		A	B	C	D				
Classification result	A	**35**	14	11	1	61		43	57%
	B	4	**11**	3	0	18		39	61%
	C	12	9	**38**	4	63		40	60%
	D	2	5	12	**2**	21		90	10%
	Total	53	39	64	7	**163**			
Error of Omission		34	72	41	71		**Overall Accuracy = SumDiag/SumTotal**		
		(4+12+2)/53	...	...	...		**53%**		
Producer Accuracy		66%	28%	59%	29%				
		35/53	...	...	...				

Figure 4.22: Confusion matrix

The likelihood to be correctly classified decreases when:

- Distance to box or Mean increases
- Absolute maximum probability decreases
- Relative maximum probability decreases

If one is not satisfied with the quality assessment of the classification the whole procedure requires careful analysis and possibly iterations for improvement:

- Is the selected input image data the proper one for the job?
- Can classes be separated by means of spectral value only, is class definition proper?
- Is the selected algorithm applicable?
  - Can clusters be described by a box?
  - Do clusters have a normal distribution and thus can Mean and SD be used?
- Are samples representative (Date, Time, Location)?
- Can classes be merged or split up to make algorithms more applicable?

Alternative Classification

Other, alternative, classification algorithms and procedures exist. Without going into detail a shortlist of options is presented. Many of these are subject in the Module Advanced Image Classification and Change Detection:

- Hybrid (stratified) Classification - Application of appropriate classification or information extraction algorithms depending on the feature of interest (e.g. water by slicing, followed by land cover through maximum likelihood and land use by expert knowledge)
- Unsupervised/Clustering - Automated partitioning of the feature space on the basis of the statistical pattern in the feature space
- (Hyper)Spectral Classifications - Spectral angle mapping, unmixing
- Subpixel Classification - Determination of proportion of classes within each pixel, assumption of mixed pixel composition
- Object Based Classification - Combination of spectral and spatial criteria determine spatial boundaries and subsequent classification
- Expert/Knowledge Based Classification - Use of other knowledge to improve classification. E.g. if detected Urban is thin and elongated -> road, if road and water to left and right -> bridge.
- Neural Network - Iterative/learning process in which the decision criteria change on the basis of the outcome of previous iteration.

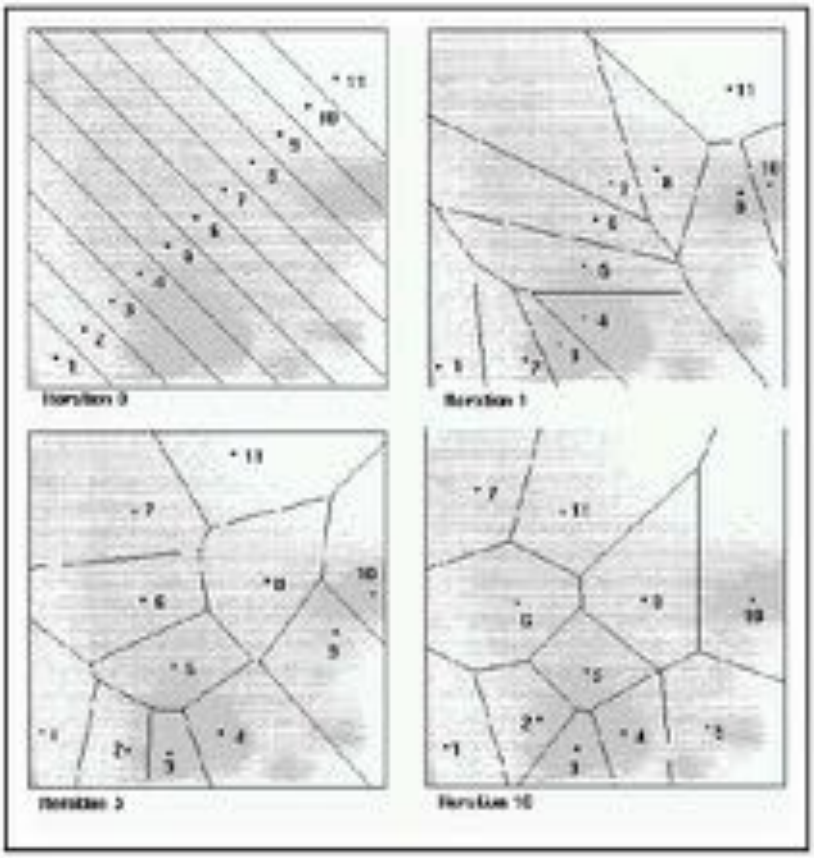
4.11 UNSUPERVISED CLASSIFICATION

One way to perform a classification without reference data is to (use software to) plot all pixels (all feature vectors) of the image in a feature space, and then to analyze the feature space and to group the feature vectors into clusters.

Software that does this automatically is called clustering software. The name for the process is unsupervised classification. Quite naturally, such software has no notion of "thematic" land cover class names, such as grass, tarmac, potatoes etc. All it can do is finding out that there seem to be x different spectral "things" in the image and give them numbers (1 to x). These "things" are called spectral classes. What you will also get is a raster map, in which each pixel has a value (from 1 to x), according to the cluster to which the image feature vector of the corresponding pixel belongs. The number of classes is usually defined by the user.

After this process finishes, it is up to the user to invent the relationship between spectral and thematic classes. It is very well possible that you discover that one thematic class is split into several spectral ones, or (which is worse) that several thematic classes got caught in the same spectral cluster.

Various unsupervised classification (clustering) algorithms exist. Usually, they are not completely automatic: The user must specify some parameters, such as the number of clusters that he (approximately) wants, the maximum cluster size (in the feature space!), the minimum distance (also in the feature space) that is allowed between different clusters etc. The software "builds" and rebuilds clusters in the feature space in several iterations until changes are within a certain threshold.



Chapter 5

GEONETCast and the European Space Agency Data Dissemination System for Food and Water Security Analysis and Monitoring

Learning Objectives

- To learn about GEONETCast
- Have an overview of available data and products that are disseminated via GEONETCast (using the Product Navigator) and the ESA Data Dissemination System
- Experience on downloading data obtained through the GEONETCast system using ILWIS.

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5.1 INTRODUCTION

Many countries face serious food and water security problems and need accurate and timely earth observation data and derived environmental information for monitoring and assessment purposes. GEONETCast – a global network of communication satellite based data dissemination systems – provides free near real-time environmental and Earth observation data (in-situ, airborne and space based) and derived products to a worldwide user community. It is part of the emerging Global Earth Observation System of Systems (GEOSS), led by the Group on Earth Observation (GEO) and has become an easy and effective way for countries to receive satellite and environmental data. Through the ESA Data Dissemination System, ENVISAT data (from ASAR, AATSR and MERIS) and products from Global Monitoring for Food Security can now be obtained on a regular basis, to complement the data from GEONETCast for food and water security analysis, monitoring and assessment. Additionally to that a set of routines are being developed specifically for the Southern African region through the AMESD project.

5.2 COMBINED GEONETCAST AND DDS RECEPTION IN AFRICA

The data contained in GEONETCast and European Space Agency Data Dissemination System (DDS) is delivered via communication satellites. For Africa the Atlantic Bird 3 (situated at 5 degree west) has been selected to disseminate these services. Using low cost ground reception infrastructure, basically a C-band parabolic antenna with LNB, pointed to Atlantic Bird and connected to a computer containing a Digital Video Broadcasting (DVB) board, both data streams can be received and stored locally. At various locations around the world, next to those at the national meteorological organizations, GEONETCast ground reception infrastructure is currently operational. Few organizations in Africa also receive the DDS, but currently do so using a dedicated antenna. As both data streams originate from the same communication satellite, a single antenna can be used to receive both data streams. Figure 5.1 is providing the layout of such a combined configuration installed at ITC (Maathuis and Mannaerts, 2010). The coaxial cable that originates from the antenna simply has to be split and from there they have to be connected to each of the ground receiving stations. The DVB board in each of these systems ensures that the data is captured and stored. Organizations with an already operational GEONETCast ground reception infrastructure can easily upgrade their reception capacity, also incorporating the DDS.

Currently the GEONETCast data stream is a one way system, only reception is therefore possible. This is a continuous data stream and data is broadcasted on a 24 hour – 7 days basis. Non operation of a ground receiving system results in a data gap as data is only broadcasted once (Eumetsat, 2004). On the other hand the ESA DDS can be configured as a two way data dissemination system, allowing one to receive as well as broadcast data. The DDS is operated during specific periods on a daily basis for reception of the data. Using a fixed IP address of the ground receiving station, the data packages actually received are monitored and in case of reception failure the data is re-broadcasted (Badessi et al, 2010).

5.2.1 Complementarities of the Two Data Streams

GEONETCast is currently disseminating images derived from various geostationary and polar orbiting sensors/platforms as well as derived products. As the dissemination system started off to provide the European and African national meteorological centres with relevant and timely information mainly focusing on meteorological applications, currently the system is rapidly expanding and is disseminating also environmental data from various third party data providers. The system is furthermore seen as the data delivery backbone by the Group on Earth Observation (GEO) to provide in-situ, airborne and space borne data as part of the Global Earth Observation System of

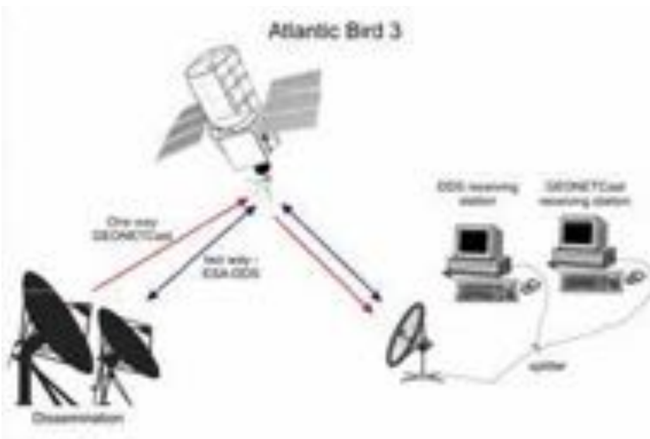

Figure 5.1 Combined GEONETCast and DDS reception configuration

Systems (GEOSS) to the user community. For further details on the images and products the so called "Product Navigator" can be consulted, available at the home page of EUMETSAT (http://www.eumetsat.int).

By means of the ESA Data Dissemination System (DDS) within 24 hours after sensing the ENVISAT orbits acquired over Africa are transmitted, allowing the user to receive (pre-processed) images and derived products from MERIS, AATSR and ASAR such as calibrated TOA radiances, reflectance's, brightness temperatures, cloud thickness, water vapor and other geophysical products. Next to this, a set of other products, like the ones produced in the framework of the Global Monitoring for Food Security (GMFS) project for early warning, agricultural mapping and crop yield assessment, covering eastern and western Africa and the 10 days maximum value composites derived from the SPOT- Vegetation instrument, like the normalized difference vegetation index (NDVI) and the normalized difference water index (NDWI), are disseminated when produced.

Being able to receive both data streams therefore offers the user near real-time complementary data highly relevant for food and water security assessment free of charge and without internet connectivity.

5.2.2 Managing and Making Use of the Data Streams for Food and Water Security

The "adagium" that there is no free, near real time environmental data available is not valid anymore. The data delivery systems currently operational provide the user with continuous data streams. In order to effectively use the data, open source and freeware utilities are required facilitating continuous automated storage based on the user requirements with minimum user-interference coupled with (semi-automated) data processing and visualization capabilities. To meet these objectives, the GEONETCast and ESA DDS toolboxes were developed.

5.3 THE GEONETCAST TOOLBOX

The main objective of the Toolbox is to allow the user, who operates a GEONETCast ground receiving station to easily manage the incoming data stream and to import the data into a common freeware GIS-RS environment for display and further analysis, in this case using the functionality of ILWIS version 3.8 or higher. The overall approach is further elaborated upon in Figure 5.2.

The data disseminated via GEONETCast are received on a continuous basis. The Data Manager checks the newly arrived data at the ground receiving station and automatically moves these to a dedicated storage location. The Data Manager uses an ASCII configuration file that can easily be modified by the local system administrator to ensure that only the data relevant for the organization is kept and if new images or products are received the configuration file can be easily updated using a text editor, without the need to wait for a new software release.

Figure 5.2 Overall concept of the GEONETCast-Toolbox

The data disseminated by GEONETCast consists of various formats. Over time a number of utilities have been developed at ITC to be able to import these data types, such as the geostationary high rate images transmitted of METEOSAT 8 and 9 and the other low rate images transmitted, like those from Fengyun, MTSAT, GOES and METEOSAT 7. Also other existing freeware utilities have been used and integrated in the toolbox, such as GDAL, BUFR and GRIB(2) decoders. These utilities are required to import the data provided by EUMETSAT's Meteorological Product Extraction Facility (MPEF) and from the Satellite Application Facilities (SAF's).

These distributed centres are utilising the specialised knowledge available within EUMETSAT Member

States to complement the production of the standard meteorological products disseminated such as those from the Land Surface Analysis SAF like the surface radiation budget and the bio-geophysical products. Import routines have been developed to incorporate the METOP-ASCAT products disseminated through the C-band turn around service, like the ocean vector winds and the land surface soil moisture. Also use can be made of other available software routines, such as the Basic ENVISAT Toolbox for (A)ATSR and MERIS (BEAM) for pre-processing of METOP AVHRR/3 images, the Basic Radar Altimetry Toolbox (BRAT) for pre-processing of the JASON altimetry data and the VGT-Extract utility for pre-processing of the SPOT Vegetation products. In those cases import routines are available to seamless transfer the data into an ILWIS data format. The GEONETCast toolbox also allows import and pre-processing of various environmental and atmospheric products produced by the Chinese Meteorological Administration (CMA).

Import and pre-processing routines are also available to ingest third party data, such as the active fire product derived from MODIS, rainfall products from TAMSAT, various 10 day composite products derived from SPOT Vegetation (for Africa and Latin America) and various products and images produced by the European, African and Latin American partners within the DevCoCast 7th Framework programme, consisting both of land and ocean products (Jacobs et al, 2008).

Last but not least attention was given to use data available through the World Wide Web. A number of routines are available to incorporate relevant environmental information and in situ data in this manner, extending the functionality beyond GEONETCast direct reception. To be able to use these services an internet connectivity is required.

Figure 5.3 The GEONETCast toolbox plug-in Graphical User Interface

The utilities described can be downloaded from the "ILWIS" and "Earth Observation" Community pages at http://52North.org, such as an installation and user manual including exercises, data manager and XML configuration files as well as sample data.

Recently, the GEONETCast toolbox, initially developed as a plug-in under ILWIS 3.6 (Maathuis et al, 2008) has been upgraded and is now available as a plug-in under ILWIS 3.8, see also figure 3. This toolbox version allows easy import of various data sources, disseminated via GEONETCast, relevant for food and water security assessment in especially the African region, using a Graphical User Interface (GUI) that can be easily manipulated by the user.

Through the GUI currently over 130 satellite image and product import routines can be accessed. To start an import routine mostly a time stamp has to be specified. The GUI generates a command string that is executed. This command string calls an ILWIS script and this script subsequently calls a batch routine. The scripts and batch files are at disposal of the user and can be modified if necessary and if new products or images are received new import routines can be developed using the available batch and script routines as examples. The XML based user interface can be easily updated as well. All these procedures do not require high level programming skills, eliminating the need to wait for new software releases.

5.4 THE ESA-DDS TOOLBOX

A newly developed plug-in is the "ESA-DDS toolbox". This utility allows automated archiving and pre-processing required for use of the data in ILWIS from the DDS data stream. The design is identical to the GEONETCast toolbox and can be obtained from the 52North.org website as well. The layout of the graphical user interface is presented in Figure 5.4.

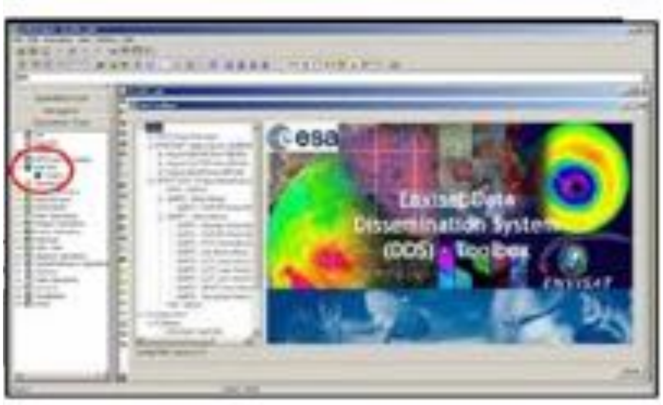

Figure 5.4 The ESA-DDS toolbox plug-in Graphical User Interface

An identical data management approach is used here as well to keep track of the incoming DDS data stream and moves the data to a dedicated storage location. For pre-processing of the ENVISAT data use is made of BEAM as pre-processor. In BEAM the data can be calibrated radiometrically and geometrically, subsequently the images can be exported into a geotif format and routines are available to import these in ILWIS. For the other products like those delivered through the Global Monitoring for Food Security project and the 10-day SPOT Vegetation NDVI and NDWI products can be directly imported into an ILWIS format.

The user now has the capability to extract from the data streams and the Web the application domain relevant information and integrate it into a common GIS/RS open source and free ILWIS software utility for further processing and analysis. Also within ILWIS 3.7 new functionality has been developed to meet the demands for dedicated analysis. Also a French language option has been included to serve the African francophone regions. Additional routines, including improved visualization and animation utilities and a HTML based Help functionality are planned to be implemented in the ILWIS 3.8 release, foreseen for March 2011, , to facilitate users to contribute to the content themselves as well.

Also a French language option has been included to serve the African francophone regions.

5.5 FOOD AND WATER SECURITY ANALYSIS AND MONITORING IN AFRICA

Agricultural production and water supply management are risky activities, governed to a considerable extend by weather and climate uncertainties and extreme event hazards. The real-time data supply via GEONETCast, when coupled to the open source ILWIS analysis system gives the user the capability to produce early warning, agricultural mapping and crop yield assessment services. Also water resources related early warning indices like drought and soil moisture monitoring, extreme and accumulated rainfall, potentially leading to increased flooding risk, can be generated on an "ad hoc" basis using the GEONETCast toolbox and the RS/GIS functionality of ILWIS. Coupling of these geodata and information to crop growth, hydrological and soil moisture models creates an integrated analysis environment, permitting improved quantitative analysis of food and water security at user defined regional or local scale levels.

Applications for food security and agricultural production may use simple vegetation indices like the NDVI, Dry Matter Productivity (European Commission, 2006) or the more typical water supply vegetation index (WSVI). This vegetation status evaluator includes besides the standard red and infrared signatures of vegetation cover and soil, also a thermal image signature which highlights the land or vegetation surface temperature and associated moisture stress status. The construction of time series of the vegetation index maps, typically on a 10-day basis for vegetation assessment purposes permits to set-up of a near real-time monitoring system for the area of interest of the user. An example of NDVI variability is given in Figure 5.5. Using a similar approach also comparisons can be made between the actual dekadal value and long term statistics, such as the mean, maximum and minimum value for that corresponding location. In a similar manner also other surface radiation budget and bio-geophysical products provided through GEONETCast can be integrated and analysed.

Satellite datasets available in real-time through the system can be coupled to a surface energy balance model, readily available in the ILWIS Open software as the SEBS plug-in. This permits to evaluate e.g. daily

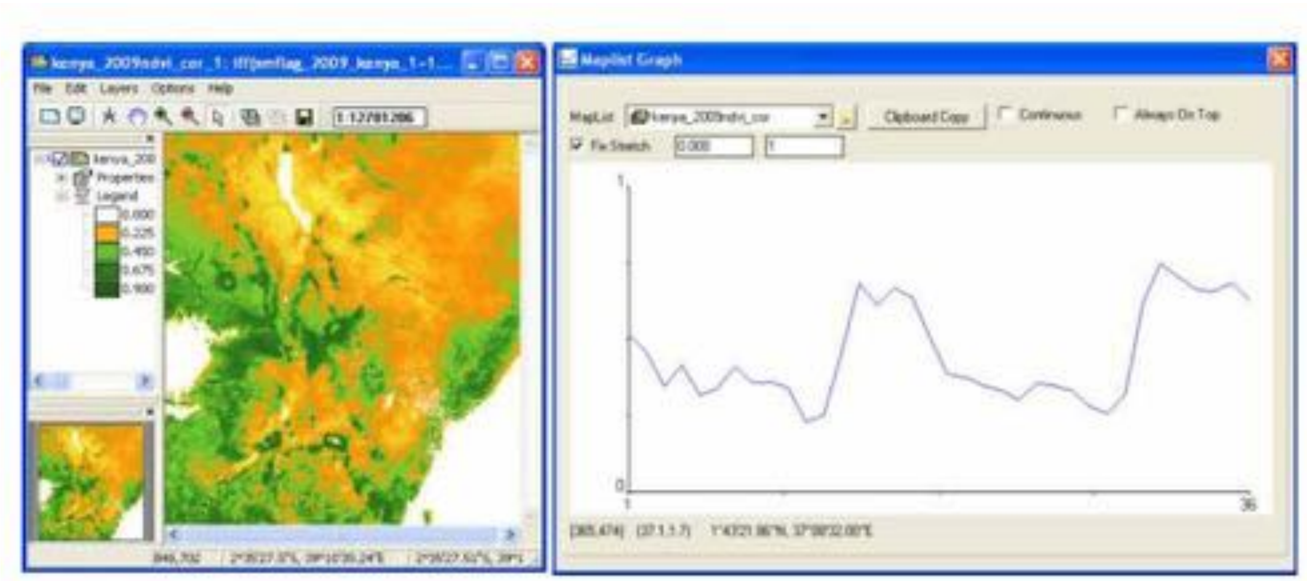

Figure 5.5 NDVI sub map of decade 1, 2009 (left) and the map list graph for each decade of 2009 for a selected pixel location (right), Eastern Africa

or even sub-daily evapotranspiration estimates over regions of interest, and can be used for a variety of purposes ranging from evaluation of crop water use efficiencies to the evapotranspiration component in hydrological water balance models. Figure 5.6 shows an example of a daily ET estimate (in mm) for the Zambesi river basin using SEBS.

Satellite datasets available in real-time through the system can be coupled to a surface energy balance model, readily available in the ILWIS Open software as the SEBS plug-in. This permits to evaluate e.g. daily

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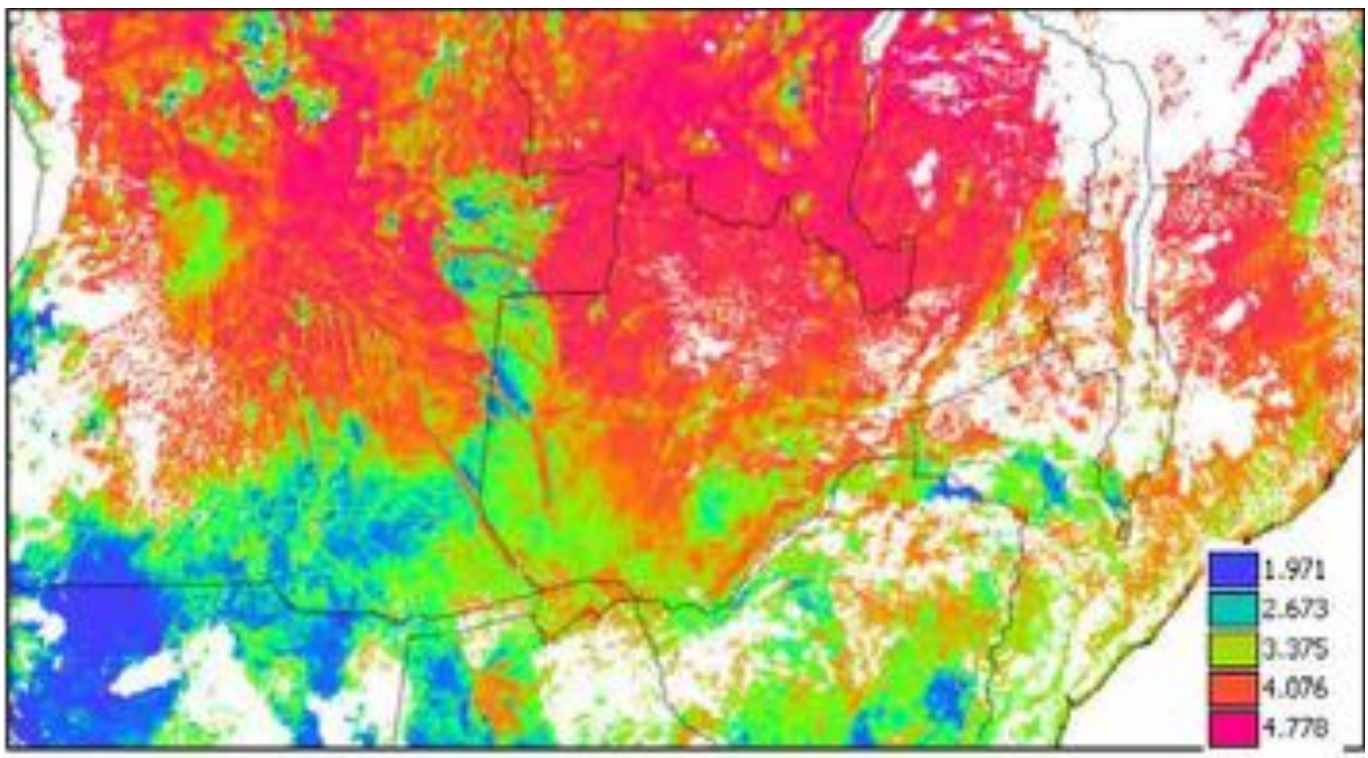

Figure 5.6 Daily ET estimate of the Zambezi basin.

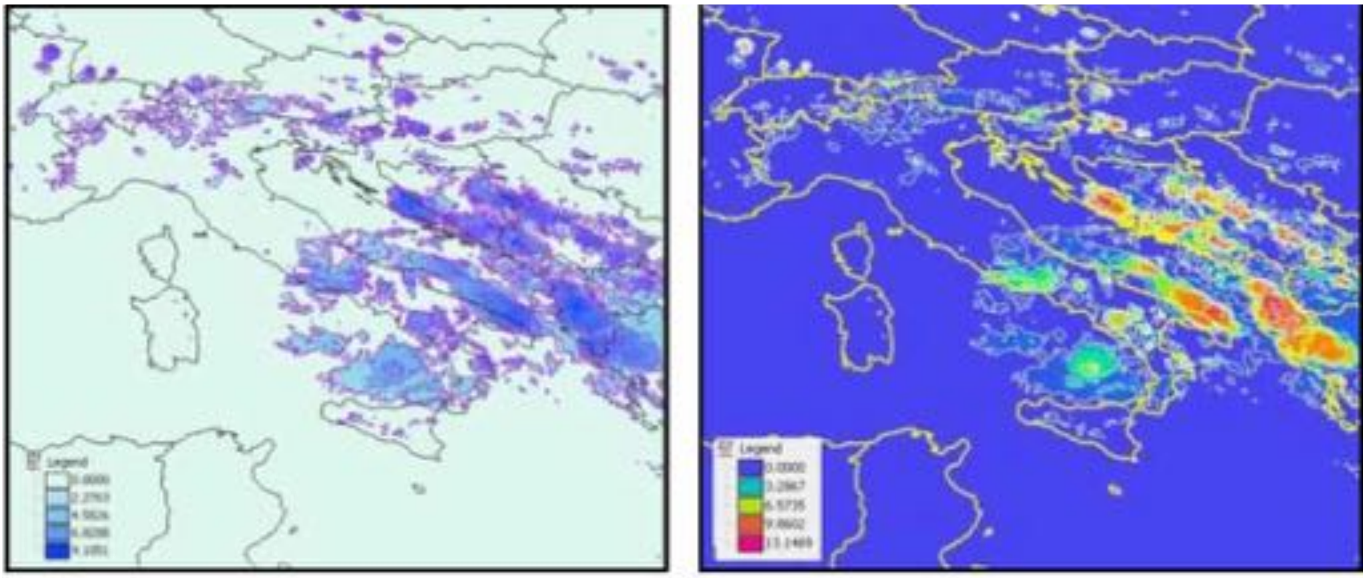

Figure 5.7 Rainfall erosivity from weather satellites, rain erosivity EI30 (left) and rain 30'-max intensity (right)

5.6 CONCLUSIONS

Satellite estimates of short duration rainfall from e.g. MSG ranging from a 5-minute interval for the European- North African Rapid Scanning Service to 15-minute interval for the whole MSG disk covering Europe, Africa and part of the Middle East can be transformed into rainfall intensity time series. This permits to evaluate maximum and extreme rainfall intensity and rainfall risk for e.g. runoff and flooding and associated land degradation. The rainfall erosivity index shown in Figure 5.7 is a typical climate hazard index used to evaluate rainfall risk for land degradation and soil erosion (Mannaerts and Maathuis, 2007).

Output generated by the toolbox can be disseminated to a larger user community and decision makers using a build-in web mapping service utility. This utility permits direct import and generation of Google Map overlays. Figure 5.8 presents an example of the 24 hour MSG based multi sensor precipitation estimate, downloaded from the ITC FTP site.

The toolbox plug-ins, together with the existing processing utilities of ILWIS, facilitates the user to easily integrate large amounts of environmental data, which is delivered via communication satellites on a global scale, into various applications related to weather, atmosphere, oceans, land, vegetation, water and environment. Further developments of the toolbox will, besides access to more datasets, include coupling and integration of Earth Observation and in situ data, provided by GEONETCast and DDS, to open source assessment models and data assimilation tools. Also (distance education based) training materials and application demo's are currently being developed, in direct collaboration with the user community.

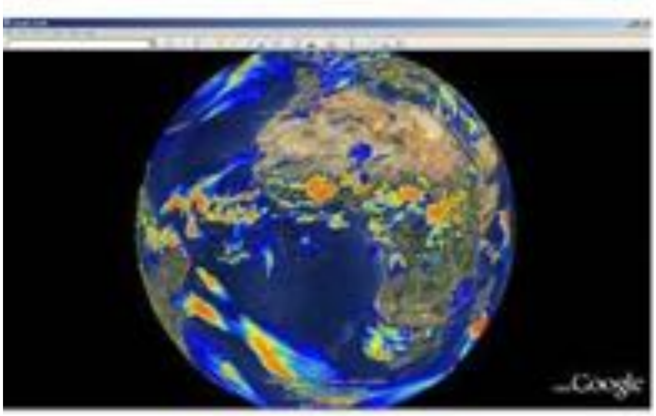

Figure 5.8: 24 hr aggregated MSG based MPE

5.7 REFERENCES AND SUGGESTED READINGS

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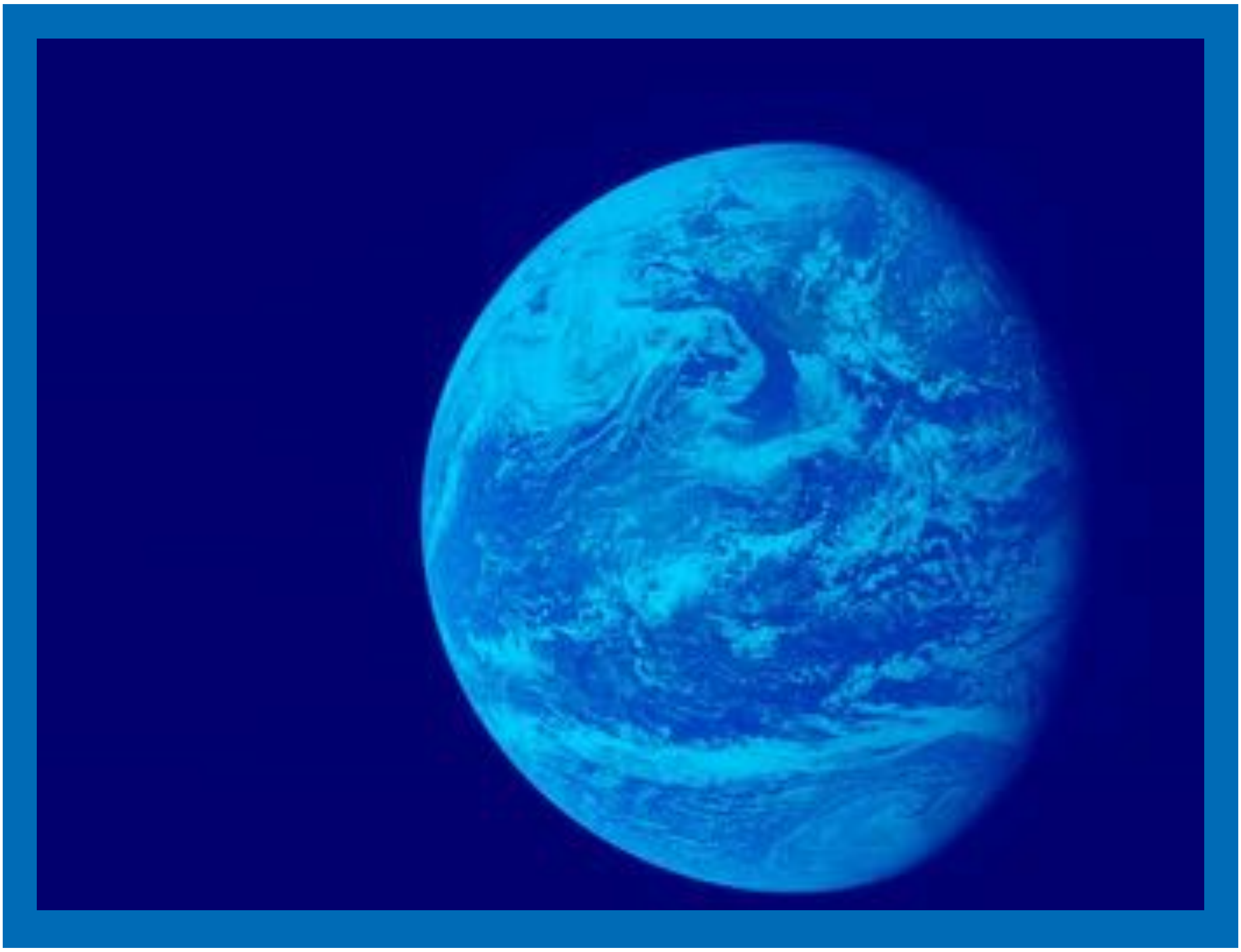

Chapter 6

Feature Extraction from Earth Observation Systems [Tutorial 1]

Learning Objectives

- To learn about feature extraction through digitization, supervised and unsupervised classification, Radar and Lidar.
- Experience feature extraction using ILWIS

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6.1 INTRODUCTION

The extraction of features from remotely sensed images has a long history beginning with aerial photography which was used to create maps for many decades. Initially features were identified by humans and hand digitized to create line, point and polygon features such as buildings, roads and lakes. With the advent of geographic information systems (GIS) and the availability of satellite imagery the automation and semi-automation of feature extraction has grown with spectral analysis of images used to identify features. In the past decade the technology has grown even more with radar and lidar increasingly used to create maps.

While there are many methods of feature extraction that exist currently, this document will introduce the following: Digitization, Supervised and Unsupervised Classification, Radar and Lidar.

6.2 DIGITIZATION

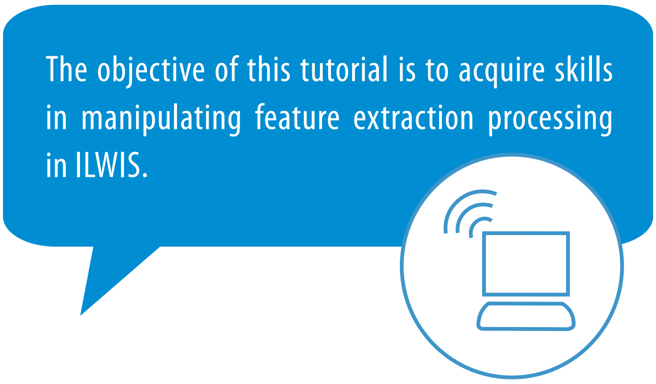
Digitization is the drawing of points, lines or polygons to represent features on a map using visual analysis. Originally done by hand to create analog maps eventually digital layers were created with the use of digitizing tables where desired features on a paper map were traced with a puck that's connected to a computer and GIS. The spatial coordinates were automatically recorded as the puck is moved and stored on the machine. Even with digitizing tables however, the process is a time consuming one and requires skill, training and dedication.

Over the past few decades however, image processing algorithms have been developed that can interpret the spatial signature, spectral information and texture of a pixel and its relationship to neighboring pixel to extract vectorized features from satellite images as shown in Figure 6.1.

6.3 INTRODUCTION TO FEATURE ANALYST EXTRACTION USING ILWIS

6.3.1 The Concept and Objective

Feature Analyst is the process of extracting vector feature data from high-resolution satellite and aerial imagery such as roads, buildings, vegetation, land-cover/land-use and many other features. This tutorial is designed to allow the user to explore the graphical user interface (GUI) of the ILWIS program and become familiar with the basic functionality of feature extraction.



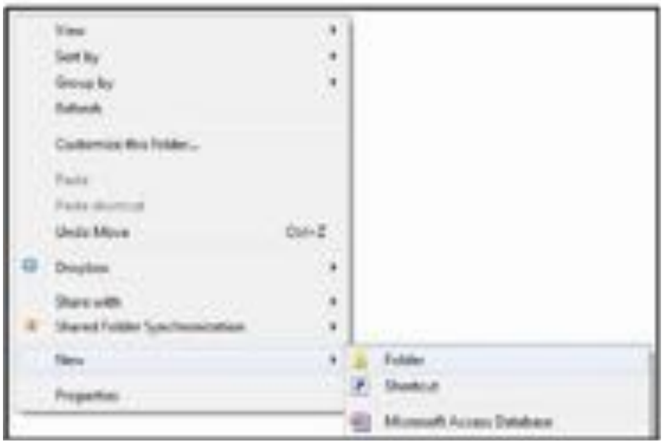
The tutorial uses IKONOS high-resolution (1m) images of Trinidad, West Indies though the principles are applicable to a wide range of resolutions.

Figure 6.1: Vectorized river, Wahiawa, Hawaii. Quickbird imagery courtesy of DigitalGlobe

6.3.2 Importing files into ILWIS

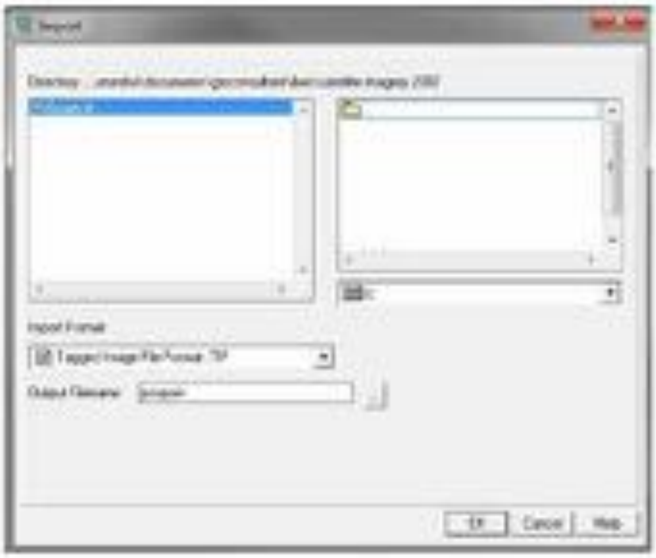
1. Right-click on START and click on "Open Windows Explorer" (See Figure 6.2)

2. Navigate to the 'Satellite Imagery 2007' folder and right-click on any blank space
3. Select 'New'
4. Select ' Folder'
5. Name the new folder 'ILWIS_Files'
6. Hit the 'Enter' key



7. Select Start: All Programs: ILWIS: ILWIS

8. To import the satellite image of Port-of-Spain to be used click on 'Operation-Tree' in the left window
9. Click on 'Import/Export'
10. Double-click on 'Import Via GDAL'
11. In the Import window that opens, under Import Format click on the drop arrow and select 'Tagged Image File Format .TIF"
12. In the right window use the browse folder icon to navigate to the satellite imagery 2007 folder
13. Click on the "PoSpain.tif file that shows on the left
14. Click OK



Once the file has been created it can then be opened as a multiple layer image:

15. In the Main window navigate to the ILWIS_Files window and double click on the PoSpain folder
16. The imported .tif consist of 3 colour bands – bands 1, 2 and 3. These can be opened separately or as a colour composite
17. Right-click on the stacked 'PoSpain' file and click "Visualization" and then "as color composite" (See Figure 6.6)

18. Click OK in the Color Composite window that opens

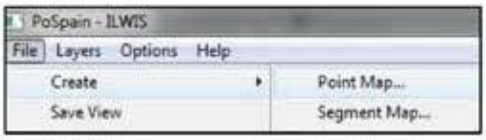
6.4 DIGITIZING FEATURES

For the purpose of this tutorial we shall focus on point, line and polygon features found within Port-of-Spain, the capital city of Trinidad.

6.4.1 Point features

For the point features we are going to map the location of the numerous parks in the capital city.

1. Open the 'PoSpain' composite image
2. Use the zoom button to zoom in to the parks of the city (highlighted in red in the image 6.2 below) 
3. In the PoSpain image window click on 'File'
4. Then click 'Create'
5. Click 'Point Map'



6. In the 'Create Point Map' window that opens enter'Parks' under Map name
7. Under description enter 'Point map of Port of Spain Parks'
8. Under Domain click on the drop arrow and select 'Unique ID'

9. Click OK
10. The created Parks point map can now be seen in the main window. We shall now digitize the parks as points
11. Right-click on 'Parks' and click on 'Edit'

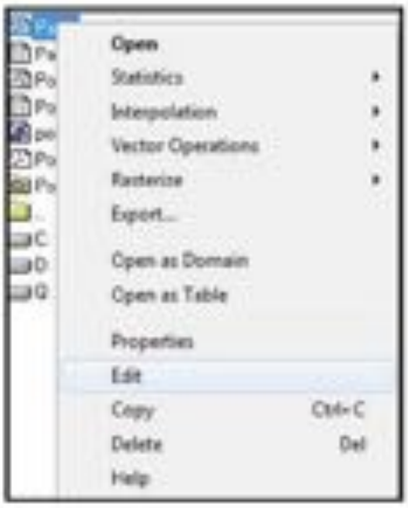
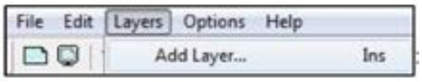


Figure 6.2

12. This opens the Parks map which is currently empty.



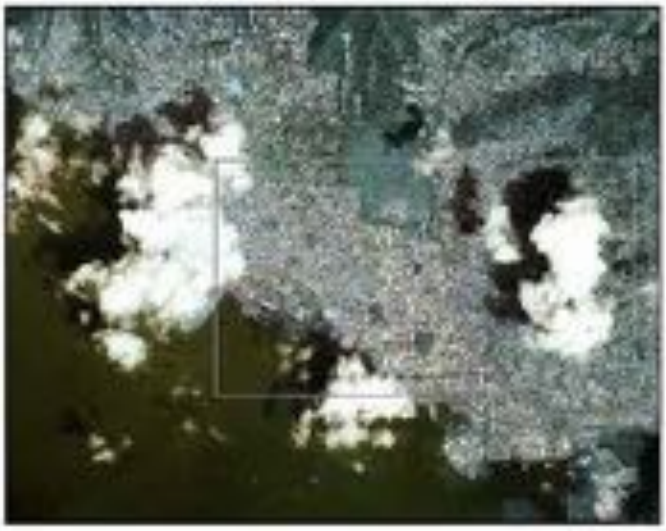
13. In the Parks window click on "Layers" and then "Add Layer"

14. In the Add Data Layer window that opens navigate to the satellite imagery 2007 folder and click on the PoSpaincolor composite file.

15. In the "Show Map List" window click "Color Composite and click ok

16. In the Color Composite window click ok. This adds the Port of Spain satellite image to the window which we will use as our basemap for the location of the parks.

17. Use the Zoom in  icon to zoom into Port-Spain by drawing a rectangle on the map



18. In the Point Editor: Parks window click on the 'Insert Mode' pencil icon 

19. Click on the large round park in the top left-hand corner of the map

20. The attribute column for the point opens automatically. Under 'pnt 1' enter Queen's Park Oval

21. Click the red x to close the attribute window

22. Click the remaining parks on the map (refer to the map in section 2.1). For this exercise they can be named "Parks 2 – 7"

23. Minimize the Park window and look at the files list in the main window

24. Right click on the attribute table titled 'Parks'

25. Click 'Open'

26. The Attribute table opens. Note the points are all labelled with info entered.

27. Edits to the names can be done at this point

28. Close the Attribute table and the Parks window

29. To adjust the point Symbology right-click on 'Parks' in the main window and click 'Open'

30. In the Display Options window that opens click on the square 'symbol' button

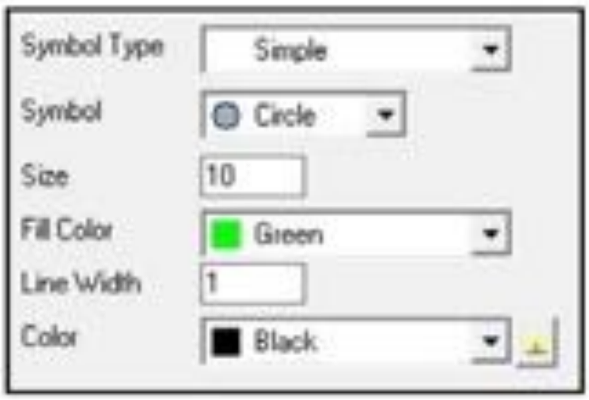
31. In the Symbol window enter 10 under 'Size'

32. Click on the drop arrow under 'Fill Color' and select 'Green'

33. Click on the drop arrow under 'Color' and select Black

34. Click OK

35. Click OK



36. This opens the Parks window with the digitized points shown as green circles

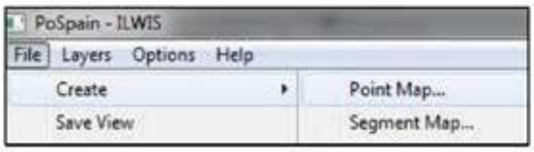
37. Add the Port of Spain color composite map to the parks window

6.4.2 Line features

Creating line features is similar to creating point features.

For this exercise we shall digitize 2 main streets of Port-of_Spain: Wrightson Road and Tragarete Road. You can locate them in the map on the right.

1. Open the Port of Spain satellite image 'PoSpain' as a color composite
2. In the PoSpain window click on 'File' then 'Create'and then on 'Segment Map'



3. In the 'Create Segment Map' window that opens enter 'Streets" under Map Name
4. Click OK
5. Note that the window name changes to 'Segment Editor: Streets'

6. Use the Zoom in tool to zoom into Port-of-Spain until you can visually identify the two streets

7. Click on the 'Insert Mode' pencil icon 

8. Digitizing of the road can be done in one continuous drawing motion or as a series of short lines. Work with which ever method feels comfortable to you.

9. Click at the beginning of Wrightson road and digitize the road

10. If an error is made and you need to delete the last portion you digitized simply click on 'Edit' in the toolbar and select 'Delete'

11. If you wish to remove the entire feature you're digitized then double-click on the map to stop insert mode then click on the 'Select Mode' hand icon  and click on the line drawn

12. Then click 'Edit' and 'Delete'

13. At the end of digitizing Wrightson road double-click to exit insert mode. Note that the attribute table opens

14. Enter the name 'Wrightson Road'

15. Digitize Tragarete road and enter its name in the Attribute column

16. Click File and then Save

17. Close the Streets map

18. To change the Symbology of the roads you created open the Port of Spain satellite image as a color composite

19. In the PoSpain window click on 'Layers', 'Add Layer' and select 'Streets'

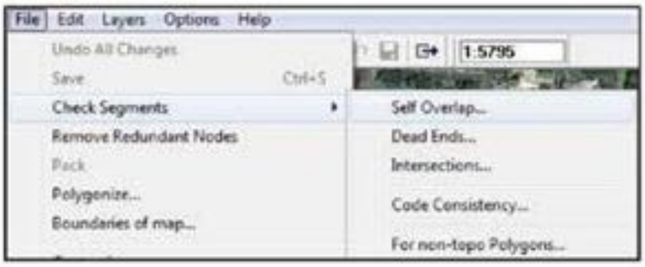
20. In the Display options window that opens select 'red' as the color and increase the line width to 2

21. Click OK

6.4.3 Polygon features

For this tutorial we can create a polygon to represent the Queen's Park Savannah, the large irregular shaped park at the top of the map.

1. Open the Port-of-Spain satellite image as a color composite map
2. In the PoSpain window click on File|Create|Segment Map
3. In the Create Segment Map window that opens enter 'Savannah' under 'Map Name' and click OK
4. Use the Zoom in icon to zoom in to the Queen's Park Savannah
5. Click on the 'Insert mode' pencil icon and just like the digitizing of the roads from the previous section, digitize around the boundary of the Queen's Park Savannah (see figure 6.3)
6. When you arrive at the beginning of the line double-click on the endpoint to close the loop
7. This automatically opens the Attribute table. Enter Queen's Park Savannah under 'seg 1'
8. Click File | Save
9. Now we must check the polygon for erros. Click on File and then 'Check Segments'



10. Click on each item in the list and click OK to check segments

Figure 6.3

11. If an error is found a window will automatically open asking if to zoom to the error. Click YES

12. Use the Zoom icon to zoom in as much as needed. The example below shows a 'Dead End' error which occurs when the two ends of the polygon do not actually connect

13. Click the 'Move Points' icon 

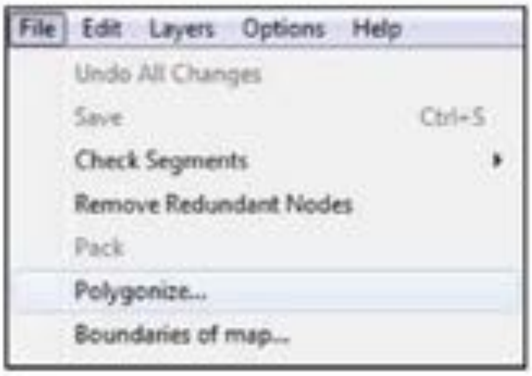
14. Click on one end of the segment and drag it over to the other end

15. Click File | Save

16. Click File | Check Segments | Dead Ends

17. Repeat procedure until no dead ends are found

18. C lick File | Polygonize



19. In the Polygonize Segment Map window that opens enter 'Savannah' under Output Polygon Map

20. Click on the 'Create' icon next to 'Domain' 

21. In the Create Domain window that opens enter 'Savannah' under Domain Name

22. Click OK

23. Close the Domain window that opens. Do not make any changes in it.

24. Click OK in the Polygonize Segment Map

25. A new window titled 'Polygon Editor; Savannah' opens with the Savannah outlined

26. Click on the 'Normal' hand icon  and then click on the savannah polygon.

27. Click on Layers | Add Layer

28. Add the Parks layer and then the Streets layer

Figure 6.3

Chapter 7

Modelling Flood Susceptibility using Integrated Land and Water Information System (ILWIS) Tutorial 2

Learning Objectives

- To provide a step-by-step guide necessary to build and run the landslide and flood susceptibility models as well as the risk models.

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7.1 INTRODUCTION

The flood susceptibility model of Trinidad was developed using GIS-based Multi-Factor Modeling (MFM) techniques. GIS layers were prepared for each of the following flood inundation factors: elevation, slope, drainage density, road density, landcover, and rainfall. The contributing properties of each factor were ranked into 5 ranks: very high, high, moderate, low, and very low. Weights were also assigned to each of the factor as an indication of the level of significance among each other. Table 7.1 shows the weight and ranking used in the flood model.

Please note that you "the modeller" is free to use other weights and ranking schemes but these must be supported by local knowledge and literature review respectively.

The MFM incorporated the assistive influence of higher susceptibility level of the instability and inundation factors to produce the flood susceptibility map. The factors were weighted by importance to combine all the ranked factors (layers) to produce the susceptibility map. This tutorial is designed to allow the user to derive susceptibility maps using the freely available Integrated Land and Water Information System (ILWIS) software. The resulting flood susceptibility was ranked into five (5) classes of susceptibility: very lowly, lowly, moderately, highly, and very highly susceptible.

This tutorial is designed to allow the user to derive susceptibility maps using the freely available Integrated Land and Water Information System (ILWIS) software.

Table 7.1: Flood Inundation Factors

Factors	Weight	Classification scheme	Ranking scheme	Ranked Values
Rainfall (mm)	3	0 - 132	Very Low	1
		133 - 159	Low	2
		160 - 196	Moderate	3
		197 - 237	High	4
		238 - 315	Very High	5
Elevation (m)	2	478 – 932	Very low	1
		287 - 477	Low	2
		148 - 286	Moderate	3
		57 - 147	High	4
		0 - 56	Very High	5
Slope (degrees)	2	49 - 78	Very low	1
		28 - 48	Low	2
		11 - 27	Moderate	3
		6 – 10	High	4
		0 - 5	Very High	5
Drainage density	2	0 – 0.2	Very low	1
		0.21 – 0.6	Low	2
		0.61 – 1.0	Moderate	3
		1.1 – 1.45	High	4
		1.46 – 1.9	Very High	5
Road density	1	0 - 10	Very low	1
		11 - 20	Low	2
		21 - 30	Moderate	3
		31 - 50	High	4
		51 - 72	Very High	5
Land Use (related to water absorption and drainage capacities)	1	Forest	Very Low	1
		Rangeland	Low	2
		Agricultural land	Moderate	3
		Barren land	High	4
		Urban, Wetlands, Water bodies	Very High	5

7.2 OVERALL PROCESS USED IN BUILDING AND RUNNING THE MODEL

The model was built using a four (4) step approach. The steps are:

1. Design of cartographic models
2. Pre-processing of raw input data
3. Running the model
4. Classification of the result

7.2.1 Step 1: Design of Cartographic Models

Cartographic Model for Flood Susceptibility: The cartographic model designed for flood susceptibility model this process is shown in the figure below. The model is based on the weighted sum overlay of the ranked factors.

7.2.3 Step 2: Pre-processing of raw input data

The step entails the pre-processing of the raw input layers for spatial analysis. The attributes of each input layer were ranked according the schema presented in Table 1. Six types of pre-processing tasks were performed. These are:

a. Importing files into ILWIS

b. Assigning coordinate systems

c. Calculation of densities (road and drainage)

d. Generation of slopes from elevation data (DEM)

e. Generation of rainfall surface from rainfall point data

f. Conversion of vector data layers to raster data layers

g. Reclassification of raster data layers

A. Importing files into ILWIS

Several factors play a role into assessing flood risk: density of roads and drainage, elevation and slope of the land, the rainfall pattern of the region and the land use. To begin the tutorial we shall import the basic files needed: roads, drainage, landcover and rainfall vector files and the digital elevation model raster file.

1. Right-click on START and click on "Open Windows Explorer"
2. Navigate to the 'Flood Susceptibility' folder and right-click on any blank space
3. Select 'New'
4. Select ' Folder'

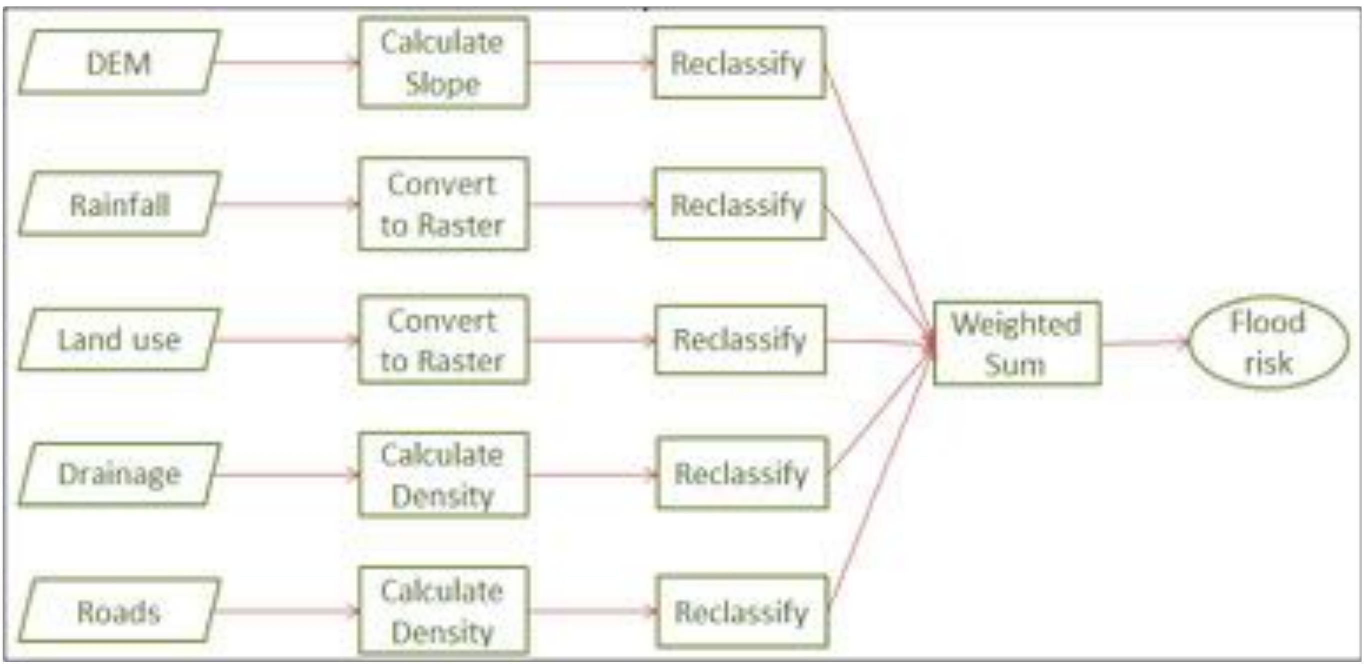


Figure 7.1

5. Name the new folder 'ILWIS_Files'

6. Hit the 'Enter' key

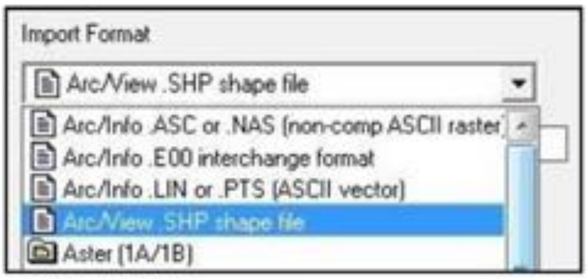
7. Select Start: All Programs: ILWIS: ILWIS

8. To import the raw data to be used click on 'Operations-Tree'

9. Click on Import/Export

10. Double-click on 'Import Via GDAL'

11. In the Import window that opens, under "Import Format" click on the drop arrow and select "Arc/View .SHP Shapefile"

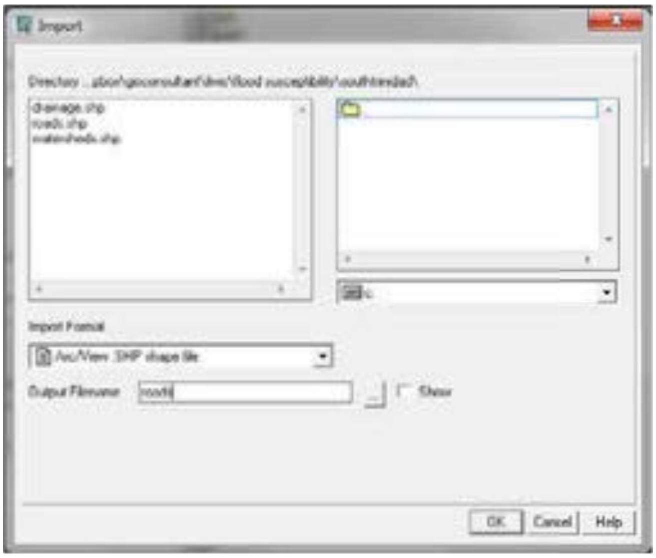


12. In the Directory window on the right side of the Import window, navigate to the Flood Susceptibility folder

13. Click on the 'Roads' shapefile

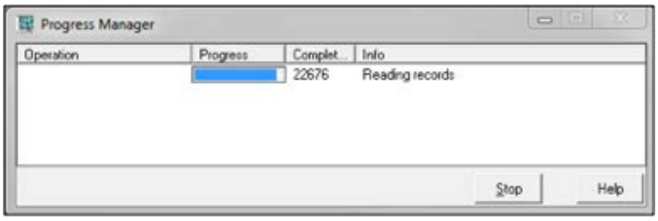
14. Under 'Output Filename' enter 'roads'

15. Click 'OK'



16. Click 'OK'

17. The Progress Manager window will show the progress of the conversion



18. Repeat steps 12-17 for the shapefiles 'Drainage', 'Landcover' and 'Rainfall'

19. To display the imported files click on 'File : Open'

20. In the 'Open Object' window use the browse folder to navigate to the ILWIS_Files folder

21. The files will be displayed on the on the left-hand side of the Open Object window. Click on 'Roads'

22. Click OK in the Display Options window

23. Repeat for the Drainage, Landcover and Rainfall files. Note that the rainfall map is a point map, the roads and drainage files are segment maps and the landcover file is a polygon map (see figures 7.2 and 7.3)

24. In the main window right-click on the Landcover attribute table landcover

25. Click open

Figure 7.2 Roads

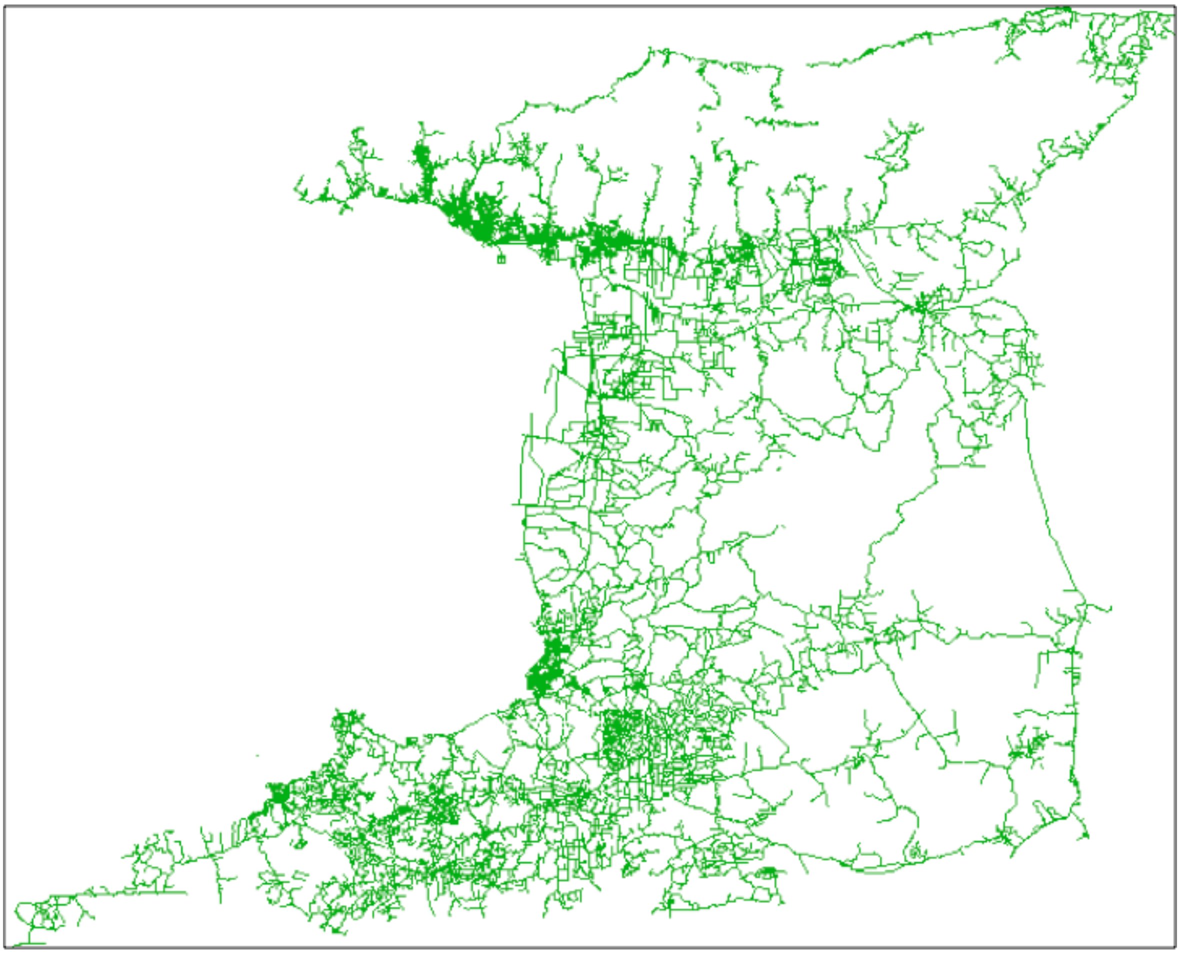
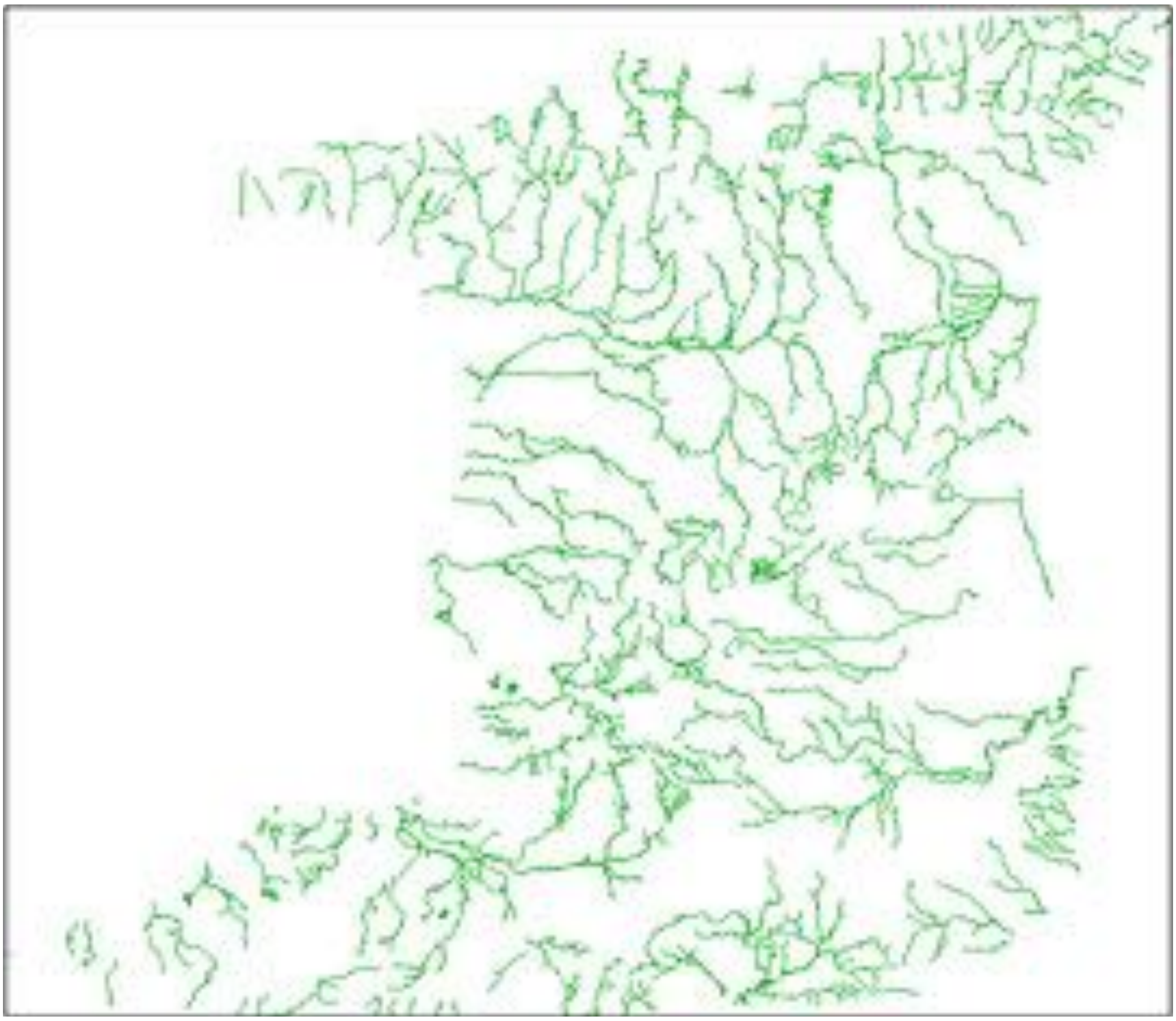
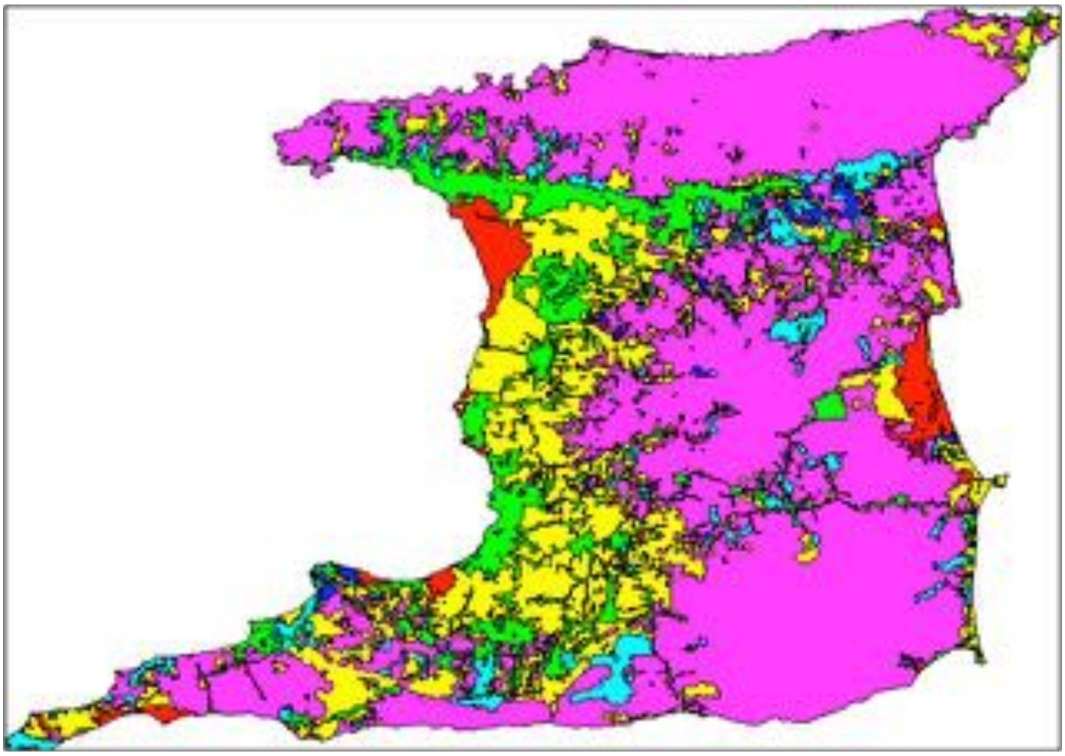
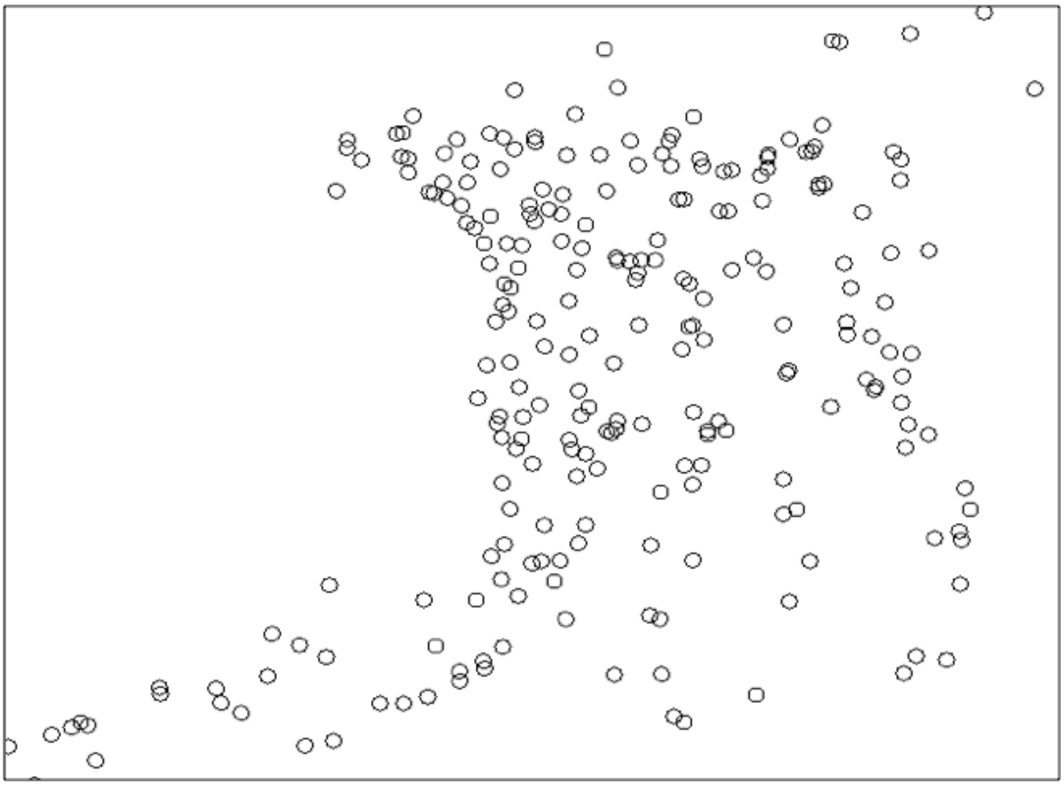


Figure 7.3 Drainage



26. Note that the attribute data for each landcover class is available





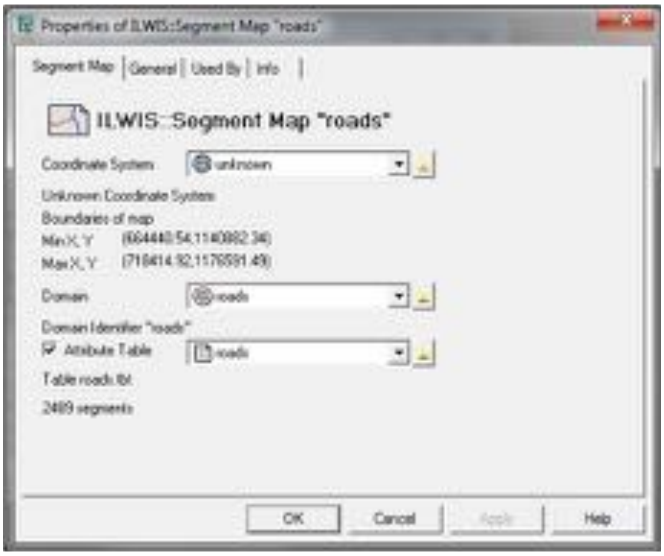
B. Assigning Coordinate Systems

When you import a vector file into ILWIS from ArcInfo the projection information is also imported but you have to create the Coordinate System (vector files) and then the Georeference to use with raster files.

1. In the ILWIS Main window navigate to the Flood Susceptibility folder

2. Right-click on the 'Roads' vector file. It has the vector symbol next to it.

3. Click on 'Properties'

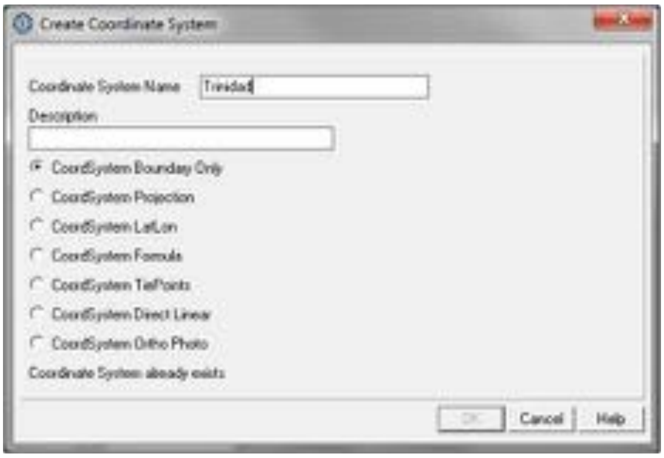


4. To the left of the Coordinate System field click on the create button 

5. Under Coordinate System Name enter 'Trinidad'

6. Leave the defaults for the rest of the window and click 'OK'

7. Click 'OK' on the Properties window



8. Right click on the Drainage file and select 'Properties'

9. Click on the drop arrow under 'Coordinate System' and select the Trinidad Coordinate system just created.

10. Click OK

11. Repeat steps 8-10 for the Rainfall point file

12. N.B. For raster layers, a Georeference must also be assigned. This will be shown in section 4 - Calculating densities.

C. Calculating Densities

The susceptibility component of the analysis requires that the drainage and road densities of each watershed be calculated. Ideally this would be done based on watersheds however ILWIS calculates densities based on pixels. In this tutorial we shall import the density files but will also include the directions on how calculate the densities in ILWIS using pixels.

1. Using the directions detailed in Step 2: Preprocessing of Raw Data to import the shapefiles "Roads_density" and 'Drainage_Density". These density files are calculated based on the watersheds of Trinidad in ArcGIS.

2. If one does not have ArcGIS and need to calculate the density files in ILWIS then follow the following steps.

Create Georeference

Segment densities are calculated per pixel. It is important therefore that a georeference is created with a large pixel size.

1. In the main window click the + next to Create.

2. Double-click on New GeoReference

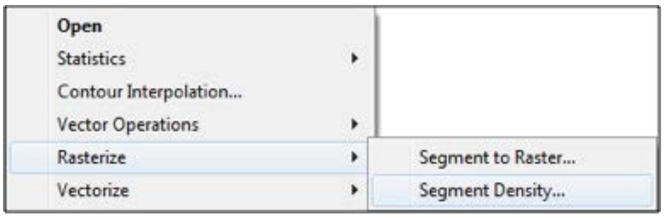
3. Under GeoReference Name enter 'Central_Trinidad'

4. Under Coordinate System click on the drop arrow and select the previously created coordinate system 'Central_Trinidad'

5. Under the Pixel size field enter 5000

6. Click OK

Calculating Segment Density



1. Right-click on the Roads vector file

2. Select Rasterize

3. Select Segment Density

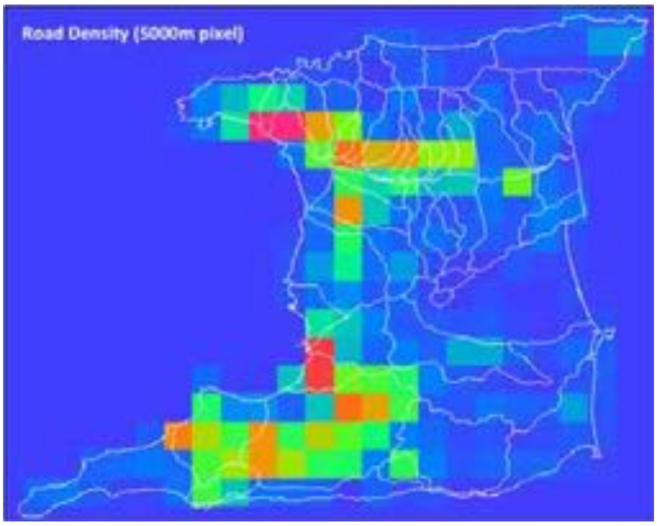
4. Under 'Output Raster Map' enter 'roadsden'

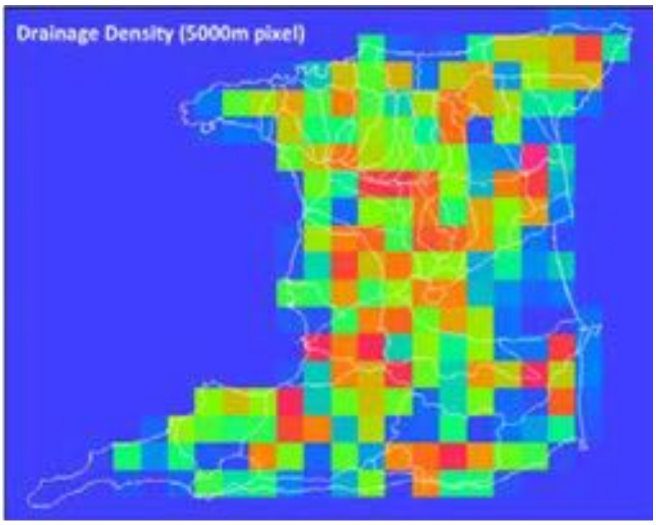
5. Under GeoReference click on the drop arrow and select the previously created georeference 'Trinidad'

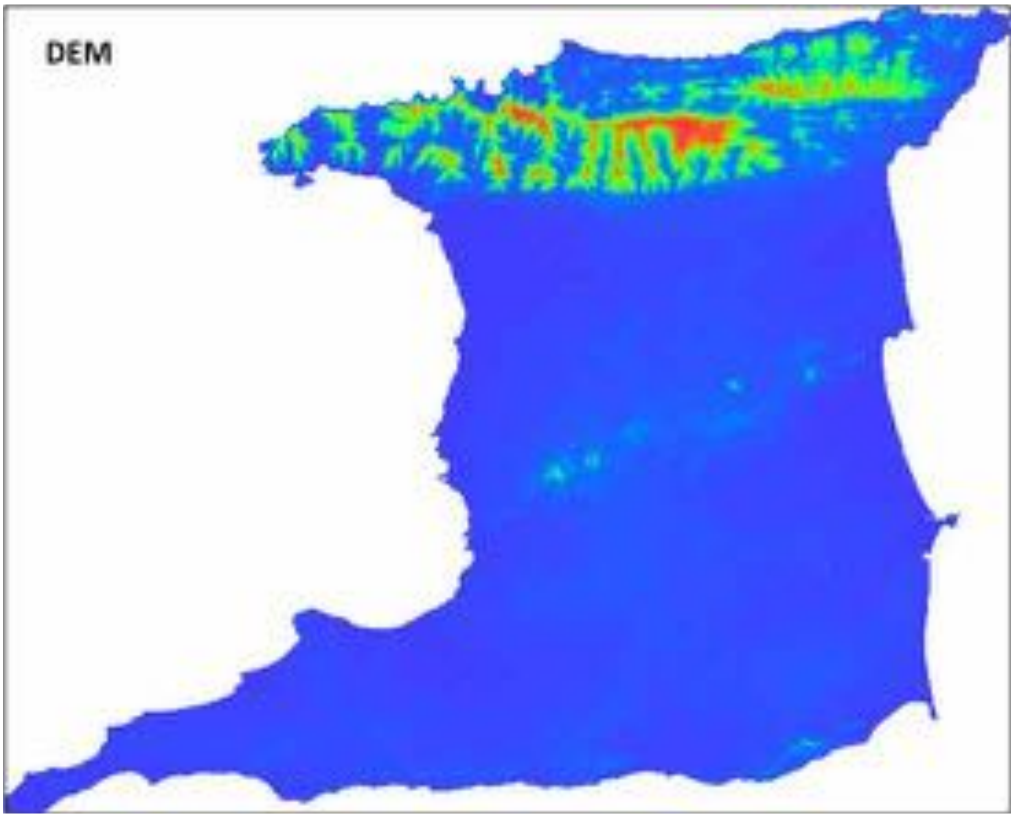
6. Click 'Show'

7. The image below shows the resultant roads density map overlaid by the watersheds layer for reference

8. Repeat steps 1 – 7 with the drainage file and name it drainageden







D. Creating a Slope Map

Calculate the slope gradient in the X and Y direction

1. Navigate to the Flood Susceptibility folder and open the DEM file

2. To create a slope map first the slope gradient or the change in slope in the x and y directions must be calculated:

3. In the Navigation window right-click on 'dem'

4. Select 'Image Processing' and then 'Filter'

5. In the Filtering dialog window that opens, under Raster Map ensure that 'DEM' is selected

6. Under Filter Name select 'DFDX'

7. Under Output Raster Map enter 'DEM_DX'

8. Accept all other defaults and click SHOW

9. In the Display Options window leave the defaults and click OK

10. The resultant map can be seen below. It shows the change in slope in the X-direction

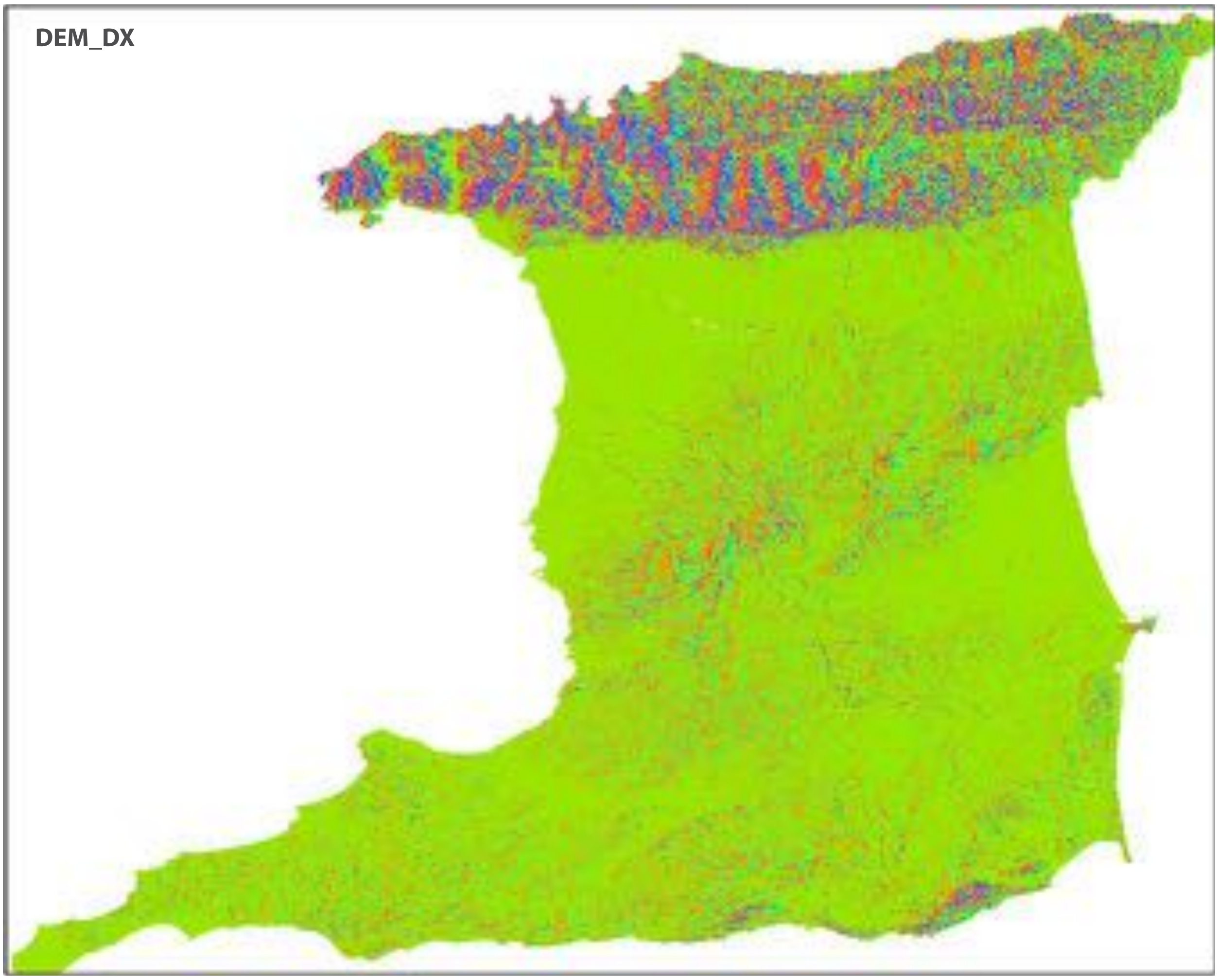
11. Repeat steps 1 – 8 with the following changes:

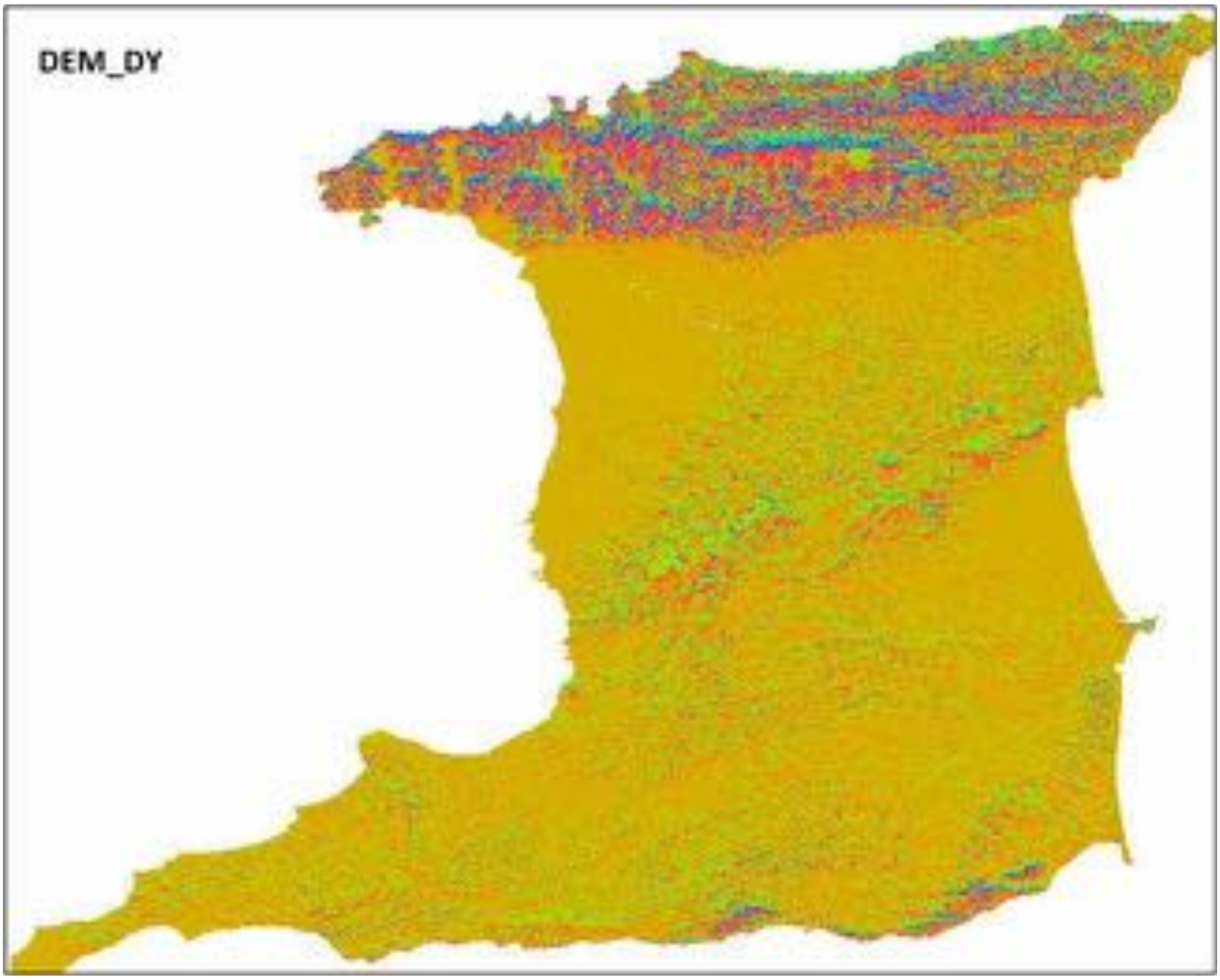
    a. Select DFDY instead of DFDX under Filter Name

    b. Name the Output Raster Map 'DEM_DY"

12. The resultant map shows the change in slope in the Y-direction

13. Now that the gradient maps in the X and Y directions have been created we can now create a slope map


DEM_DX


DEM_DY

Create Slope Map

14. The command line of the main window is the blank space directly below the Main menu options

15. Type the following command in the Command line: Slope_degrees = raddeg(atan((hyp(dem_dx,dem_dy))/90))

16. Hit the Enter key on your keyboard

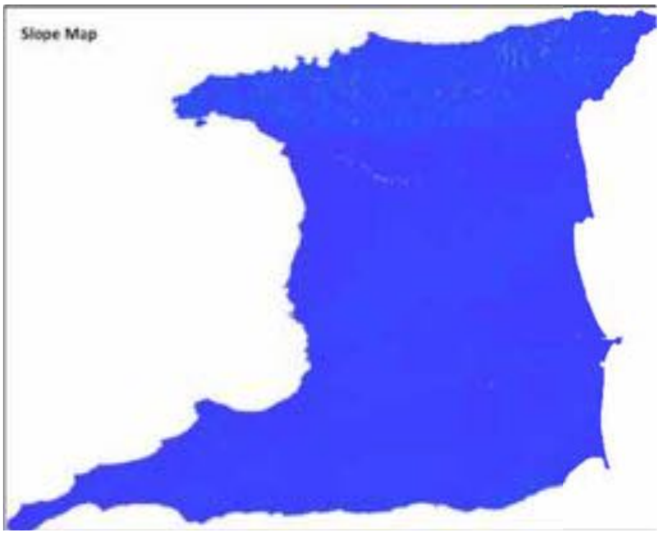
17. The Raster Map Definition box opens

18. Under Description enter 'Slope map in degrees'

19. Click OK

20. The file 'Slope_degrees' will be created and seen in the ILWIS_files folder

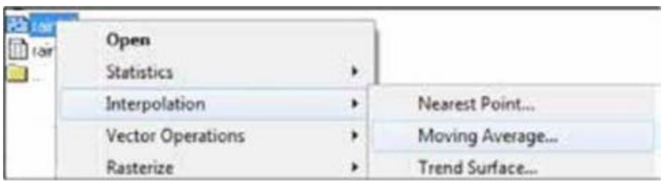
21. Right-click on it and click Open to view the slope map



E .Generation of rainfall surface from rainfall point data

In this step, the input rainfall point data is interpolated into surface raster grid file.

1. In the main window right click on the 'rainfall' point file and select 'Interpolation' and then 'Moving Average'



2. In the Moving Average window select 'rasters' for the Georeference

3. Click SHOW

4. In the Display Options window click OK (See figure 7.4)

F. Converting Segment maps to Raster Maps

Before the flood susceptibility model can be run all the segment (vector) files created must be converted to raster format. All raster files must have a georeference assigned to them. Refer to section 2 and create a georeference titled 'Rasters' with the coordinate system 'Trinidad' and pixel size '10'.

1. There is only 1 segment maps left to be converted: Landcover

2. In the main window right-click on the 'Landcover' polygon file and select "Polygon to Raster'

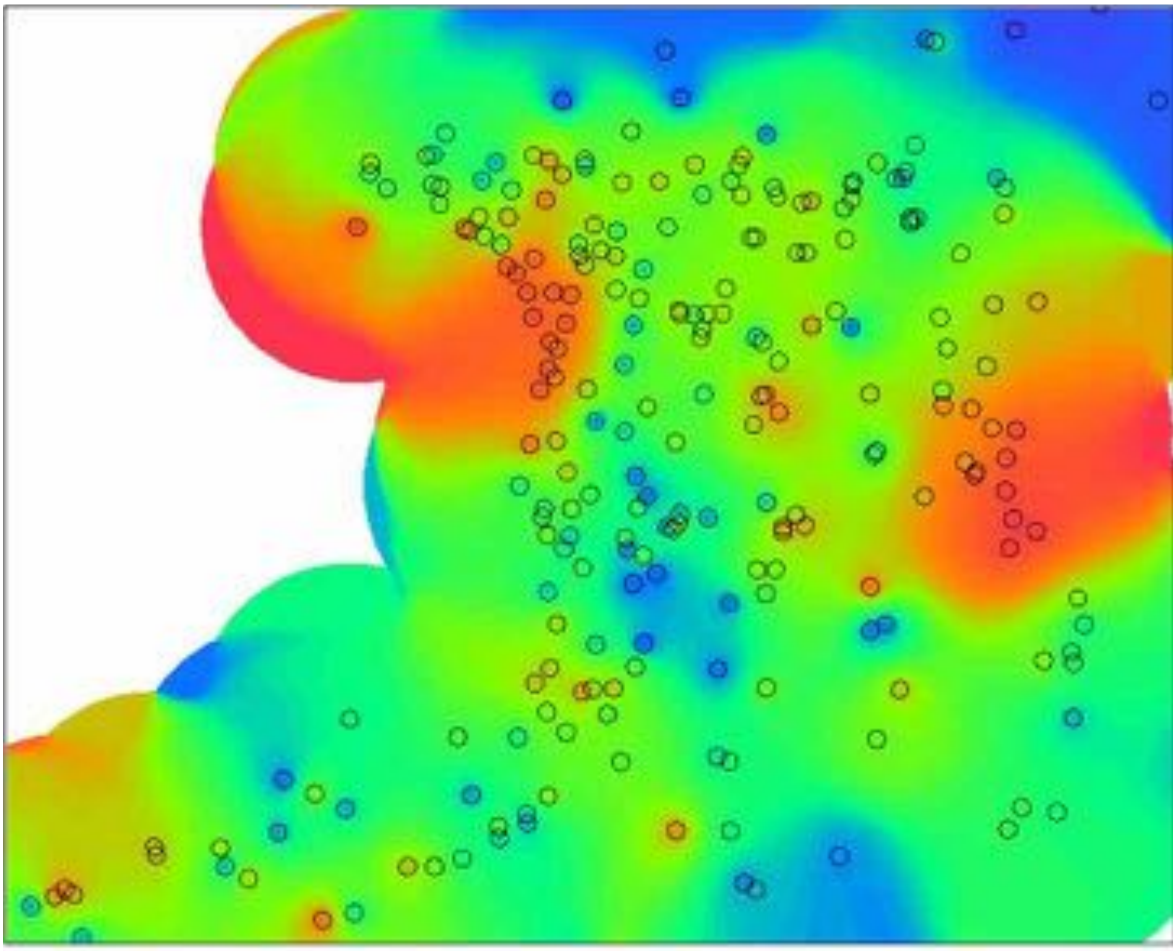
3. In the Rasterize Polygon Map window that opens click on the drop arrow under Georeference and select the 'rasters' georeference just created.

4. Click on Show

5. In the Display Options window select the 'Light' radio button

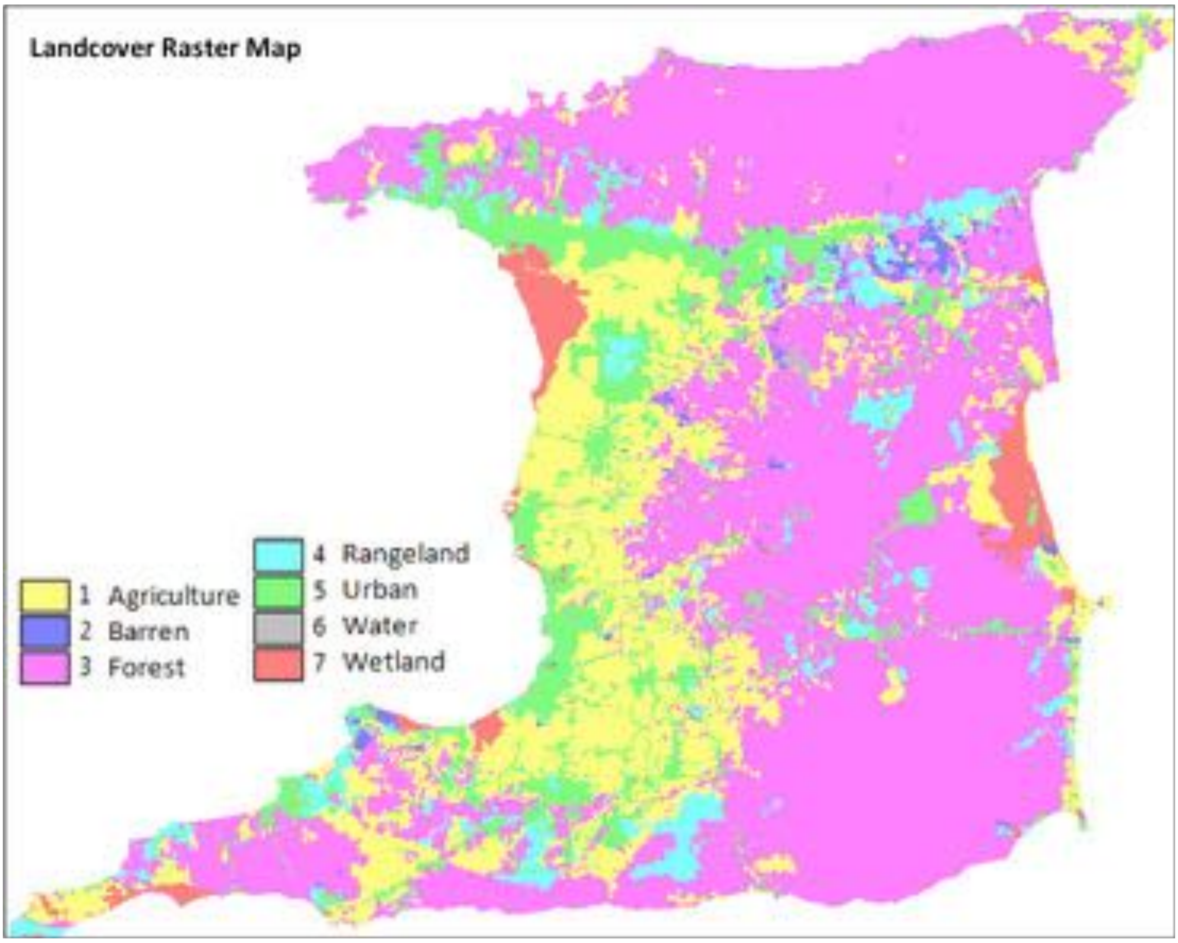
6. Click OK (See figure 7.5)

Figure 7.4



Rainfall Interpolation Surface (rainfall points overlaid for reference)

Figure 7.5



G. Reclassification of Raster Files based on the ranked values of each factor

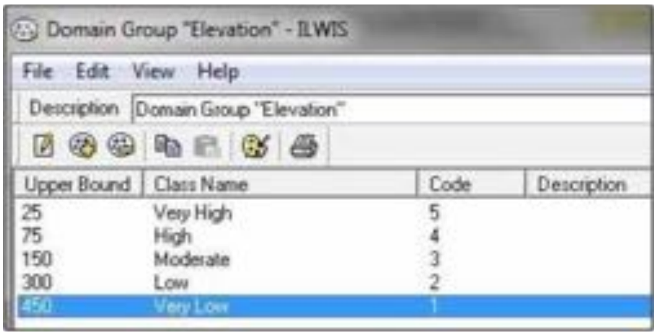
The raster grid files need to be reclassified based of the ranking scheme provided in Table 1.

1. In the main window right-click on DEM raster map, select Image Processing and then Slicing

2. In the Slicing window that opens enter 'Elevation' under 'Output Raster Map'

3. Click the 'Create Domain' icon
4. Under Domain name enter 'Elevation'
5. Click on 'Group'
6. Click OK
7. In the Domain Group window click on the 'Add Item' button

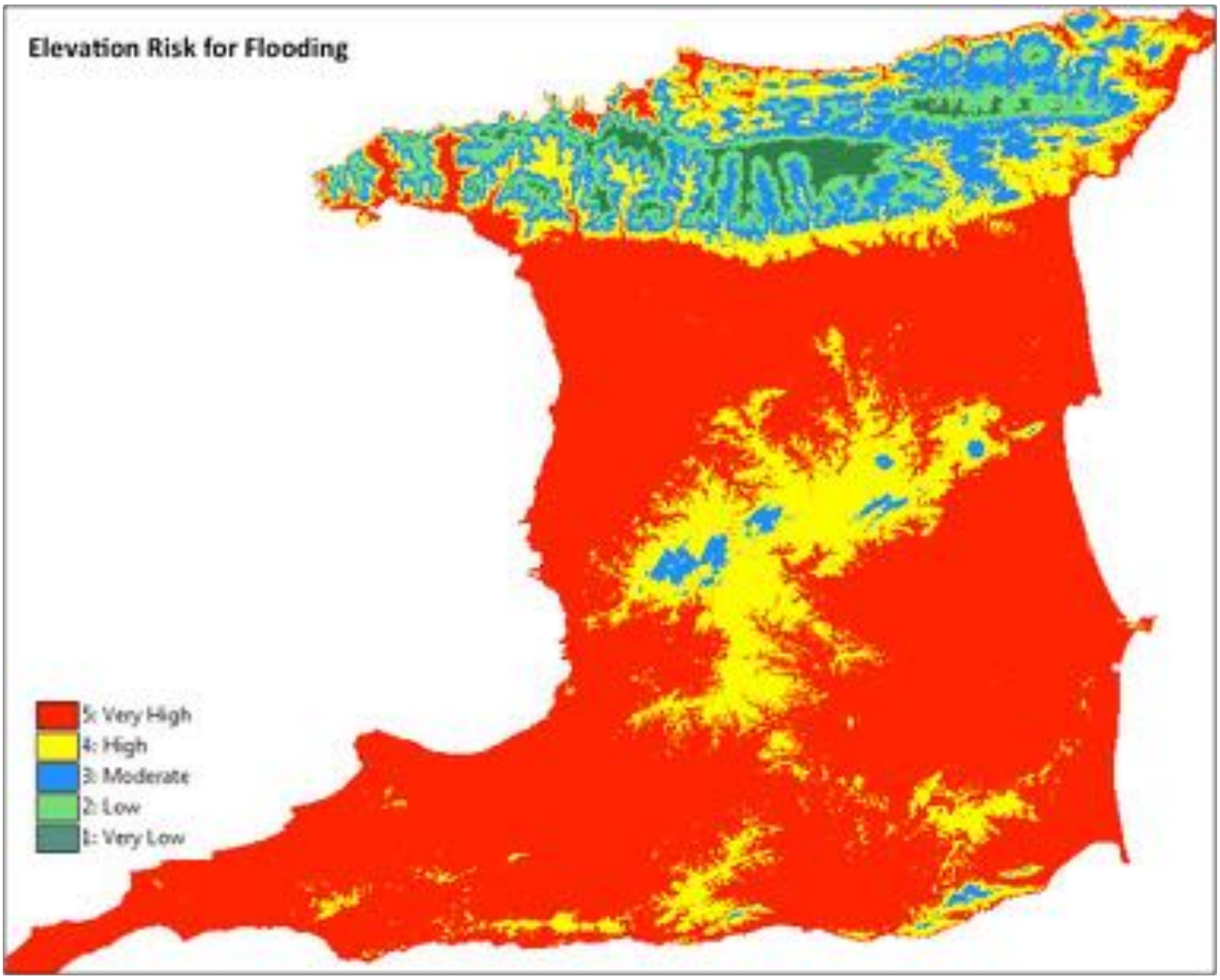
8. In 'Add Domain Item' enter '932' under 'Upper Bond', 'Very Low' under Name and '1' under 'Code'
9. Click OK
10. Refer to Table 1 and enter the remaining 4 classes for Elevation
11. Once all have been entered click File | Exit to close the window
12. Click OK on the Create Domain window
13. Click SHOW on the Slicing window
14. In the Display Options window ensure that 'Elevation' is selected under 'Representation'
15. Click OK

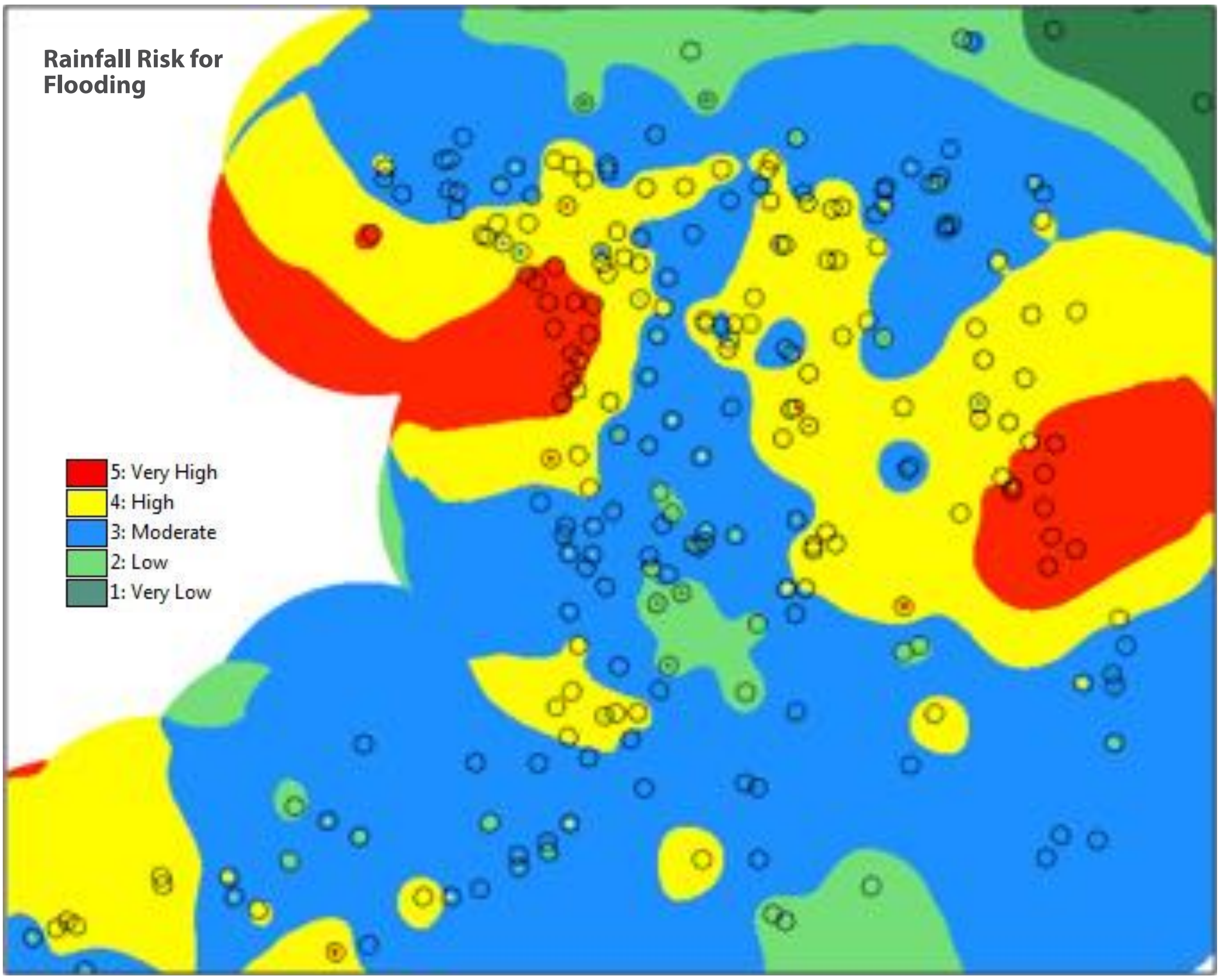


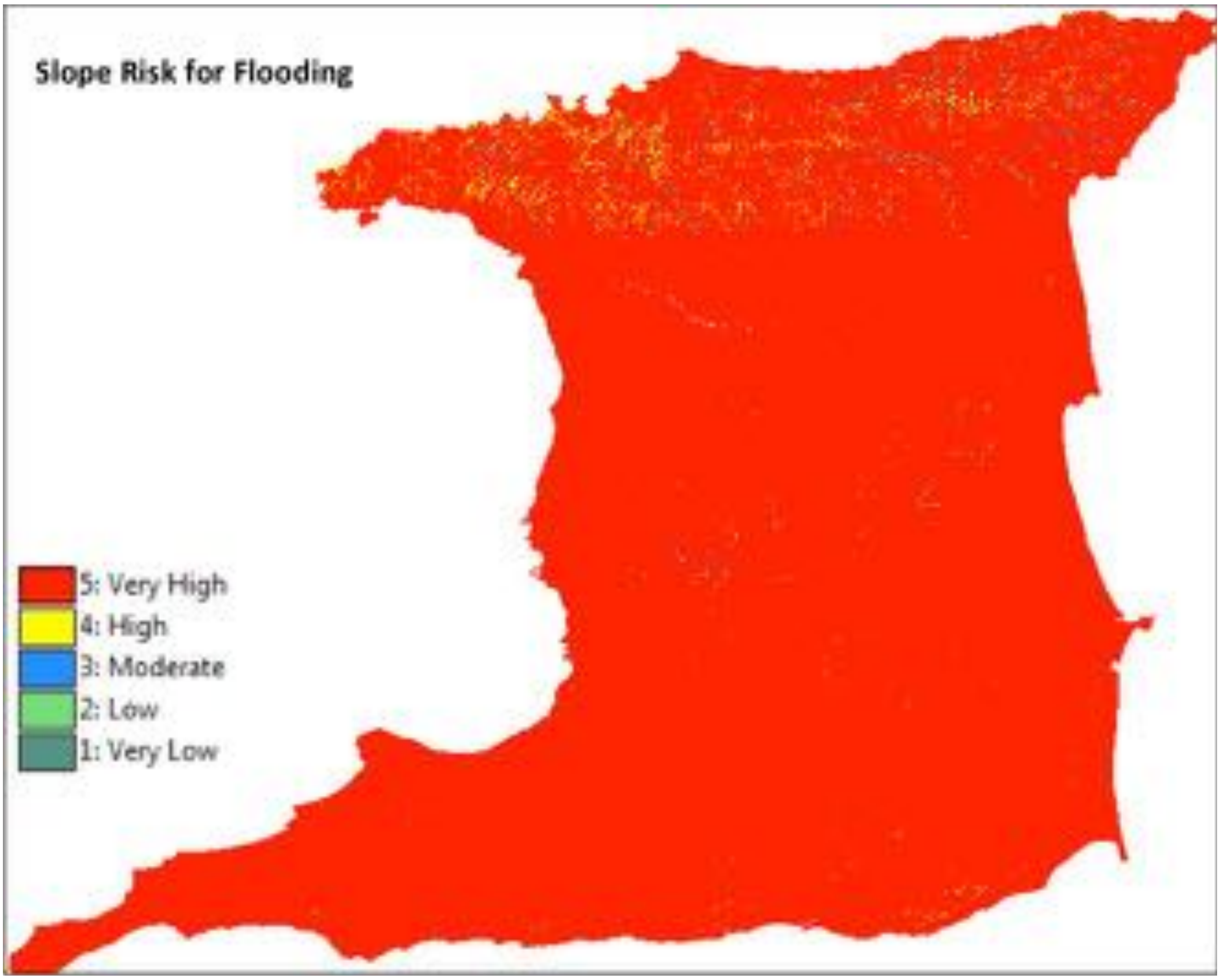
16. Using the information provided in Table 1 create classified risk maps for Rainfall, Slope, Drainage and Road density and Land Cover raster files
17. Refer to the table below for the classification of the Land Cover map

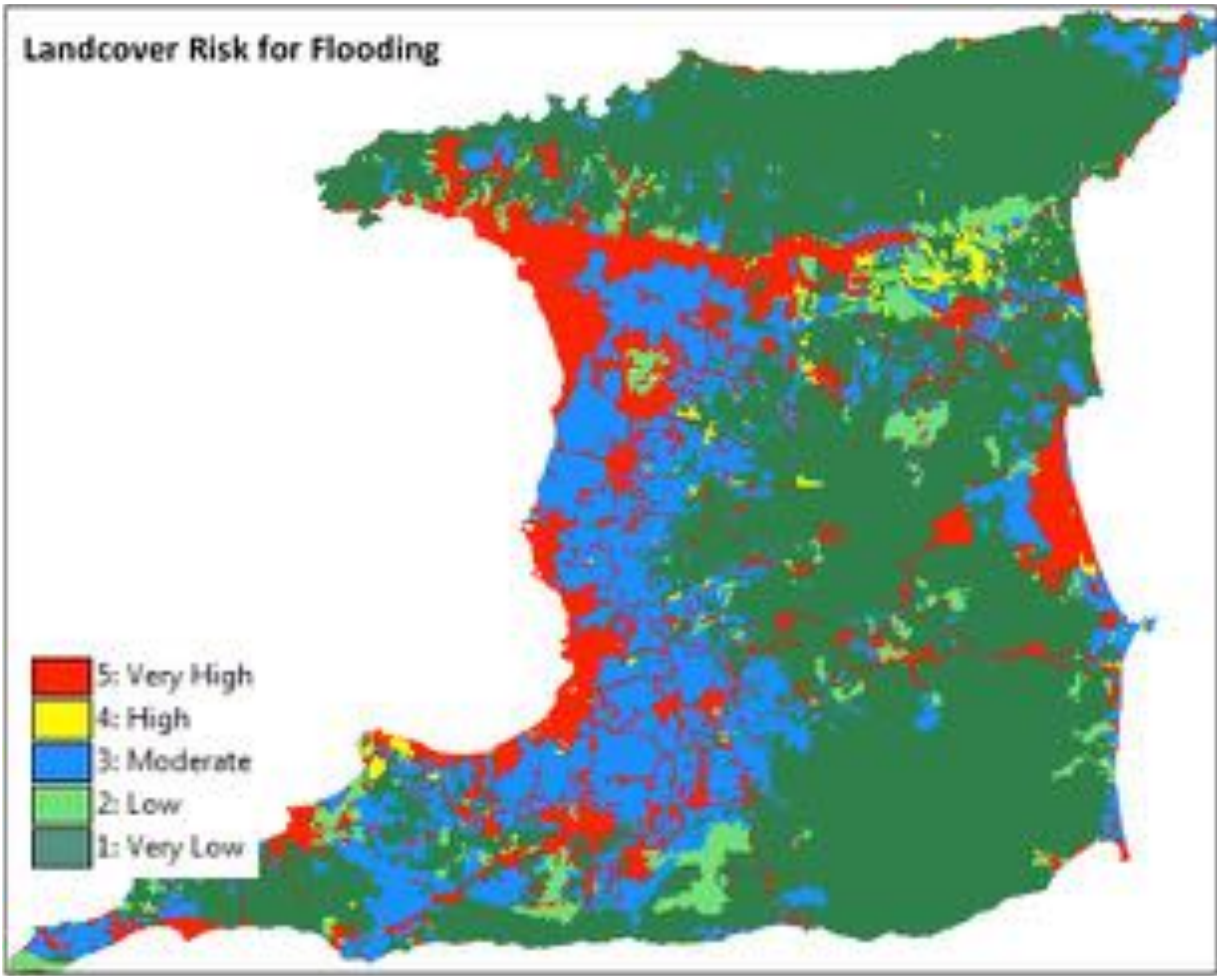
Upper Bound	Class Name	Code	Description
1	Moderate	3	Agriculture
2	High	4	Barren Land
3	Very low	1	Forest
4	Low	2	Rangeland
7	Very High	5	Urban/Waterbodies/Wetland

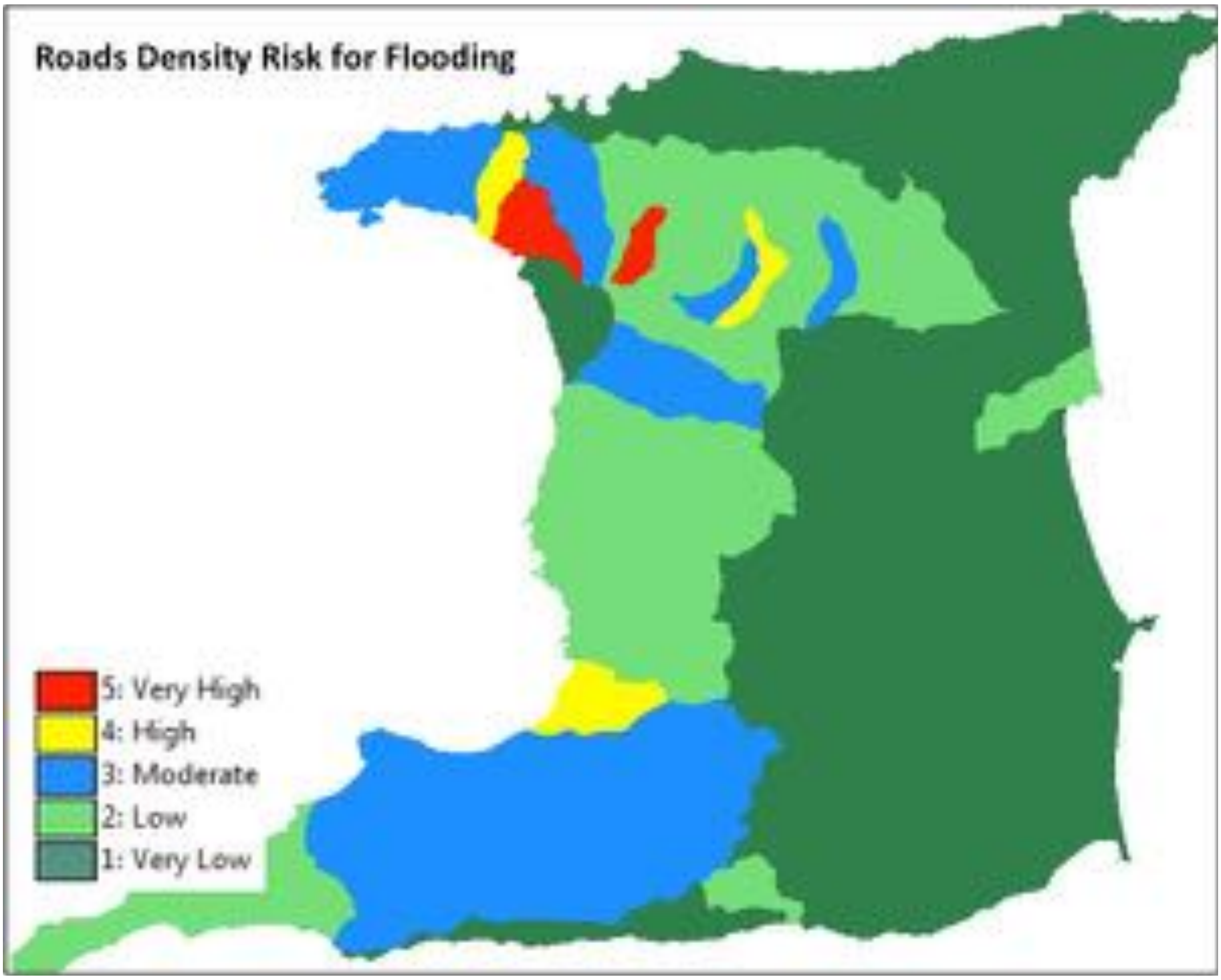
Classification of the Landcover Map

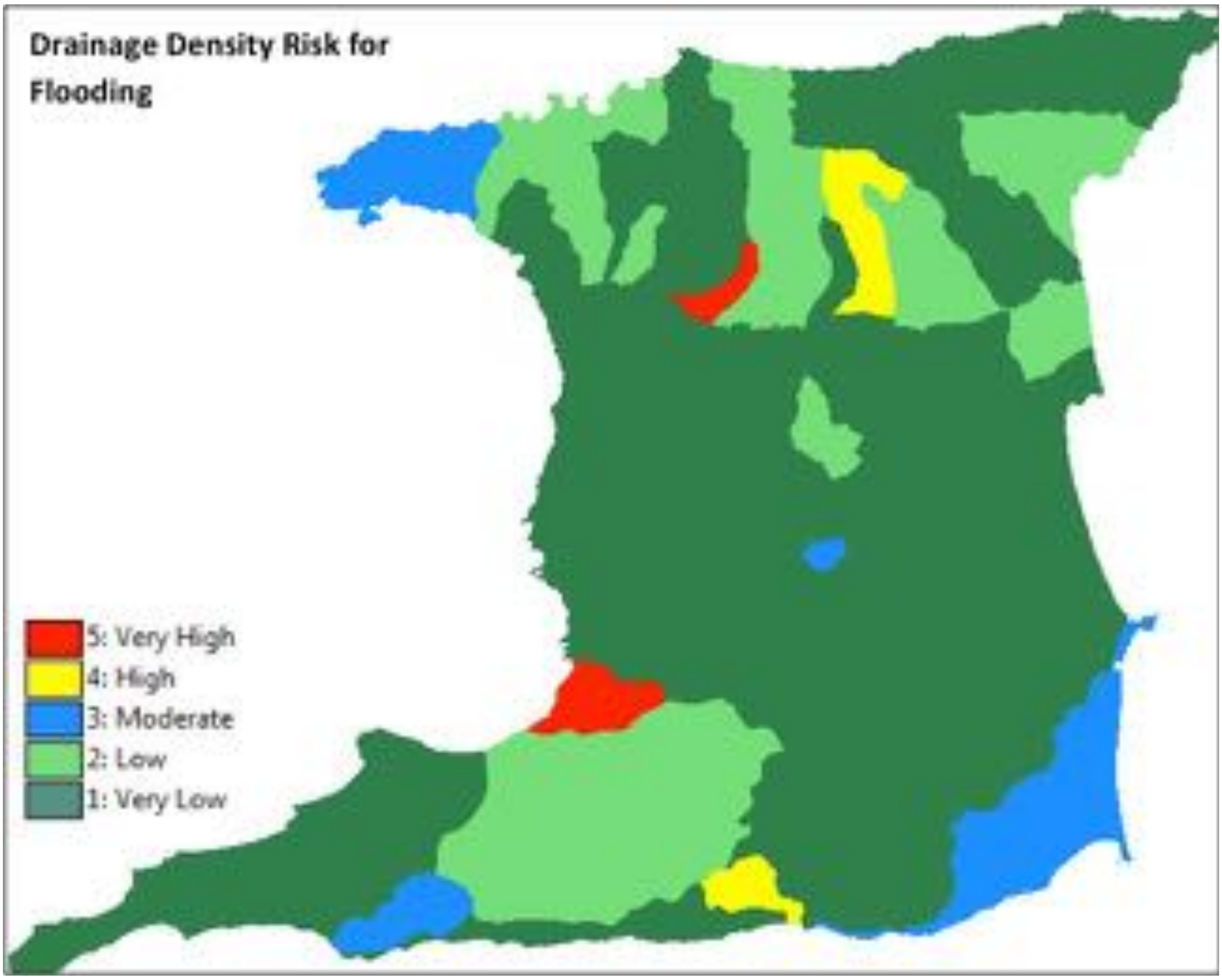

Elevation Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low


Rainfall Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low


Slope Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low


Landcover Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low


Roads Density Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low

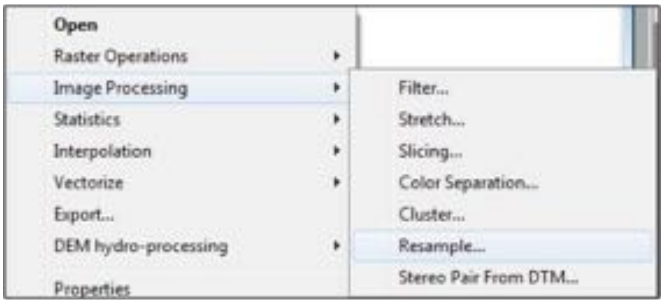

Drainage Density Risk for Flooding
5: Very High
4: High
3: Moderate
2: Low
1: Very Low

Resampling of the Roads and Drainage density files (if created in ILWIS)

1. Before the flood susceptibility model can be run all the raster maps must have the same georeference. If the density files were created in ILWIS using the 5000m pixel they need to be resampled. This is described in the following steps.

2. In the main window right-click on the roads reclass raster map

3. Select 'Image Processing' and then 'Resample'



4. In the Resample window enter 'Roadsreclass_Resample' under Output Raster Map

5. Click the drop arrow and select the 'rasters' georeference

6. Click Show

7. In the Display Options window click OK

8. The new resample map looks just like the original Roads Density map but the pixel size now matching that of the other raster files.

9. Repeat steps 19 – 24 for the Drainage reclassed raster map

H. Creating value maps of the reclassified maps

The classified maps created as not 'value' maps as they show classes for each pixel rather than a value. Before we can run the model we first have to recreate the classified maps as value maps.

1. Using the Operation Tree go to 'Raster Operations' then double click on 'Cross'

2. In the Cross window that opens select 'Slope_degrees' for the 1st Map and the 2nd Map options.

3. Enter 'slopecross' under 'Output Table'

4. Check the box for 'Output Map' and enter 'slopecross' for the name

5. Click Show

6. In the Main window double click on the 'slopecross' table that was just created

7. Click on 'Columns' and then 'Add Column'

8. Enter the name 'slopevalue' under Column Name

9. Change the Value Range to 1 to 5

10. Change the Precision to 1

11. Click OK

12. In the Operation Tree click on Raster Operations and then click on the Attribute Map from Raster Map

13. In the window that opens select the 'SlopeCross' under Raster Map

14. Under Table select 'slopecross'

15. Under Attribute select 'slopevalue'

16. Ensure that 'value' is showing under 'Domain'

17. Ensure that the Value Range is 1 to 5

18. Ensure that the Precision is 1

19. Click Show

20. In the Display Options window ensure that the range is 1 to 5

21. Click OK

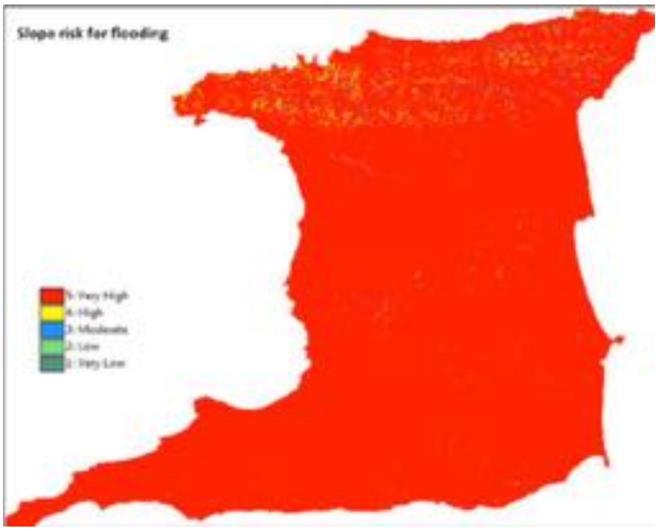
22. Note that the new image looks identical to the previous Slope reclass image but now each pixel carries a value rather than a class.

23. Repeat steps 1 to 22 for all the reclassed files – DEM_reclass, Rainfall_reclass, roadsreclass_resample, drainagereclass_resample and landcoverreclass

7.2.4 Step 3: Running the Model

Now that all the raster maps have been reclassed according to risk we can calculate the overall flood susceptibility map using the Command line of ILWIS. Note in Table 1 that each risk factor does not carry the same weight.

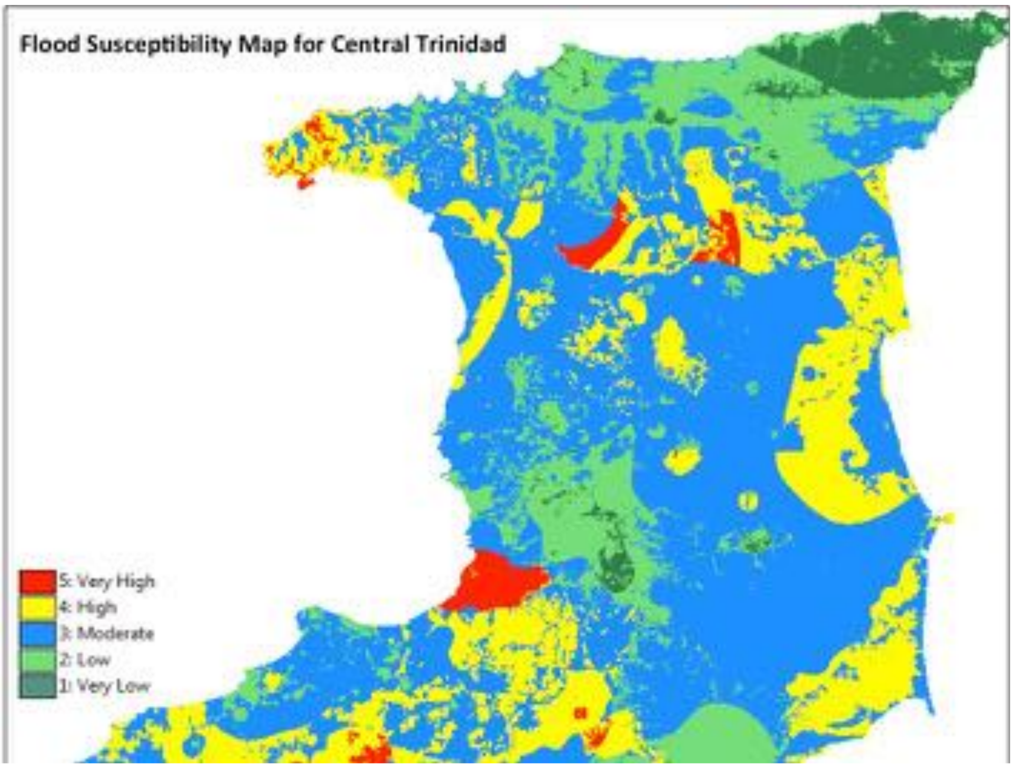
1. In the main window enter the calculation below in the Command Line: weightedsum = (rainfallvalue*3) + (demvalue*2) + (slopevalue) + (drainagevalue*2) + (roadsvalue) + (landcovervalue)



2. The file ‘weightedsum’ is now created and found in the main window. Right-click on ‘weightedsum’ and select ‘Image Processing and then ‘Slicing’

3. Reclassify the weighted sum file using the following categories:

Classes	Class Name	Code
0 – 8	Very Low	1
9 - 16	Low	2
17 - 24	Moderate	3
25 - 32	High	4
33 - 40	Very High	5



4. The resulting map shows the areas in terms of flood susceptibility.

Chapter 8

Drought Characterisation Monitoring and Forecasting

Learning Objectives

- To show how water managers could get answers about drought in order to make decisions.
- To learn the techniques to identify and estimate the different drought characteristics using state of art LSP (ground and RS based) estimations and to derive drought severity from these parameters using prepared datasets.

GO BACK TO TABLE OF CONTENTS

8.1 KEY LEARNING TOPICS

At the end of this chapter, participants are expected to:

a. Understand what is a drought linking to module 1 – types of drought;

b. Understand which interaction between drought status and the water balance

c. Understand how water balance components can be measured from ground and space

d. Understand how droughts can be characterized using the different data.

e. Identify the Risk associated with the drought phenomena

8.2 INTRODUCTION

Drought is a reoccurring and worldwide problem that will grow in future

Drought is a reoccurring and worldwide problem that will grow in future (Edossa et al., 2010). Droughts cause significant socio-economic and environmental impacts like reduced agricultural products (Boken, 2009), reduced water levels, increased fire hazards, and damage to wildlife. As drought is a slow hazard it is difficult to predict the temporal start and end. This prediction is further troubled because drought is depending on a lot of variables. Hence studying droughts incorporates the investigation in land surface parameters (Mishra and Singh, 2010a), of which not all can be determined accurately. Drought characteristics, like intensity and frequency, will vary from one climate regime to another and therefore, need to be investigated thoroughly.

Because of its nature drought cannot be viewed solely as a physical phenomenon, and it is usually defined both conceptually and operationally (Heim, 2002;Nagarajan, 2010). The conceptual definition of drought is important in establishing drought policy and to declare exceptional drought based on science-driven assessments. While the operational definitions help to define the onset, severity, and end of droughts (Rossi et al., 1992), this helps policy makers, resource planners, and others in recognizing and planning for drought. Drought can be categorized as meteorological, agricultural, hydrological and socioeconomic droughts (Nagarajan, 2010) in which the first three deal with mechanisms of measuring drought as a physical phenomenon, while the last deals with drought in terms of supply and demand following the effect of shortage of rain fall.(Wilhite and Glantz, 1985). Drought occurs in all parts of the world, but it is severe when it occurs in developing countries specially Africa.

The impact of climate change on drought is severe. Climate change causes not only global temperature rise, but also the increase of extreme weather events (IPCC, 2007). Such extremes are intense rainfall followed by prolonged absence of precipitation. Both the rise in temperature and the long absence of precipitation are major factors for causing droughts. Therefore in forecasting future droughts this global change needs to be incorporated.

8.3 DROUGHT ASSESSMENT

Assessing and analyzing drought is very important in water resource planning and management.

Droughts are assessed under meteorological, agricultural, hydrological, and socio-economic aspects (Nagarajan, 2010). Drought assessment depends on the factors that caused the drought and the impacts of the drought. Assessing drought requires the understanding of historical droughts and its impact during the drought.

Traditional methods of drought assessment and monitoring depend on rainfall data, are regionally limited, inaccurate and difficult to obtain in near-real time. In contrast, the satellite data are consistently available in near real time and can be used to identify the start of drought, its duration and magnitude prior to harvests (Ataklti, 2012).

While drought is defined as the absence of water, different droughts can be identified depending on which of the specific hydrological component which is absent. The different droughts that are recognised are: meteorological drought, agricultural drought and hydrological drought. An additional socio-economic drought is usually also recognised which associates the different droughts with the supply and demand of economic goods.

8.4 DROUGHT CLASSIFICATION

According to (Mishra and Singh, 2010b) the droughts are generally classified into four categories. This classification is in fact cascading from minor to major impacts, illustrated by Figure 8.1.

1. **Meteorological drought** is defined as a lack of precipitation over a region for a period of time. Precipitation has been commonly used for meteorological drought analysis (Salinger, 2005;Anderson et al., 2007;Edossa et al., 2010). It should be noted that meteorological drought can also occur if precipitation amounts remain stable, but evapotranspiration increases. Especially in a changing climate this needs to be considered.

2. **Agricultural drought**, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources (Narasimhan and Srinivasan, 2005a;van der Molen et al., 2011). A decline of soil moisture depends on several factors which affect meteorological and hydrological droughts along with differences between actual evapotranspiration and potential evapotranspiration (Seneviratne et al., 2006). Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant and stage of growth, and the physical and biological properties of soil (Allen et al., 2005a;Beyazgul et al., 2000). Several drought indices, based on a combination of precipitation, temperature and soil moisture and evapotranspiration (Palmer, 1968;Narasimhan and Srinivasan, 2005a), have been derived to study agricultural droughts.

3. **Hydrological drought** is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis (Hirschi et al., 2007;Rodell et al., 2004;Mohamed et al., 2004;Harmsen et al., 2009).

4. **Socio-economic drought** occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply. It is therefore less of a physical drought definition, as it also takes into account the risks that specific stakeholders have to specific deficit of water. As such this particular drought can only be monitored when all the risks on the above droughts have been characterized.

8.5 WATER BALANCE

When considering drought only to be a lack of precipitation the drought problem can never be

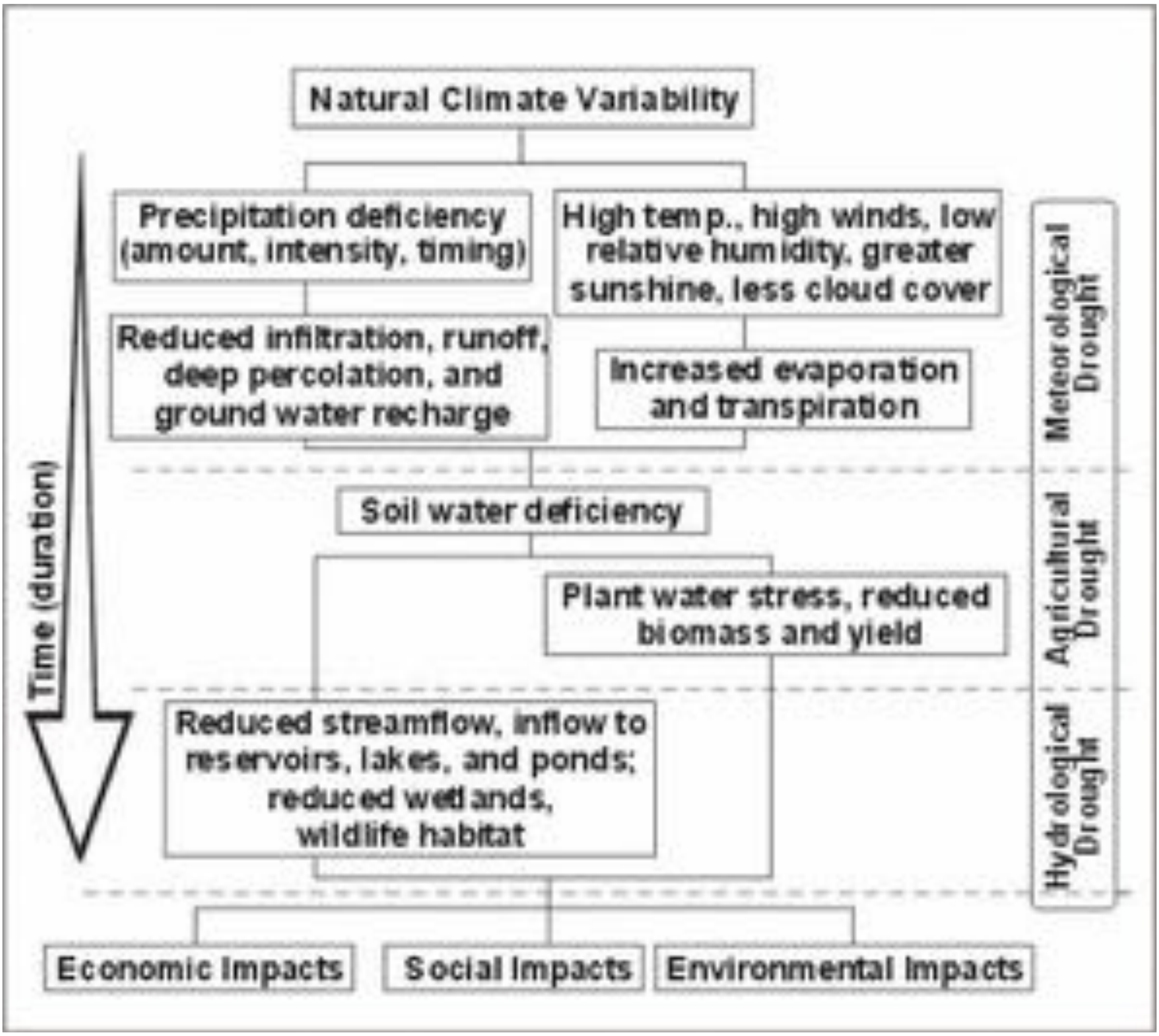


Figure 8.1: Drought cascade

fully solved. Instead only meteorological drought is investigated. As such drought in general is a problem caused by multiple-variables, and varies in both space and time. In order to characterise drought one should look not only into one part of the water cycle but all the components. This water cycle is illustrated in Figure 8.2.

Here, the sun is the dominant driving force behind the water cycle as its heats water in the oceans. This causes evaporation of the water into air (vapor). In addition the land surface also loses water to the atmosphere in the form of evapotranspiration (which is the combined transpiration by plants and the evaporation by the soil). Due to heating of the atmosphere this air rises taking the vapor up into the atmosphere. The vapor rises into the air where cooler temperatures cause it to condense into clouds.

Air currents move clouds around the globe, and cloud particles collide, grow, and fall out of the sky as precipitation. Some precipitation falls as snow and can accumulate as ice caps and glaciers. Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans. Runoff, and groundwater seepage, accumulate and are stored as freshwater in lakes.

Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration. Some of the water infiltrates into the ground and replenishes aquifers (saturated subsurface rock). Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs.

Yet more groundwater is absorbed by plant roots to end up as evapotranspiration from the leaves. Over time, though, all of this water keeps moving, some to reenter the ocean.

In drought monitoring it is superfluous to investigate the complete water cycle over the whole earth while the area of interest is much smaller. Instead a local water balance (Syed et al, 2008) can be written such that all the components within an area are covered. The water balance equation is (Equation 7-1) and explained for each of the components.

$$P + I = ET + R + \Delta S$$

With P is precipitation $\left[mm\,day^{-1}\right]$, I is inflow ET is the evapotranspiration $\left\lfloor mm\,day^{-1}\right\rfloor$, R is runoff $\left\lfloor mm\,day^{-1}\right\rfloor$, and ΔS $\left\lfloor mm\,day^{-1}\right\rfloor$ is the change in storage. Which is characterised as $S = SM + GW$, with SM soil moisture $\left\lfloor mm\,day^{-1}\right\rfloor$ and GW is the ground water $\left\lfloor mm\,day^{-1}\right\rfloor$. Of course inflow can be assumed to be the runoff from the neighbouring pixels. Regional Drought can thus be investigated using the local values of each of these water balance components. However as each of these components in the water cycle has a different temporal variation, different droughts exist (McKee et al., 1993). Note that inflow into a catchment/pixel can be considered as the runoff/outflow from a neighbouring catchment/pixel. Hence they are treated as the same variable. It becomes clear that a more detailed look at the water balance components is needed in order to understand drought and its impact. is precipitation , is inflow is the evapotranspiration , is runoff , and is the change in storage. Which is characterised as , with soil moisture and is the ground water . Of course inflow can be assumed to be the runoff from the neighbouring pixels. Regional Drought can thus be investigated using the local values of each of these water balance components. However as each of these components in the water cycle has a different temporal variation, different droughts exist (McKee et al., 1993). Note that inflow into a catchment/pixel can be considered as the runoff/outflow from a neighbouring catchment/pixel.

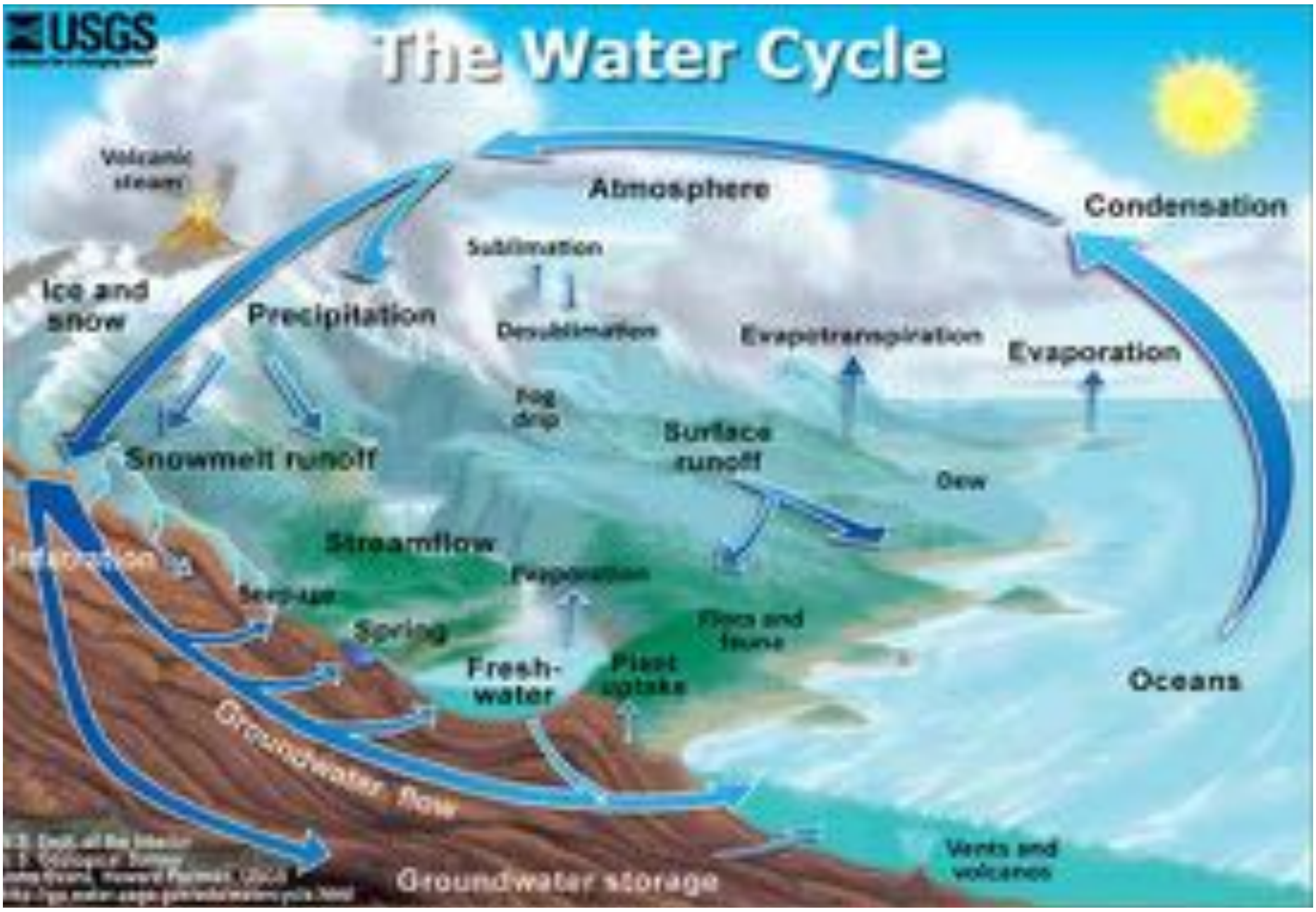


Figure 8.2: The global Water Cycle (taken from the USGS website)

Hence they are treated as the same variable. It becomes clear that a more detailed look at the water balance components is needed in order to understand drought and its impact.

8.6 PRECIPITATION

Precipitation in most areas is the dominant source of fresh water. Precipitation arises from water vapor in the air and as such is mostly dependent on the evaporation of the sea (and consequently the sea surface temperature), even though evapotranspiration from the surface also plays a huge role.

As water continually moves between oceans, atmosphere, cryosphere and land, Clouds play an important role in the water cycle of the Earth. The properties and motion of the coherent cloud features are primarily determined by large-scale atmospheric circulations, which are pertinent manifestation of the weather systems. The amount of water moved through the hydrologic cycle every year is equivalent to the amount of water uniformly distributed over the surface of Earth with a depth of 1m. This amount of water annually enters the atmosphere through evaporation and returns to the surface as precipitation. In this cycle, clouds are the medium through which the transport takes place.

8.7 SOIL MOISTURE

The amount of water stored in the soil can be divided up into two parts: soil moisture and ground water. Soil moisture is the water stored within the top level of the soil. It is fundamentally important the rate of actual evaporation (Seneviratne et al., 2006;Seneviratne and Stöckli, 2007;Seneviratne et al., 2010), ground water recharge (Rodell et al., 2004) and runoff. Consequently it is of vital importance looking into drought (Szép et al., 2005;Narasimhan and Srinivasan, 2005a;Boken, 2009). Not only the amount of soil moisture is important but also the water-holding capacity of the soil. The water-holding capacity of the soil, which is different depending on the soil type, will affect possible changes in soil moisture deficits; the lower the capacity the great the sensitivity to prolonged absence of precipitation.

8.8 EVAPOTRANSPIRATION

Evapotranspiration (ET) is the largest sink of the water balance (Thornthwaite and Mather, 1951;Kite, 2000). It represents the combination of water loss to the atmosphere through on the one hand evaporation of water bodies and soil and on the other hand the transpiration of leaf water content by the vegetation. While transpiration of the soil is a pure physical process and only dependent on the energy available at the leaf level and the meteorological conditions; transpiration from the vegetation is a combined biological and physical process, called biophysical (Shenbin, 2006;Cammalleri et al., 2012). Therefore the combined process of ET is not only dependent on the meteorological parameters but also processes within the canopy, like carbon assimilation and growth patterns.

A difference must be made between actual ET and the potential ET (Allen et al., 2005b). Potential ET is the hypothetical maximum amount of water lost by the soil/vegetation for specific meteorological conditions in case that there is not any water stress (FAO, 2007), while actual ET is the real water loss for the calculated for those same conditions. The combination of these two estimations is therefore of incredible value for determining the water stress level and consequently drought at the surface (Allen et al., 1998).

8.9 GROUND WATER, RUNOFF AND INFLOW

Inflow, Ground water and Runoff can all be considered as leftover parts of the water balance. They are very difficult to determine as they depend water available by precipitation, the amount of loss of water through precipitation, the amount of water that is stored in the soil through soil moisture and the roughness of the surface. This last parameter characterizes the flow speed of the runoff and consequently also the duration of the runoff over a specific area. Therefore it influences the amount of water that is evaporated and percolated in the soil, as is illustrated in Figure 8.3.

In this way Precipitation is divided into direct runoff and infiltration. Direct runoff occurs if the simulated soil moisture storage SM exceeds the maximum storage capacity. The remaining precipitation infiltrates in the soil moisture reservoir and seeps through the soil layer to the quick runoff reservoir. The quick runoff routine accounts for percolation to the base flow reservoir, capillary transport to the soil moisture reservoir and quick runoff.

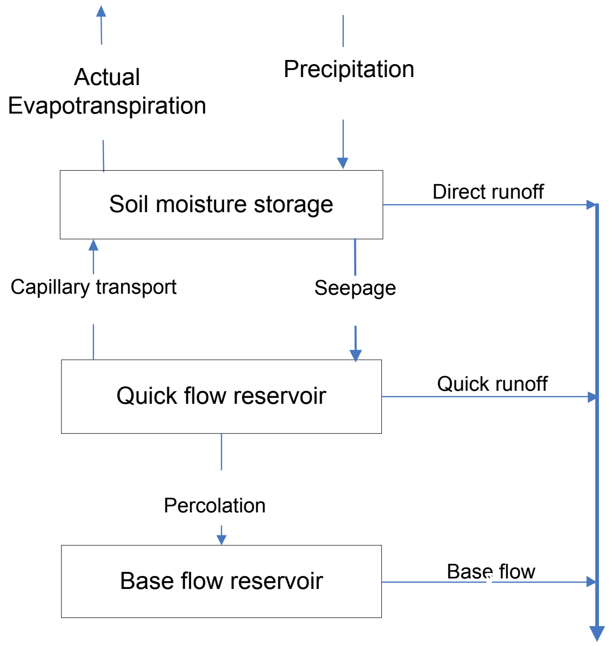


Figure 8.3: Estimating Runoff from the Water balance according to the HBV model

8.10 OBSERVING HYDROLOGICAL PARAMETERS FROM SPACE

8.10.1 Ground based measurements

There is a large variety of ground based measurements that can measure the different components of the water balance

1. Precipitation relies mostly on tipping buckets and radar measurements (Rinehart, 2004) for their measurements. While tipping buckets themselves are accurate instruments, rain aevents are very distributed over the land. As such a large number of tipping buckets is required to fully capture the precipitation of a specific region. Using radar measurements the coverage of precipitation estimation is greatly improved. However the measurement still needs to be interpreted to actual rainfall amount. In addition the measurements only range to regional not large scale areas and are very costly to maintain.

2. Conventional methods of ET estimation are based on the ground measurements. Some examples of conventional ET estimation methods are Bowen ratio(Pauwels and Samson, 2006;Pauwels et al., 2008), eddy covariance (Kljun et al. 2004), lysimeter, scintillometer (Hartogensis, 2006), sap flow(Ford et al., 2007;Mac Nish et al., 2000). Though conventional methods have shown relatively accurate ET for homogenous area, their uses are limited for larger heterogeneous area. Hence more instruments need to be put up for larger areas (Kite and Droogers, 2000).

3. For soil moisture measurements include theta probes (Dente et al., 2012a;Dorigo et al., 2010), ground radar measurements (Su et al., 2009) and gravimetric measurements. For the first two measurements additional information such as the soil conductivity are necessary to estimate soil moisture. This is not needed for the gravimetric measurements in which a sample of the soil is taken to the lab, weighted, dried and then weighted again. For all measurements however multiple points need to be investigated and the number of soil moisture networks are limited.

4. For runoff one determines the river flow at the end of the catchment. This can be done using flow meters, water levels.

5. Ground Water level (change): Common methods of measuring the ground water are boreholes, soil moisture stations, and lake level measurements. Such methods have good accuracy but they are too costly for monitoring a large area with an adequate network of measuring stations. Accurate measurement of ground water at large scales is challenging due to limited number of ground water monitoring stations.

While quantitative estimation of these components both on high spatial and temporal resolution is vital in water management the number of operational networks for such data is low. Although in Europe and North America a vast number of measurements exist, vast lands are still unrepresented. This is because it is costly to establish a single fully fledged hydro-meteorological station together with associated infrastructure. In addition, hydro-meteorological equipment are general unique in design expensive and prone to periodic break-down, due to the effects of the environment. Therefore remote sensing is needed to cover larger scales.

Satellite remote sensing has become a vital technique within the water managers' toolbox.

8.10.2 Remote sensing techniques

Satellite remote sensing has become a vital technique within the water managers' toolbox. Satellite sensors provide the potential of observing large areas at once with a single sensor. In addition these observations are made several times per week, while data is available within 2/3 days after the satellite image has been taken. In the past drought related remote sensing observables were limited to air temperature, but recently are extended which includes precipitation and soil moisture. Using advanced algorithms, it is even possible to estimate land surface processes like the evapotranspiration.

Remote sensing uses observations of radiation to determine the state of the atmosphere/sea or land surface. Hence only land surface parameters that have a significant impact on the reflection or emission of radiation can be detected from remote sensing. Remote sensing sensors can be divided up into two categories: namely active and passive sensors. The active sensors emit themselves radiation and measure the return signal, while passive remote sensing only observes radiation. In addition a difference is made between optical and microwave measurements.

- Optical remote sensing looks into the sun radiation reflected from earth surface and the thermal radiation emitted from the earth surface. The wavelength of this radiation is in between 400 nm and 15   and needs to be corrected first for the absorption/ reflection of the atmosphere. The emitted radiation is a direct measure of the temperature of the cloud/land surface, while the reflected radiation provides direct information about the amount of land surface

- Microwave remote sensing measure satellite emitted radiation refracted back by the atmosphere/ earth surface or radiation emitted by the earth surface. The wavelength of this radiation is in between 0.1 cm and 10 cm and therefore is unimpeded by cloud cover during day and night. As such the amount of radiation received at the sensor cannot directly be identified as a reflection from a specific object, but instead measure of the dielectric constant of the soil/atmosphere.

The advantage of optical remote sensing over passive remote sensing is that the resolution is several times higher. On the other hand optical remote sensing observations of the earth are only made if there are no clouds; while for microwave remote sensing this does not pose a problem. Finally the resolution of the observation differ also between optical and microwave remote sensing, with optical RS having resolutions between 15m and 3km, and microwave remote sensing having resolutions between 12.5 km and 50 km.

In both passive and active remote sensing radiation is observed. From this radiation the land cover characteristics need to be determined. In general two methods exist for computing land surface parameters from remote sensing observations: 1) statistical methods and 2) the full radiative transfer inversion. In statistical methods the observations of reflected radiation are combined into vegetation indices, such as NDVI (Kustas et al., 1993). Using ground observations a statistical relationship is created between the desired land surface parameter and such a vegetation type (Kustas et al., 1993;Jimenez-Munoz et al., 2006). Full radiative transfer inversion (Gastellu-Etchegorry et al., 2003;Meroni et al., 2004;Rautiainen, 2005;Verhoef, 2008;Timmermans et al., 2009)deals with the estimation of land surface variables from detailed radiative transfer models (RTM) (verhoef, 1984, 1985;Kuusk, 1998;Jacquemoud et al., 2000;Gastellu-Etchegorry et al., 2003;verhoef et al., 2006). First an initial guess is made what the land surface variables are, and the RTM is used to simulate the reflected radiation. Afterwards the simulated radiation and the observed radiation (by remote sensing sensors) are compared. On basis of this comparison a new guess is made and the RTM is rerun. This continues until the radiation simulated by the RTM is the same as the radiation observed from space.

Box 8.1. As the satellite moves around the earth it does not have observe a specific location each day and also the observations do not have the same view angle. The amount of days in between satellite overpasses is called revisit time which is usually around 2/3 days. Only after a specific time does the satellite again view the specific area with the same view angle. This is called repeat cycle and is usually around 16days/28 days.

8.10.3 Remote sensing observables

Precipitation: Precipitation can be measured from both optical and microwave measurements. Precipitation from optical remote sensing is estimated using the cloud (top) temperature (Roebeling and Holleman, 2009) which is correlated to precipitation amounts. The Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infra Red Imager (SEVIRI) is good at detecting back-scattered radiation from cloud tops and is used in many studies (Han et al. 1994; Watts et al. 1998). Precipitation from microwave remote sensing have recently gained popularity in this field, with the potential to improve precipitation estimates from the surface and from space (Joyce et al., 2004;Huffman et al., 2007). Microwave retrievals over the ocean are thought to rival radar retrievals for accuracy, but retrievals over land have more uncertainty due to the effect microwave reflections of the land surface (Morrissey and Greene, 1998).

Soil Moisture: Since the early days satellite remote sensing was seen as a potential tool to provide spatial and temporal continuous soil moisture measurements (Wagner et al., 1999). These traits have motivated much research, particularly in the microwave domain of the electromagnetic spectrum. Using a map of different soil types the dielectic constant observed from microwave remote sensing can be converted into an estimation of soil moisture (Dorigo et al., 2010;Liu et al., 2011;Dorigo et al., 2012). The depth of measurement in microwave remote sensing depends on the wavelength of the observation and can vary between 2.5 cm and 15 cm(Dente et al., 2012b;Dente et al., 2012a)

Evapotranspiration: Evapotranspiration cannot be directly measured from space. Instead evapotranspiration is estimated from algorithms (Su, 2002;Bastiaanssen et al., 1998;Norman et al., 1995;Anderson et al., 2008) that model the different processes. These models use land surface parameters, like land surface temperature (Sobrino et al., 1994;Sobrino et al., 2003), Leaf Area Index (Tang et al., 2007;Gitelson et al., 2007;Song et al., 2009) in combination with meteorological conditions like air temperature, humidity and windspeed.

Note that the ground water change is also measured using remote sensing by detailed analysis of the earth gravity. However, this is not treated here because the footprints of these measurements are about 100 kmx100km and as such is not valuable for drought monitoring.

8.10.4 Remote sensing processing chain

In satellite remote sensing the sensor is at the top of the atmosphere. Because processing power on the satellite is limited due to the amount of energy available data is not processed at satellite level. Instead the estimation of the different land surface/sea surface/atmosphere parameters is performed at the ground using the following processing chain. Some large scale products freely available on the internet are listed below in Table 8.2.

a. L1a data: The data gets transmitted downwards to receiving stations by high speed microwave interlinks. At this stage the imagery the format is highly compressed and only uncalibrated and is called Level 1a (L1a). This data is usually not made available.

b. L1b data: At the receiving station the data is stored and afterwards geocorrected and calibrated to provide measured radiances at the top of the atmosphere (TOA). This data is called L1b data. This data is still stored in the coordinate system of the satellite, called swath. For more information about swath please look into Table 8.1. This data is already made available for download, and is mostly used by universities.

c. L2 data: The data is then corrected for the atmosphere and the angles for the sun and sensor to produce in the case of optical remote sensing bottom of atmosphere (BOA) reflectance's / brightness temperatures. In the case of microwave data atmospheric correction only consists of filtering data for precipitation events. This atmospherically corrected data is called L2 data.

d. L3 data: From these L2 reflectances / brightness temperatures the specific land surface parameters are calculated using a variety of algorithms. Simple algorithms (for example NDVI) simply calculate the ratio of specific bands while other more complex methods estimate land surface parameters through inversion of complicated radiative transfer models. Finally this imagery is reprojected to a specific grid.

This means that all the data for different dates can be overlaid with each other. This is called L3 data. For some of the land surface parameters the observations of different consecutive days are combined to lower the uncertainty in the products and to circumvent gaps due to cloud cover. However this does not mean that this data is gap free. If either no cloud free days were found, or there was an error within the processing chain still gaps can be present. Note that the NASA names its L3 products actually L2 products.

e. L4 data: This processing chain is to produce gap free data. For this complicated data assimilation techniques are used that try to 'interpolate' between the data to reduce gaps. These assimilation techniques might also use ground measured data for gap filling.

f. L5 data: This last processing chain is merge different products to create a completely new product. For example to combine both leaf area index, land surface temperature to produce evapotranspiration. For this a dedicated remote sensing algorithm needs to be employed

While evapotranspiration is considered a level 5 product, it still contains gaps in the data. This is because the land surface temperature input data for the remote sensing algorithm still has data gaps. Land surface temperature is one of the most difficult variables to convert into a level 5 product. The land surface temperature continuously changes based on the incoming radiation and the processes on the ground and the atmosphere. Hence filling in a gap due to cloud cover demands the knowledge of what the effect of this cloud is having on the temperature. A large international project (GlobTemperature) is currently underway to start making the first gap free land surface temperature.

8.10.5 Combining Indigenous knowledge with remote sensing

While remote sensing provides us with a viable tool for estimating land surface parameters, hydrological components it does not claim to provide absolute truth. The use of remote sensing is limited due to the following shortcomings:

1. Satellites only observe radiation. Therefore the objective of the remote sensing algorithms is to link this radiation to land surface parameters, and use models to link the land surface parameters to the hydrological components.

2. These models first need to be calibrated using ground measurements and validated over different areas. The accuracy of the remote sensing product can therefore never be higher than the accuracy of the instruments with which the calibration/validation is performed. For example, estimating evapotranspiration from ground measurements have an uncertainty of about 20%. Remote sensing models are restricted to this minimum of 20% uncertainty, but usually have uncertainties that are higher due to model errors and uncertainties within the atmospheric correction.

3. Optical remote sensing provides only data in the case of satellite overpass and only when there are no clouds over the area. In addition atmospherical-correction

Table 8.2: Freely available Large scale products for use in drought monitoring

Variable	Dataset	S. Res	T. Res.	Downloadsite
Precipitation	TRMM	5km	3hourly	ftp:/disc2.nascom.nasa.gov/
	CMORPH	8km	30min	ftp://ftp.cpc.ncep.noaa.gov/
	MSG	3km	30min	GEONETCAST
	ECMWF			
Soil Moisture	AMSRE		Daily	http://www.esa-soilmoisture-cci.org/
	WACMOS	12.5km	Daily	
Evapotranspiration	MODIS	1km	Daily	ftp://ftp.ntsg.umt.edu/pub/MODIS/ Mirror/MOD16/
	WACMOS	1km	Daily	http://wacmos.itc.nl
	LANDSAF	3km	30min	http://landsaf.meteo.pt
Land surface parameters (LAI/NDVI/LST)	MODIS	1km	daily	ftp.e4ftl01.cr.usgs.gov
	MSG	3km	30min	http://landsaf.meteo.pt

needs to be applied to correct for the absorption and reflection of the atmosphere

4. There is a trade-off between model complexity and number of required inputs. A model that is very complex, require a significant amount of input information and in addition a significant computing time, while a simple model only uses a limited amount of data, but provides less accuracy than the complex models. For each application the requirements needs to be identified and model-complexity adjusted.

In short, remote sensing data provides a fast and simple method for creating large sets of information over a spatially and temporally large area. However this information needs to be combined with the indigenous knowledge to provide ground truth information. For simple models (step 2) this can be done by calibrating/validating these specific models to each area. For more complex models that are able to distinguish between different processes the merging of the two information sets (RS and ground measurements) is by data assimilation (step 4).

8.11 Drought indices

Drought indices are the tools to identify the characteristics of drought such as the onset, severities and the spatial extent. Drought indices provide a basis for drought assessment.

The Characteristics of a good drought index are

a. The index should respond to a specific temporal domain

b. The index should be able to respond to all seasons (summer or winter).

c. The index should be spatially comparable irrespective of climatic zones.

However a single drought index cannot characterize the complete extend of the drought types. Therefore with different type of droughts, several different drought indices have been introduced. Therefore, like drought, drought indices do not have a universally accepted definition. Use of drought indices depends on the study of interest like meteorological, hydrological or agricultural domains (S.Niemeyer, 2008) and also on the data available. Some of the drought indices are as follows:

- Percent of Normal: is one of the simplest rainfall measurements for a location or a single season. Percent of normal is calculated by dividing actual precipitation by normal precipitation and multiplying by 100%. Normal precipitation for a location is considered to be 100%. Percent of normal is suited for the weather forecast.

- Standardized Precipitation Index (SPI): SPI is less complex as it depends only on precipitation data at least 30 years (longer the better) (McKee et al., 1993;Reichstein et al., 2002). The long-term precipitation record is normalized using a probability distribution so that the mean SPI for a location and desired period is zero. SPI is computed for different time scales ranging from 3, 6, 12, 24, and 48 months. Negative SPI values indicate dry condition and positive for wet conditions. SPI is helpful in early warning of drought and in assessing drought severity. The only disadvantage of using SPI is that the values based on preliminary data may change and it does not involve important parameters such as temperature and ET.

- Palmer Drought Severity Index(PDSI): PDSI was developed to measure the duration and intensity of long term drought (Palmer, 1965;Szép et al., 2005). It is calculated based on the precipitation, temperature, and soil moisture data and therefore, responds to abnormally dry and wet conditions. The disadvantage of PDSI is that the values may lag emerging droughts and well suited for homogeneous regions.

- Crop Moisture Index(CMI): CMI is used to monitor short-term soil moisture condition (Palmer, 1968), based on mean temperature and precipitation for each week especially agricultural droughts. Similar to PDSI, CMI also responds to change in weather conditions. CMI can only be used during the crop growing season and not for long-term drought.

- Evapotranspiration Deficit Index (ETDI): is calculated using the water stress ratio. The water stress is calculated using the actual and reference ET. Water stress values ranges from 0 to 1, where 1 indicates no ET and 0 indicating ET occurring at same rate as the reference ET (Narasimhan and Srinivasan, 2005b)
- Soil Moisture Deficit Index (SMDI): is calculated similar to the ETDI, but instead of water stress ratio the soil moisture anomolies are taken (Narasimhan and Srinivasan, 2005)

In the calculation of each of these indices a long time series of data is required. This long time series of for example precipitation is necessary to characterize the normal situation of the land. The intensity of the drought is than characterized by the deviation of this parameter from its 30year value.

8.11.1 Precipitation drought indices

Drought occurs due to shortage of water at land surface which is mainly from a lack of precipitation. In order to start the monitoring of drought, precipitation needs to be investigated. Although several indices have been used in literature, only two will be discussed here due to simplicity and their frequent use in current day practices:

Precipitation anomaly

As rainfall is very intermittent (see Figure 8.4) precipitation at a particular day cannot be compared to that particular day in previous years. Instead first the data needs to be averaged over a particular period (3 monthly, 6 monthly). Afterwards this can be compared to the 3monthly/6monthly average of the previous years. In this way the precipitation anomaly is defined:

$$\Delta P = \left(P_i - \overline{P}\right)$$

With P_i the average precipitation during a particular period and $\overline{P}$ the multiyear average precipitation at the same period but during previous years. In order to provide a reasonable estimate of the normal precipitation in this period the multiyear average ($\overline{P}$), should be calculated over at least 30 years.

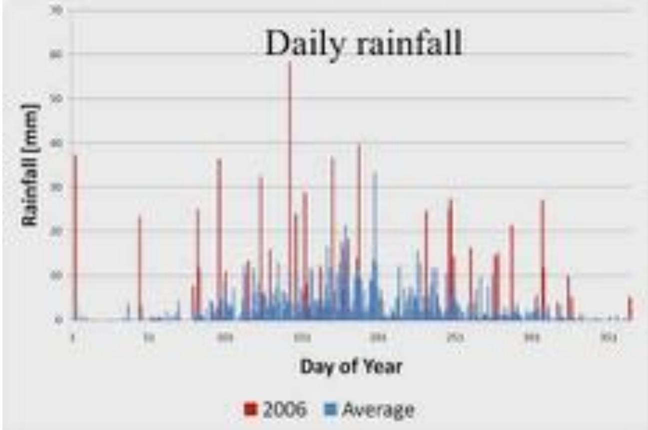


Figure 8.4: Daily Rainfall

In the case of drought lack of precipitation is not necessarily the biggest problem; instead prolonged absence of rain is the biggest problem. In that way the accumulative precipitation anomaly is defined.

$$\Delta P_{acc} = \left(P_{acc,i} - \overline{P_{acc}}\right)$$

With $P_{i,acc}$ the accumalted precipitation during a particular period and $\overline{P}$ the multiyear average of the accumulated precipitation. It is shown in Figure 8.5 that is much easier to derive the shortage of water from the difference between the normal accumulative rainfall and the accumulative rainfall during a drought event.

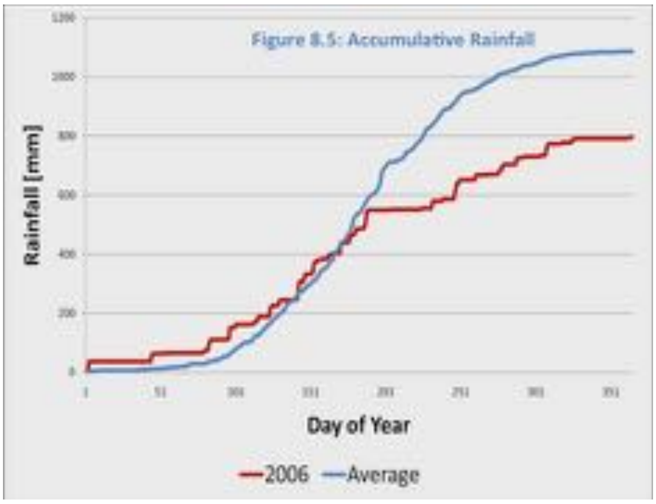


Figure 8.5: Accumulative Rainfall

The use of the precipitation anomaly is however is limited due to the fact that it is not comparable between different locations. The precipitation anomaly does not take into account the natural variability of the precipitation in a specific area. This is solved by the introduction of the standardized precipitation index.

Standardized Precipitation Index

The standardized precipitation index (SPI) is based on the same principle as the precipitation anomaly, using only precipitation data. However this value is than divided by the standard deviation in the specific area. This creates a standardized value which provides similar results for different study areas. As a result the droughts over different study areas can thus be compared. The SPI is calculated using the following formula:

$$SPI = \frac{\left(P_i - \overline{P}\right)}{\sigma}$$

where, P_i is the monthly precipitation observation, $\overline{P}$ is the mean monthly precipitation, and σ is the standard deviation of this mean. Negative SPI value indicated dryness and positive indicates wetness as categorized in Table 8.3.

Table 8.3 : Category of SPI values by McKee and Edward

SPI Values	
2.0 and above	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

While precipitation is able to predict meteorological drought it does not take into account the state of the land surface. Therefore for agricultural drought using the precipitation anomaly or the standardized precipitation index is not sufficient. One way to solve this problem is to use (in parallel with SPI), soil moisture.

Soil Moisture drought index

Soil moisture Deficit Index

In the development of SMDI and ETDI (see later) the following demands were set (Narasimhan and Srinivasan, 2005a):

1. The index should respond to the agricultural drought.
2. The index should be able to respond to all seasons (summer or winter).
3. The index should be spatially comparable irrespective of climatic zones.

The Soil Moisture Deficit Index is therefore defined as a weighted average between the previous SMDI value and the current soil moisture deficit:

$$SMDI_j = 0.5SMDI_{j-1} + \frac{SD_j}{50}$$

where, $SMDI_{j-1}$ represent the SMDI for the previous period and **SD** is the soil moisture deficit:

$$SD_{i,j} = \frac{SWS_j - MSW_{i,j}}{MSW_j - \min SW_j} * 100$$

if

$$(SW_{i,j} \leq MSW_j)$$

$$SD_{i,j} = \frac{SW_j - MSW_{i,j}}{\max SW_j - MSW_j} * 100$$

if

$$(SW_{i,j} > MSW_j)$$

where, MSW_j is the long-term median available soil water in the soil profile (mm), $\max WS_j$ is the long-term maximum soil water, $\min WS_j$ is the long-term minimum soil water. On average, the monthly soil deficit index value ranges from -100 to +100 indicating very dry to very wet conditions. As soil moisture depends on the depth of the measurements and its impact on the plant depends on the root zone several SMDI`s are defined: SMDI-2, SMDI-4 and SMDI-6 for respectively a depth of 2, 4, and 6 feet. While some plants do not take their water from the first 15cm an additional hydrological parameter should be investigated, namely the evapotranspiration.

Evapotranspiration drought indices

As evapotranspiration from remote sensing is an emerging product. Therefore not a lot of drought indices have been created to fully use this new information. However increased evapotranspiration can be one of the other main causes of drought, while at the same time a decrease in evapotranspiration provides a clear indication that the land surface is undergoing water stress. It is therefore of vital importance to in addition to soil moisture and precipitation also look into the evapotranspiration for drought monitoring. Two drought indices based on evapotranspiration are listed below:

a. The Water requirement satisfaction index.

b. The Evapotranspiration deficit index.

Water requirement satisfaction index

Water requirement satisfaction index (WRSI) is an operational monitoring which indicates performance of a crop based on the availability of water during a growing season (Allen et al., 1998). It is calculated as the ratio of seasonal actual crop Evapotranspiration (AET) to the crop water requirement (WR).

$$WRSI = \frac{AET}{WR} \cdot 100$$

Where WRSI is crop water requirement satisfaction index (%), AET is the seasonal actual crop evapotranspiration (mm d-1) and WR seasonal water requirement (mm d-1). The water requirement (WR) is the same as the potential crop evapotranspiration estimated after the FAO reference evapotranspiration has adjusted with appropriate crop coefficient (Kc) value which is the water use pattern of a crop. WR = PET * KC.

In order to define the spatial variation during the growing season for each modeling grid-cell, WRSI model requires a start-of-season (SOS) and end-of-season (EOS) time. The threshold used to determine SOS is based on amount and distribution of rainfall received in three consecutive dekads and SOS starts when there is at least 25 mm of rainfall in one dekad followed by rainfall records of having at least 20 mm in the next two consecutive decades, on the other hand the end of seasons (EOS) can be estimated by adding Length of Growing period (LGP) and SOS. The calculated WRSI value of a given pixel can represent the seasonal integrated conditions from the start of the growing season until the time of modeling period (Brown, 2008)

Evapotranspiration Deficit Index

The problem with the WRSI is that is does not correct for seasonal differences, or that it takes into account previous stages of the land. This problem is circumvented by the evapotranspiration deficit index by considering the previous drought index state. For this is follows the same methodology as the Soil Moisture Deficit Index.

ETDI have high temporal resolution (weekly) compared to the monthly temporal resolution of commonly used PDSI and SPI. But for this study, monthly temporal resolution has been used due to constrain in weekly ET from MODIS. Following are the steps involved in the calculation of the ETDI: The ETDI for the time month is calculated on incremental basis by Palmer (1965):

$$ETDI_j = 0.5 ETDI_{j-1} + \frac{WSA_j}{50}$$

where, $ETDI_{j-1}$ represent the ETDI for the initial month and ***WSA*** is the monthly water stress anomaly:

$$WSA_{i,j} = \frac{MWS_j - WS_{i,j}}{MWS_j - \min WS_j} * 100$$

if

$$(WS_{i,j} \leq MWS_j)$$

$$WSA_{i,j} = \frac{MWS_j - WS_{i,j}}{\max WS_j - MWS_j} * 100$$

if

$$(WS_{i,j} > MWS_j)$$

where, MSW_j is the long-term median water stress of the month $_j$, $\max WS_j$ is the long-term maximum water stress of the month $_j$, $\min WS_j$ is the long-term minimum water stress of the month $_j$. On average, the monthly water stress anomaly value ranges from -100 to +100 indicating very dry to very wet conditions. The water stress is given by,

$$WS = \frac{ET_0 - ET}{ET_0}$$

where, ET_0 is the reference evapotranspiration from the Penman-Monteith using meteorological data and is the actual evapotranspiration derived a remote sensing algorithm like the SEBS, SEBAL, TSEB.

8.12 HAZARD IDENTIFICATION ON BASIS OF PAST EVENTS

In the previous paragraph the drought status was classified on basis of the different drought indicators. Before from such information a hazard status and risk analysis can be performed first the drought characteristics needs to be identified from these indicators. Several drought characteristics are defined: 1) onset, 2) intensity, 3) duration and 4) frequency, see Figure 8.6.

- **Drought onset:** The start of the drought is of vital importance for prediction of food production. When drought sets in during the initial stages of the crop development this greatly reduces the crop growth and therefore food productivity of the specific crop.

- **Drought intensity:** Drought intensity if necessary to identify how fast the status of the drought for example meteorological will migrate to more severe agricultural drought. This than provides an indicator of how fast the system is moving in a specific direction. However depending on resilience (as described later) the migration of status might be avoided.

- **Drought duration:** In most cases drought starts to get attention when the drought is prolonged. At this stage it is important to know how the management system has behaved and what consequences this might have had. This directly creates input for the effectiveness of the drought early warning system and the drought mitigation management.

- **Drought frequency:** While not of direct interest when drought is identified at a specific location, the drought frequency has great effect on the construction of drought mitigation practices and early warning system development. For example, considering a high frequency of drought occurrence results into an increased risk in the future.

When all of the above characteristics have been determined current drought can be severity of the drought can now objectively be classified. In terms of disaster management several stages can be identified leading up to a disaster. These stages are: threat, hazard, disaster.

- **Threat:** Disaster varies in the amount of warning communities receive before they occur. For example, earthquakes in general have limited (if at all) any warning before they hit, while warnings for hurricanes and flooding usually can be announced several hours before they hit. Drought hazard is a creeping phenomenon that develops over time, and thus its impacts are diffuse and spread slowly, in contrast to other rapid onset natural hazards, such as floods, earthquakes and landslides. In order to provide accurate warnings in Drought monitoring drought indices levels need to be carefully identified on basis of previous events.

- **Hazard:** is generally defined as a potentially damaging phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption and environmental degradation (UNISDR, 2009). The point that the ongoing drought transforms from a threat to a hazard is when specific boundaries are exceeded. This can be estimated by thresholding the different drought indices. These thresholds can be dependent on duration, but also frequency.

- **Disaster:** is defined as a serious disruption of the functioning of a community or a society that involves widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope, using its own resources (UN ISDR, 2009). While the initial direct or physical effects of drought disaster on the water-dependent sectors may be similar regardless of the type of economy, the long-term consequences of each event will depend on specific local circumstances

In drought management we can use these different stages to minimize the risk and impact of the drought.

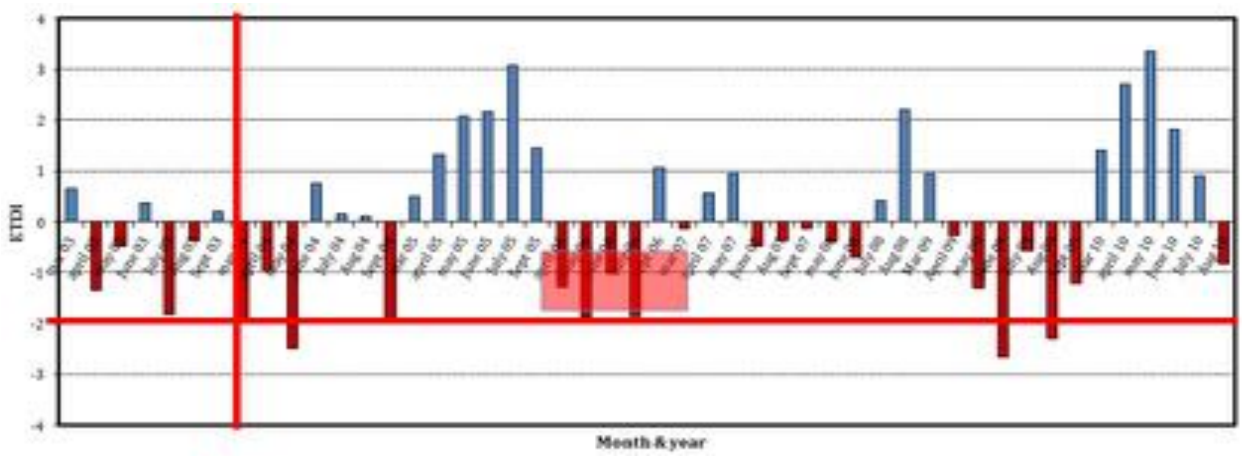


Figure 8.6: identification of drought characteristics

8.13 RISK ANALYSIS

Risk entails the combination of the probability of an event and its negative consequences (taken from "Mainstreaming Drought Risk Management" (UNDP). Drought (Disaster) Risk refers to the potential loss of lives, reduced health status, livelihoods, assets and ecosystem services in connection with drought, which could occur to a particular community or a society over a specified time period in the future (UN-ISDR, 2009).

The level of drought disaster risk is often measured by the combination of (a) the degree of exposure to a drought hazard and (b) the level of vulnerability that a community (sector or system) faces (African Development Bank, et al., 2004). This concept is expressed in the following formula:

RISK = HAZARD x VULNERABILITY

With Vulnerability referring to the characteristics and circumstances of a community, system or assets that make it susceptible to the damaging effects of a hazard, as in the case of drought (UN-ISDR, 2009). Vulnerability is an encompassing composite term. It illustrates, for example, the capacity and nature of the resource base to continue to provide ecosystem goods and services during a period of severe rainfall deficit, or the degree to which people are directly dependent on the provision of water and other resources necessary for their well-being.

According to this principle, a large number of individuals subjected to exposure to a moderate drought hazard could be considered at the same risk level as a smaller number of people who live with a higher frequency and/or severity of drought hazards. It is difficult to set a standard procedure to examine risk levels because of the slow onset and creeping nature of drought.

In some cases the Risk equation is expanded with an exposure term (see Figure 8.7). This is because while drought maybe present in a specific country/region, not all the people are in the same location as the drought. However using remote sensing data both the hazard status and the exposure are captures in the same map, and exposure can be left out of the picture.

Figure 8.7: Factors define the Drought Risk

Note that people outside the location of the hazard can however still be affected. When a disaster causes large migrations, electric power failure and shortage of medicine, the effects of drought will grow larger than its own footprint. This should be captured in the vulnerability assessment.

Resilience

It is impossible to circumvent the natural processes of drought hazards – disruptions or anomalies in the global circulation pattern of the atmosphere. Nonetheless, it is still possible to prevent drought disasters, mitigate their impacts and reduce their risks to human lives and livelihoods by increasing the degree of resilience.

Resilience is generally defined as the ability of a system, community or society that is potentially exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and effective manner, including through the preservation and restoration of its essential basic structures and functions (UN-ISDR, 2009). This ability is determined by the degree to which the social system is capable of increasing its capacity for learning from past disasters, and translating the lessons into improved future protection and risk reduction measures (African Development Bank, et al., 2004). However, the drought risk of a given community is decreased when resilience is increased. Such a relative relationship modifies the above mentioned formula as follows:

Risk = HAZARD x Vulnerability / Resilience

Considering that communities have little control over exposure to hazards other than relocating, the focus of development actors should be directed on finding ways to reduce the degree of vulnerability and increase the level of resilience. Whether a community is vulnerable or resilient to drought is largely a function of its Coping or Adaptive Capacity. This is generally defined as the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters (UN-ISDR, 2009). Coping capacity is often understood to be intrinsic to an affected community. One type of Coping is the creation of a drought forecast system together with an integrated drought management system. However to create such a system one needs to comprehend the possible causes of the drought.

8.14 TOWARDS A DROUGHT FORECASTING

Forecasting drought assists in building resilience towards the drought events and lowers the risk, and therefore mitigates the effects of drought through warning the risk holders in time. In order to prepare for hydrological drought, an adequate hydrological model that can simulate both local as well as continental hydrology and that can forecast the hydrology in the area from several months to several decades should be choosen. . In this way interlinkages can be found between meteorological conditions and drought conditions which are not necessarily in the same area. An increase in sea surface temperature (due to el nino, la nina) can have profound impact on the rainfall intensity / frequency in Australia and Indonesia.

Several large scale models exist that can perform this task. As each of these models is highly complex it would be too much for this syllabus to describe all of them. Instead the two models currently used in the two largest drought prediction monitors will be explained.

1. Variable Infiltration Capacity (VIC). VIC is used in the American Drought Monitor (http://droughtmonitor.unl.edu/) for predictive purposes (see Figure 8.8: US National Drought Monitor) VIC is a hybrid of physically based and conceptual components. It uses are daily precipitation and temperature as input and computes incoming shortwave radiation, and long-wave radiation as a function of daily precipitation and daily minimum and maximum temperature. For the other computations it uses physically based formulations for the calculation of the sensible and latent heat fluxes, and a conceptual baseflow model to simulate runoff generation from the deepest soil layer, and a conceptual scheme to represent the spatial variability in infiltration capacity and hence production of runoff. Total daily runoff and evaporation are simulated for each grid cell independently. The runoff from each of the individual cells is then combined using a routing scheme (only for the stream), to produce daily and then accumulated monthly flows at selected calibration points.

2. HTESSEL: HTESSEL is part of the integrated forecast system at ECMWF with operational applications ranging from the short-range to monthly and seasonal forecasts HTessel computes the land surface response to atmospheric forcing, and estimates the surface water and energy fluxes and the temporal evolution of soil temperature, moisture content and snowpack conditions. It has a flexible spatial resolution, depending on the input resolution, and it has been applied globally with a resolution of 0.5°. The model runs with a time step of one hour forced with sub-daily (6 hourly or less) near surface meteorology (air temperature, wind speed, specific humidity and surface pressure) and surface fluxes (solid and liquid precipitation and downward solar and thermal radiation). A detailed description of HTESSEL can be found online.

8.15 LESSONS LEARNT

In this chapter the different types of drought were identified. Depending on the severity of the drought it is classified as meteorological, agricultural, hydrological and socio-economic. In principle meteorological drought starts if precipitation is for a long time absent in comparison to other years. However an increase in precipitation (originated by climate change) might also cause the onset of meteorological drought. As such the characterization of meteorological drought is mainly performed by investigation into precipitation patterns. Agricultural and hydrological drought are in fact caused by prolonged meteorological drought that cause reservoirs in the top layer (soil moisture) and deeper in the ground (ground water) to be depleted. Agricultural drought can be characterized by monitoring soil moisture patterns, but also evapotranspiration, as this variable is highly linked with soil moisture. Hydrological drought should be determined by characterizing all variables

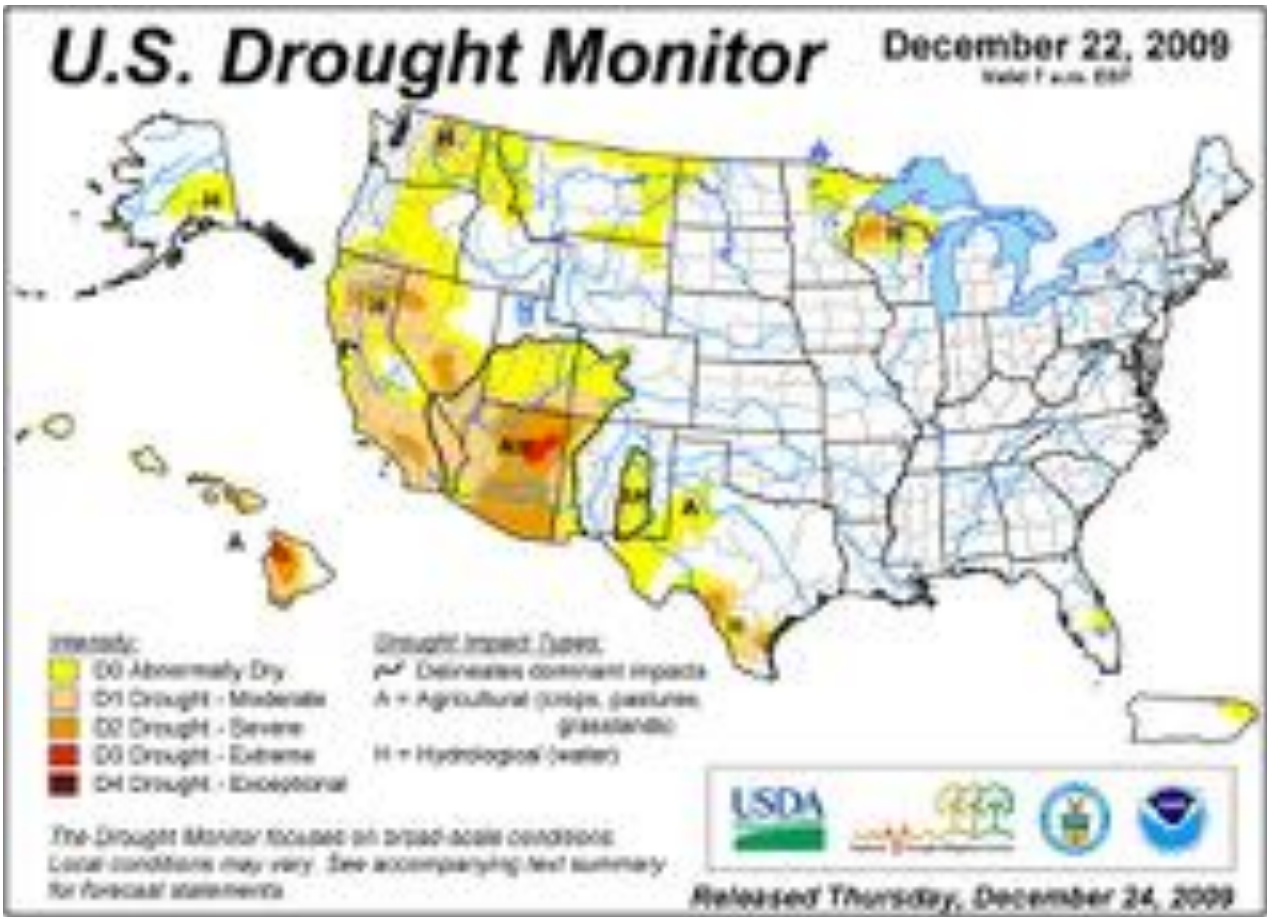


Figure 8.8: US National Drought Monitor

within the water balance to identify the complete water shortage.

While the first three drought types can be considered a pure physical phenomenon, socio-economic drought is the result of the combination of both physical effects of drought and their impact on socio economic stakeholders. As such the characterization of this kind of drought can only be performed when a risk analysis has been performed for each of the types of drought.

Considering the above definitions of drought monitoring of these water balance components is of vital importance. As drought does not restrict itself to man-made boundaries large scale investigations should always considered. It has been shown that this can be performed over using remote sensing observations. While remote sensing only (actively and passively) observes radiation a process chain was shown that is used to convert these measurements to real hydrological variables. Finally different large scale products were shown that are downloadable from the internet.

Finally it was shown how drought can be characterized by calculation of different drought indices. These drought indices should eventually by combined to provide a clear monitor for monitoring the drought characteristics such as duration, intensity and frequency. These characteristics are than be introduced into risk analysis to provide requirements on early warning systems and drought impact mitigation services.

Chapter 9

Earth Observation Tools for Groundwater Assessment

Learning Objectives

- To learn on how to apply earth observation tools for groundwater assessment
- To learn on geomorphological mapping technique and modeling groundwater contamination and potential risks

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9.1 INTRODUCTION

Water is one of the most important resources on the planet. The majority of the water on the planet is saltwater with freshwater limited to only 3%. The majority of this freshwater is locked away in glaciers and ice sheets and of the available freshwater 98% of it is groundwater making this invisible resource of prime significance, especially as population explosion over the past century has placed great demand on the availability of portable water (Figure 9.1).

Increased demand for freshwater has resulted in greatly increased use of groundwater over the past 50 years leading to severe groundwater depletion in several countries (Figure 9.2) as groundwater removal outpaces recharge rates.

The problem is compounded by several factors such as incomplete understanding of the spatial distribution and complexity of underground aquifers , degrading monitoring systems and outdated in-situ measuring devices, inadequate monitoring of groundwater contaminant levels with leads to increased pollution levels and risk of illnesses and the list goes on.

Global Water Scarcity

- Around 700 million people in 43 countries suffer today from water scarcity.
- By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions.
- With the existing climate change scenario, almost half the world's population will be living in areas of high water stress by 2030, including between 75 million and 250 million people in Africa. In addition, water scarcity in some arid and semi-arid places will displace between 24 million and 700 million people.
- Sub-Saharan Africa has the largest number of water-stressed countries of any region.

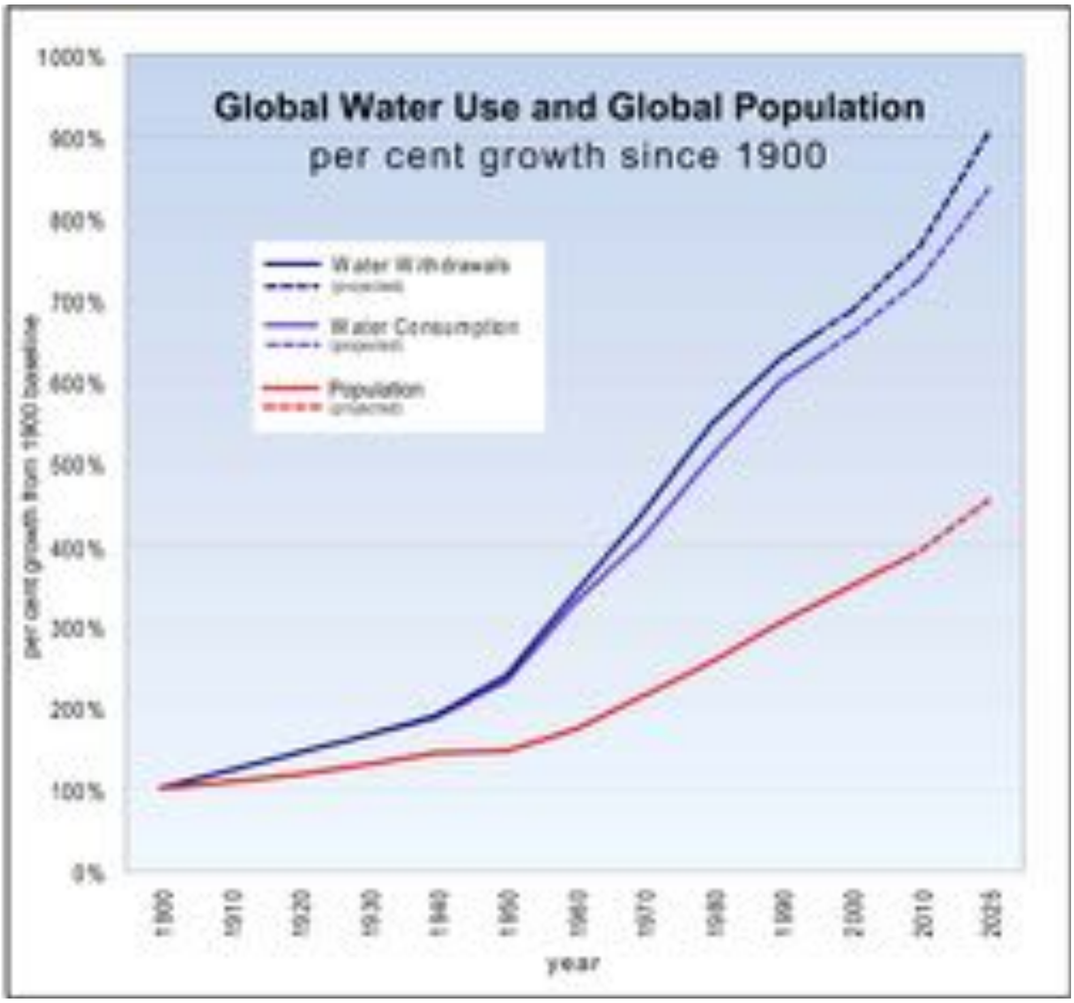


Figure 9.1: The rate of growth in freshwater withdrawal and consumption has been even more rapid than global population growth. Sources: US Census Bureau 2011, Shikomanov 1999

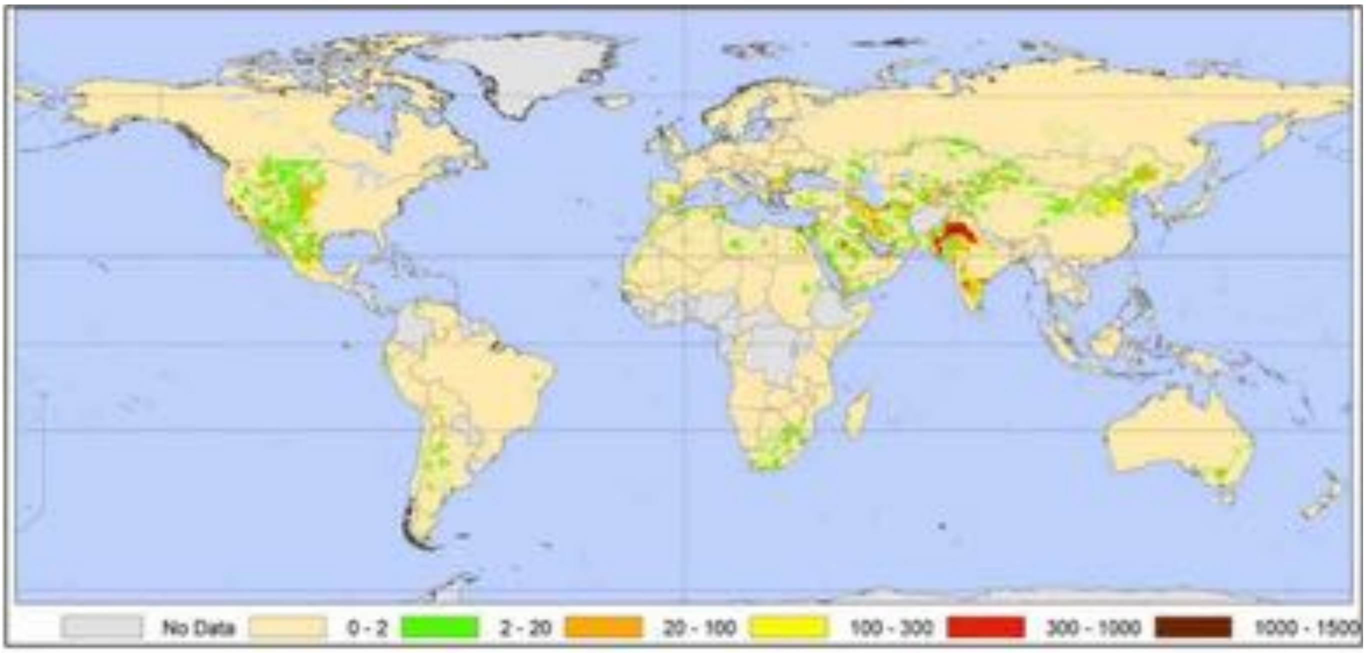


Figure 9.2: Global Groundwater depletion (mm). Wade 2010

Additionally, though groundwater is often, and rightly so, discussed as an important resource, it is also a major factor in the long term formation of a region's geology and geomorphology especially in arid and karst environments. As surface water in both these climate types tend to be limited the identification and monitoring of groundwater storage structures, flow, renewal and contamination are of prime importance.

Earth Observation tools, including remote sensing and geographic information systems (GIS) provides several methods of analysis and monitoring groundwater that helps us address several of these problems.

9.2 GROUNDWATER ASSESSMENT

Though groundwater lies unseen below the surface it is both affected by and affects the vegetation, soil, geology and geomorphology in ways that are visible through remote sensing and can be analyzed using GIS. There are numerous ways that geospatial analysis can be used for groundwater assessment. This module describes but a few of these.

9.2.1 Phreatophytic Vegetation

There are several indicators that are used to identify potential groundwater storage areas. Of these, one that is easily visible in satellite images and can be tracked over time is groundwater dependent vegetation, known as phreatophytic vegetation. Unlike xeric vegetation, vegetation which is not dependent on groundwater, phreatophytic vegetation exhibits less seasonal variation. This is typically manifested by higher density and greenness values in the dry season than xeric vegetation. Both these values can be measured using the Normalised Difference Vegetation Index (NDVI) (Figure 9.3) on multispectral images such as that from Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), and Landsat imagery. Groundwater-dependent vegetation is also commonly associated with a higher rate of evapotranspiration (ET) from the area where vegetation has access to groundwater (O'Grady, 2011). This results in a higher moisture signature at the surface which can be analysed using the Normalised Difference Wetness Index (NDWI) to highlight moisture anomalies compared to seasonal vegetation in the area. Additionally, this higher rate of evapotranspiration results in temperate anamolies that can be identified using the thermal band of multispectral images.

9.2.2 Soils

Soil reflectance is affected by the mineral type, the amount of organic matter and surface roughness but additionally, for any given soil, the surface soil moisture typically decreases the signature soil reflectance (Figure 9.4).

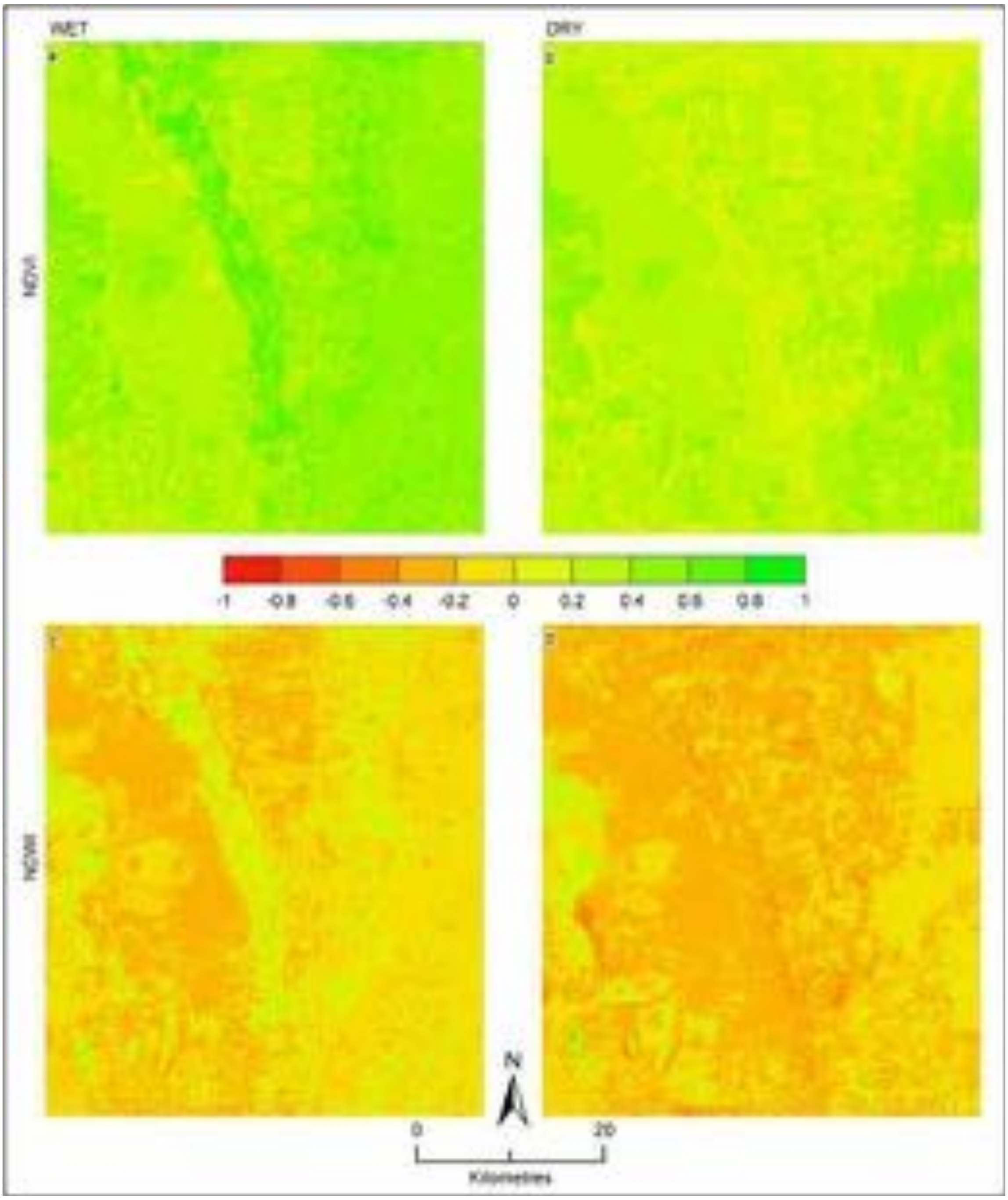


Figure 9.3: NDVI (a, b) and NDWI (c,d) data for the end of the wet seson (a,c) and the end of the dry season (b,d) for a study area in South-western Australia which experiences a Mediterranean climate.

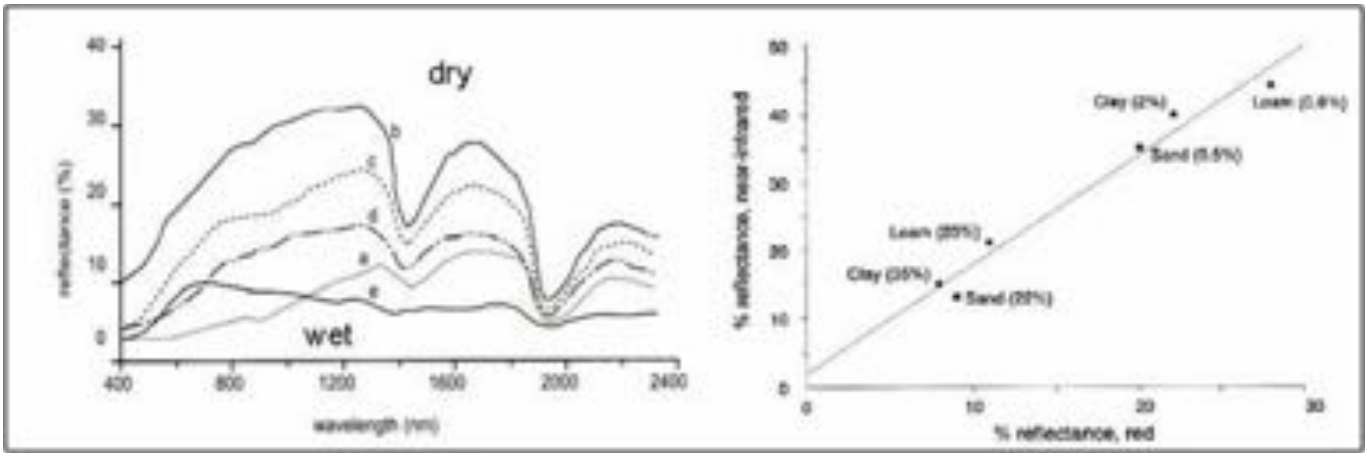


Figure 9.4: a) Spectral reflectance curves of some soils with different composition. b) Reflectance of soils of different texture and moisture contact. Curve is the 'Soil line'. Source Belward, 1991.

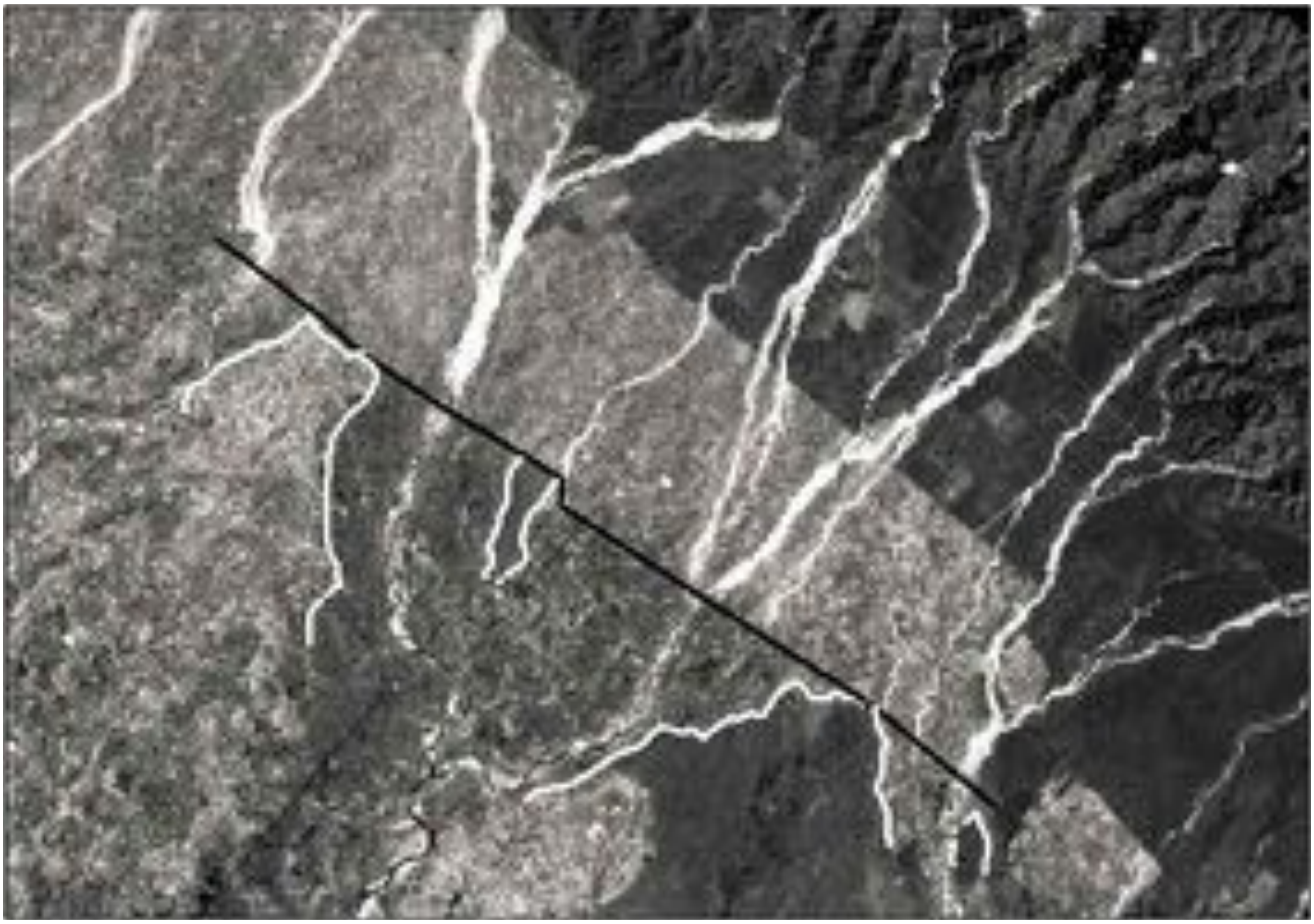


Figure 9.5: The Red band image Landsat ETM of a predominantly alluvial area in North India, showing groundwater emergence in ephemeral riverbeds along a fault (black line), and difference of reflectance of wet soils south of the fault due to capillary rise from shallow groundwater table and reflectance of dry soils north of the fault. Meijerink 2007

This lowered reflectance means that shallow groundwater which interacts with the surface shows up in the Near Infrared Band of multispectral images (Figure 9.5).

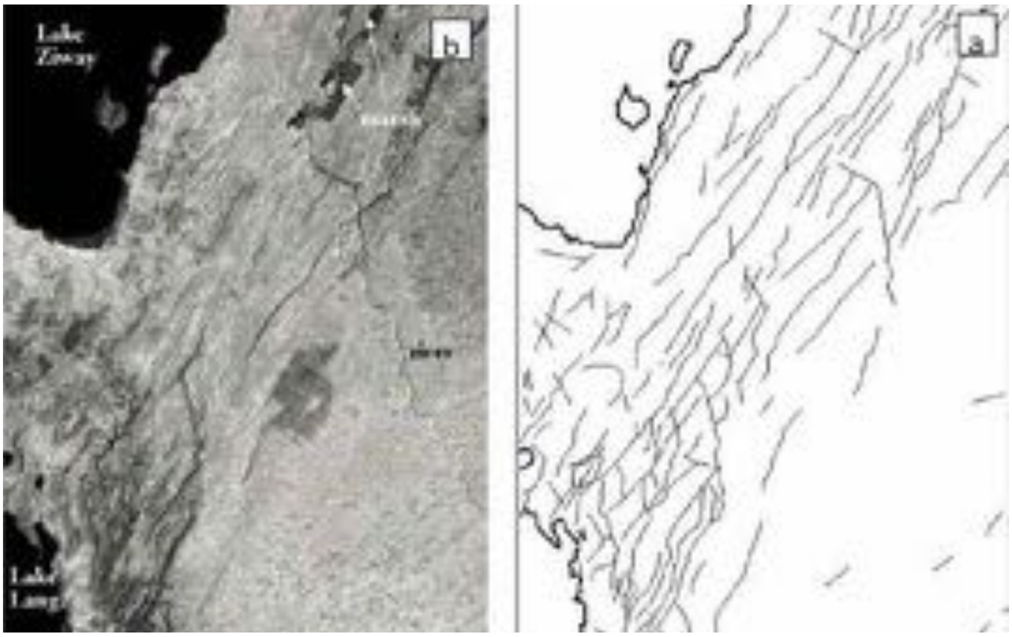


Figure 9.6: a) TM band 5 of a part of the central Ethiopian Rift, with edge enhancement filter, which sharpens contrast only a little. Distance E-W is 37km. b) Lineament interpretation, mainly tensional rift faults, using on-screen digitizing with enlargement. S = spring. Meijerink 2007

9.2.3 Lineaments

Lineaments are linear features of tectonic origin. Faults and fractures in rock can often limit or direct the occurrence of groundwater storage as water can flow along faults or be blocked by sharp bends. As these geological features tend to be linear they can often be identified in images (Figure 9.6) however because of the wide variety of the surface expression of linear features this operation is typically used as a first pass in identifying water bearing zones.

9.2.4 Geomorphological Mapping

As demand for groundwater increases the availability to accurately identify the location of readily accessible groundwater storage zones becomes more and more important. One valuable technique in this identification is the mapping of the geomorphology of a region. This can be done in a variety of ways but typically remote sensing analysis uses the tone, texture, size, shape and association characteristics of a region to detail the geomorphology (Ramaiah, 2012). Each geomorphic unit can tend be rated on its groundwater potential based on its characteristics. For example, Table 9.1 below shows the geomorphic units and their groundwater potential for the region Malur Taluk, part of the Ponnaiyar river basin in the drought prone Kolar District of India.

Simply having the hydrogeological map however, is not enough for the calculation of where the groundwater lies. To do the latter the geomorphology map (Figure 9.7) is combined with thematic maps such as drainage (Figure 9.8) to create what is known as the groundwater potential zone map (Figure 9.9).

Table 9.1: The geomorphic units and their groundwater potential based on its characteristics

SI. No.	Geomorphic Unit	Characteristics	Hydrogeology	Groundwater potential
1	Denudational hill	Small hills or heaps of angular boulders rising abruptly from surroundings.	Runoff zone	Poor-Very Poor
2	Residual hill	A group of hills occupying comparatively smaller area than composite hills.	Runoff zone	Poor-Very Poor
3	Inselberg	Isolated, very steep conical hill	Runoff zone	Poor-Very Poor
4	Pediment inselberg complex	Pediment dotted with a number of inselbergs which cannot be separated and mapped as individual units.	Inselbergs from runoff zones. Pediment contributes for limited to moderate recharge.	Moderate to Poor
5	Pediment	Pediments occur as gently undulating plains with moderate slope	Contributes for limited to moderate recharge.	Moderate to Poor
6	Shallow weather pediplain	Gently undulating plain of large areal extent often dotted with inselbergs formed by the coalescence of several pediments.	Pediplains form good aquifers depending on their composition. In hard rocks, they form very good recharge and storage zones depending upon the thickness of weathering/accumulated material, its composition and recharge conditions.	Good to Moderate
7	Moderately weathered pediplain	It is shallow depressed low relief area with good drainage networks.	Moderate infiltration to good recharge by hydrological feature. Storage complemented by secondary features.	Very good to good depending upon type of lithology and thickness of the material deposited.
8	Valley fill shallow	Valleys of different shapes and sizes occupied by valley fill material (partly detrital and partly weathered material).	Form moderately productive shallow aquaifers, subject to thickness of valley fill material, its composition and recharge conditions. The unconsolidated sediment deposited to fill a valley. Sometime controlled by fracture forming linear depression.	Very good to good depending upon type of lithology and thickness of the material deposited.

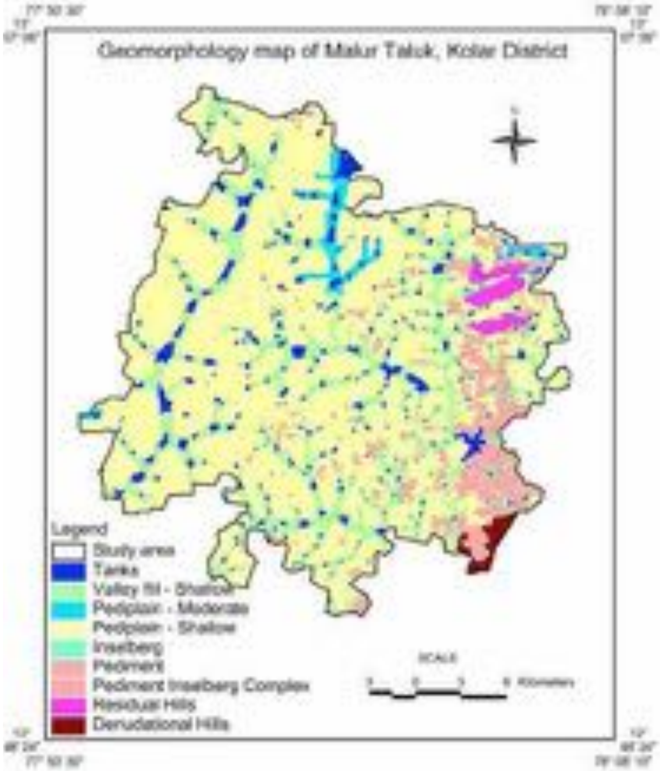
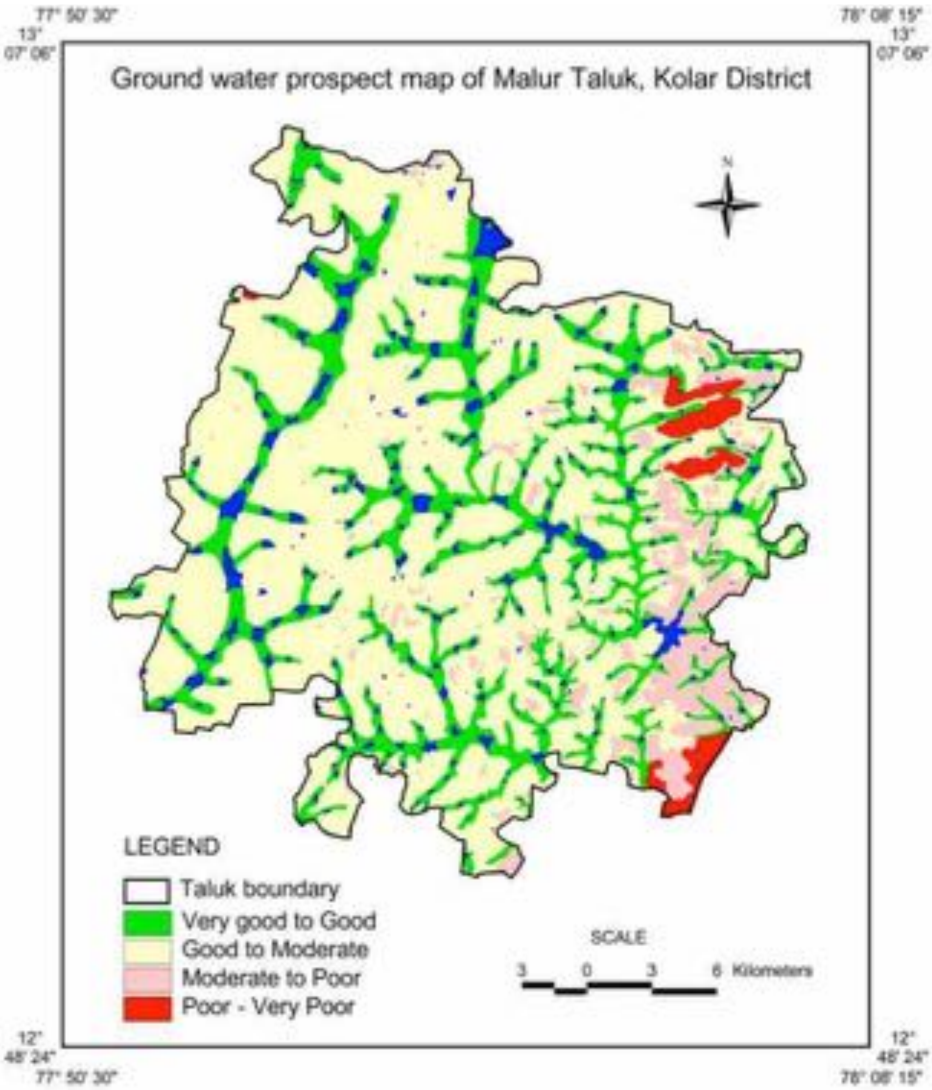


Figure 9.7: Hydrogeomorphological map of Malur taluk, Kolar district. Ramaiah 2012.

Figure 9.8: Drainage map of Malur Taluk, Kolar District. Ramaiah 2012.

Figure 9.9: Delineation of groundwater potential zone in Malur taluk, Kolar district. Ramaiah 2012.



9.3 PRINCIPAL COMPONENT (PC) TRANSFORMATION

Principal component analysis is a statistical procedure that is used to calculate the components in a dataset that account for the majority of the variability. In remote sensing it can be considered as a form of image enhancement that highlights variance. As can be seem in Figure 9.10 below, highlighting the principal component can highlight the drainage network and indicate the location of shallow groundwater.

9.4 GRAVITY RECOVERY AND CLIMATE EXPERIMENT (GRACE)

Monitoring changes in groundwater storage requires expensive in-situ equipment and even so the latter can only measure flow at one point. This creates a shortage of data points for scientists to model groundwater storage, changes in storage and flow of contaminants. In March 2002 NASA and the German Aerospace Center jointly launched a pair of identical satellites that orbit the earth in tandem and use changes in the gravitational pull of the earth to measure changes in mass of the surface below them. By removing the portion of the gravitational pull that's due to the oceans, landmasses

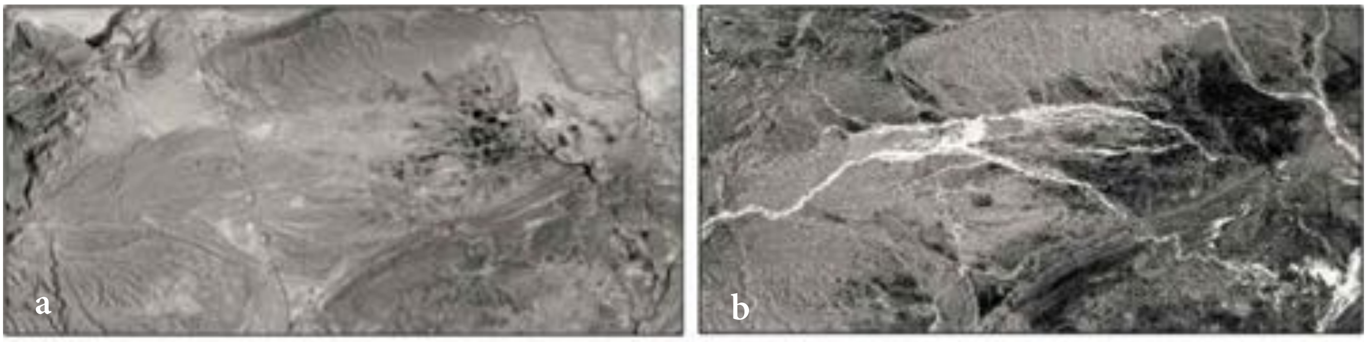


Figure 9.10: a) PC-1 image Landsat TM of alluvial aquifer in southern Iran recharged by transmission loss of ephemeral streams. Black patches are irrigated fields. Distance E-W is 21.1 km. b) PC-4 image of same area, showing active riverbeds where transmission losses occur. Image was stretched to enhance recent alluvium.

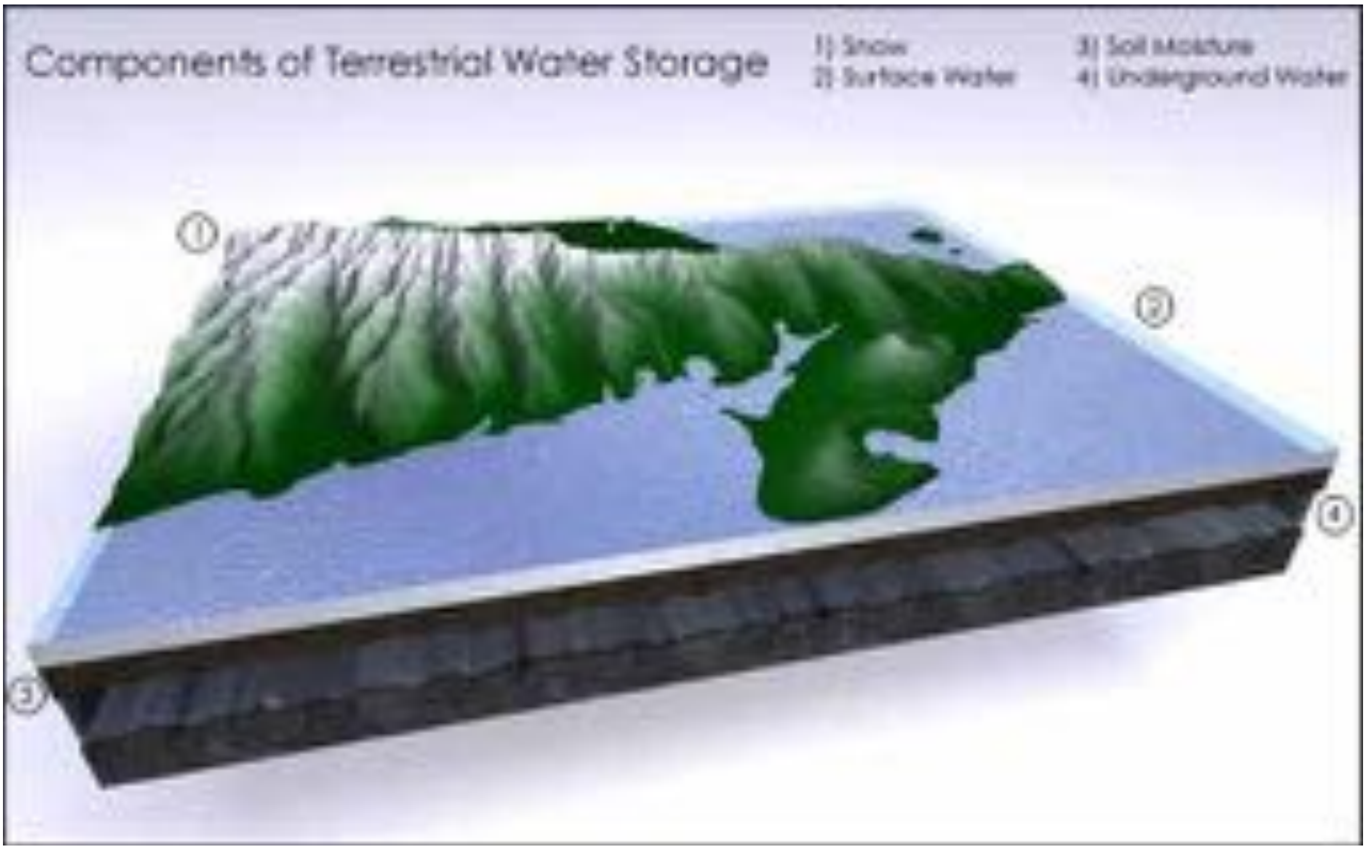


Figure 9.11: The first steps in the analysis of GRACE data produce an estimate of total terrestrial water storage change for all components pictured: snow, surface water, soil moisture, and groundwater. Additional analysis isolates the changes in groundwater from the total estimate. Ward 2003 (Image by Alex McClung).

and atmosphere scientists are able to calculate changes in deep water storage (Figure 9.11). The two satellites circle the earth 15 times a day and can sense changes as small as 10 micrometers over a distance of 220 kilometers. However though measurements are done multiple times a day GRACE is most accurate on longer timescales and for large areas. Published maps are created on a monthly basis (http://grace.jpl.nasa.gov/data/).

One of the most urgent problems in recent years is the monitoring of droughts, both in terms of changes in precipitation but also in monitoring of groundwater storage and modeling of what recharge and recovery would take. The GRACE satellites have proven to be invaluable in monitoring drought effects and recovery globally. The images below (Figure 9.12) show the loss in groundwater storage for the state of California from 2011 to 2013 as shown using the GRACE satellites.

9.5 GROUNDWATER CONTAMINANTS

Groundwater contamination is the result of typically anthropogenic materials such as gasoline, oil, road salt, fertilizers, septic systems, hazardous waste etc entering the groundwater through the soil and making it unsafe for human consumption or use (Figure 9.13). Addressing groundwater pollution involves not just cleaning and monitoring the point source of the pollutant but because of underground flow of groundwater it is necessary to understand the rate and direction of that flow and monitor the areas of highest risks. Due to the high expense of well drilling and monitoring GIS is a major tool used to model groundwater flow and to highlight potential high risk areas.

By using data from in-situ measurement stations coupled with geospatial layers such as soil type, geology, elevation, depth to water table, land use, drainage network, known contaminant point sources etc. GIS can be used to model GIS can be used to model areas of high risk for groundwater. Figure 9.14, 9.15 and 9.16 below shows some of the input layers used as well as the processes and output for the GIS-based modeling of potential agricultural contamination of surface and groundwater in the Fairchild Creek Watershed in Ontario, Canada.

Additionally GIS analysis enables the mapping of contaminant concentrations and how they change over time which allows for better decision and policy making, the ability to target problem areas and to identify pollution sources.

While modeling groundwater contamination is dependent on data from measurement wells, it allows for calculations of concentrations over a much wider area than can be covered simply with in-situ equipment thus reduces the actual number of measuring wells needed and mitigating the cost of groundwater management programs.

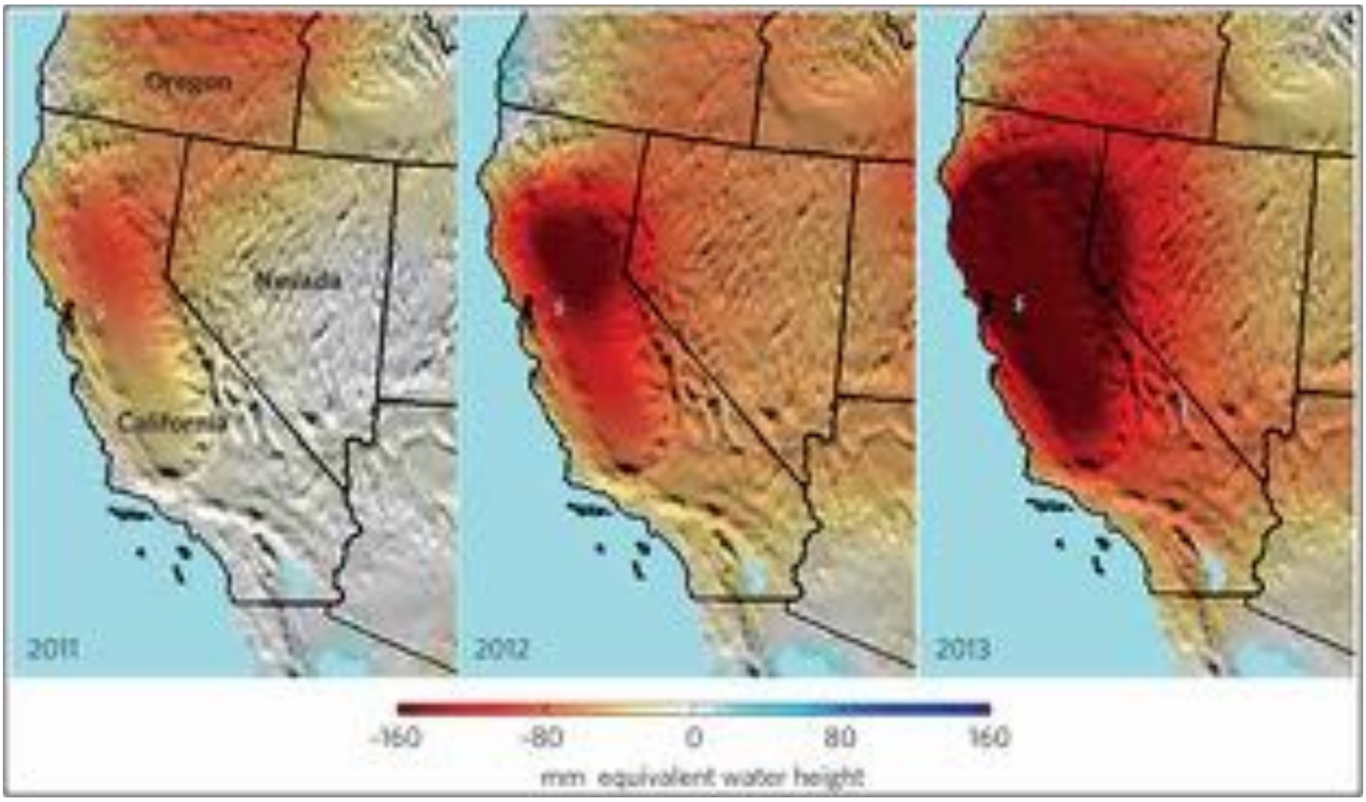


Figure 9.12: Dry Season (Sep-Nov) total water storage anomalies (in mm equivalent water height; anomalies with respect to 2005-2010) in western United States. The maps were constructed using GRACE Mascons solutions from NASA's Jet Propulsion Laboratory (M. M. Watkins, D. N. Wiese, D.-N. Yuan, C. Boening and F. W. Landerer, unpublished results). California's Sacramento and San Joaquin river basins have lost roughly 15 km3 of total water per year since 2011 — more water than all 38 million Californians use for domestic and municipal supplies annually — over half of which is due to groundwater pumping in the Central Valley3, 5. Image: Felix W. Landerer, NASA Jet Propulsion Laboratory, California Institute of Technology, USA.

Figure 9.13: Sources of Groundwater Contamination and their flow into the water table. Diagram courtesy the Groundwater Forum.

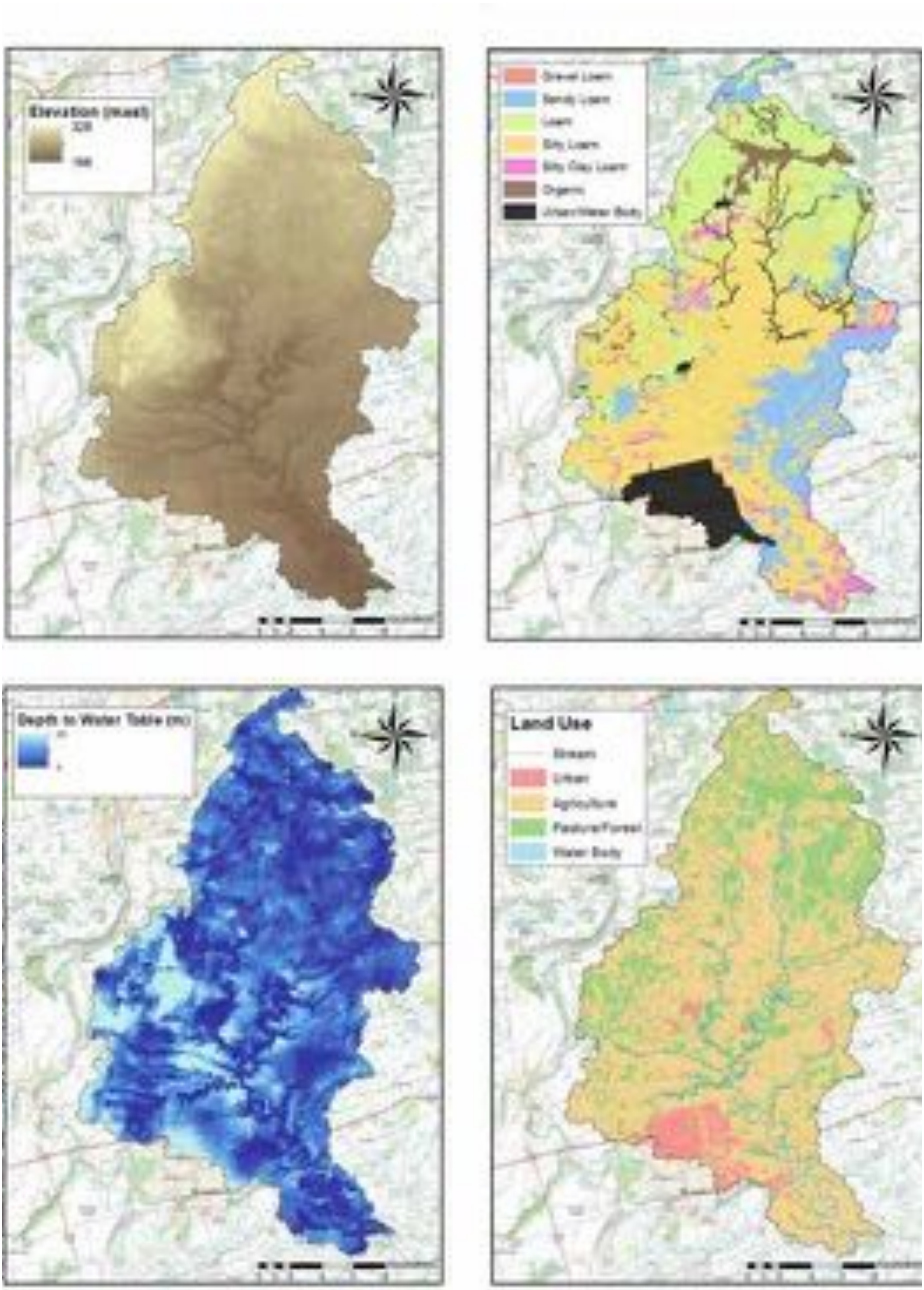


Figure 9.14: Some of the input layers for the GIS-based modeling of potential agricultural contamination of surface and groundwater in the Fairchild Creek Watershed in Ontario, Canada (Gutcher, 2012).

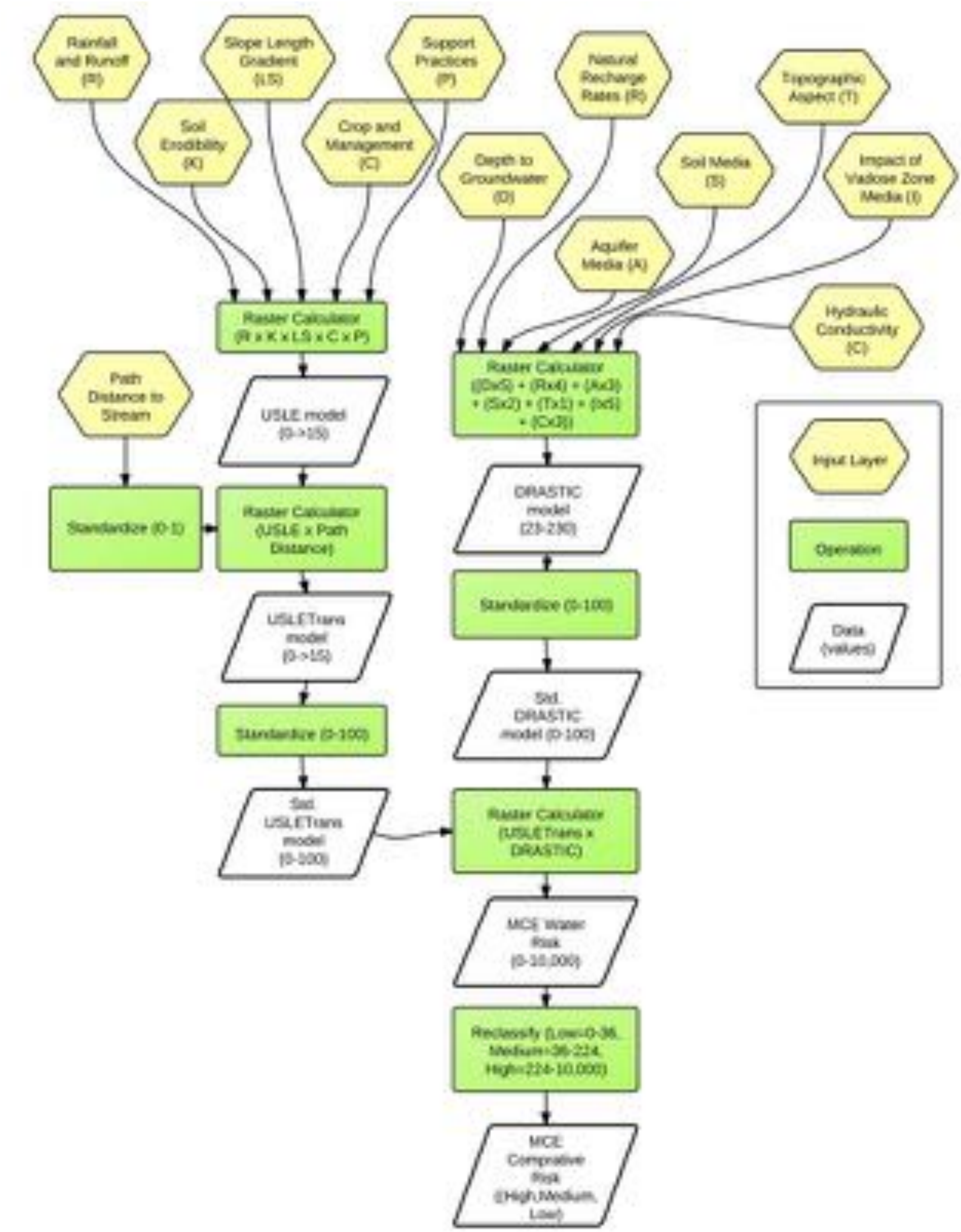


Figure 9.15: GIS model showing Input layers, operations and resultant data layers for the modeling of potential agricultural contamination of surface and groundwater in the Fairchild Creek Watershed in Ontario, Canada (Gutcher, 2012).

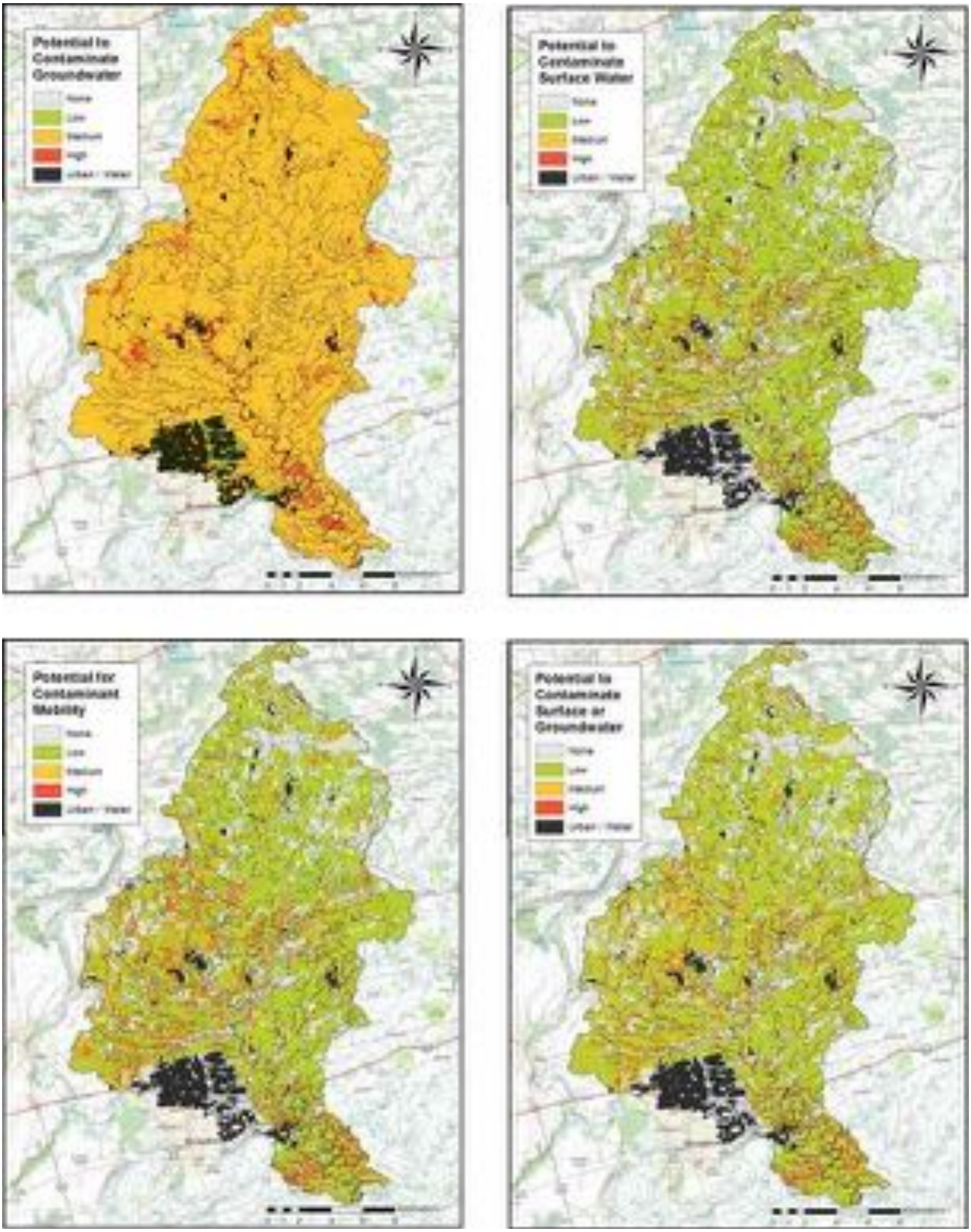


Figure 9.16: Output layers from the GIS model showing contaminant mobilisation potential (low, medium and high risk) for agricultural contamination of surface and gorundwater in the Fairchild Creek Watershed in Ontario, Canada (Gutcher, 2012)

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Chapter 10

Water Pollution and Water Quality

BEAM is an open-source toolbox and development platform for viewing, analysing and processing of remote sensing raster data. Originally developed to facilitate the utilisation of image data from Envisat's optical instruments, BEAM now supports a growing number of other raster data formats such as GeoTIFF and NetCDF as well as data formats of other EO sensors such as MODIS, AVHRR, AVNIR, PRISM and CHRIS/Proba. Various data and algorithms are supported by dedicated extension plug-ins.

Please note that BEAM is not further developed. It will remain under maintenance until at least mid of 2016. We encourage all BEAM users to use SNAP (available here) from now on. SNAP is the successor and evolution of BEAM. When installing SNAP along with the Sentinel-3 Toolbox you will have the same great user experience as with BEAM. You can even extend the number of features by installing other toolboxes like those for Sentinel-1 or Sentinel-2. http://www.brockmann-consult.de/cms/web/beam/

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Learning Objectives

- Learn on how to retrieve water quality data using satellite images
- Having hands on experiences for interpreting data on water quality and making comparisons of water bodies

EXERCISE 1: NEURAL NETWORK INVERSION, BEAM-VISTA

Dataset

In this exercise we will use MERIS image:
<MER_FR 1PNIPA20050221_074308_000000982034_00493_15577_0000.N1>.

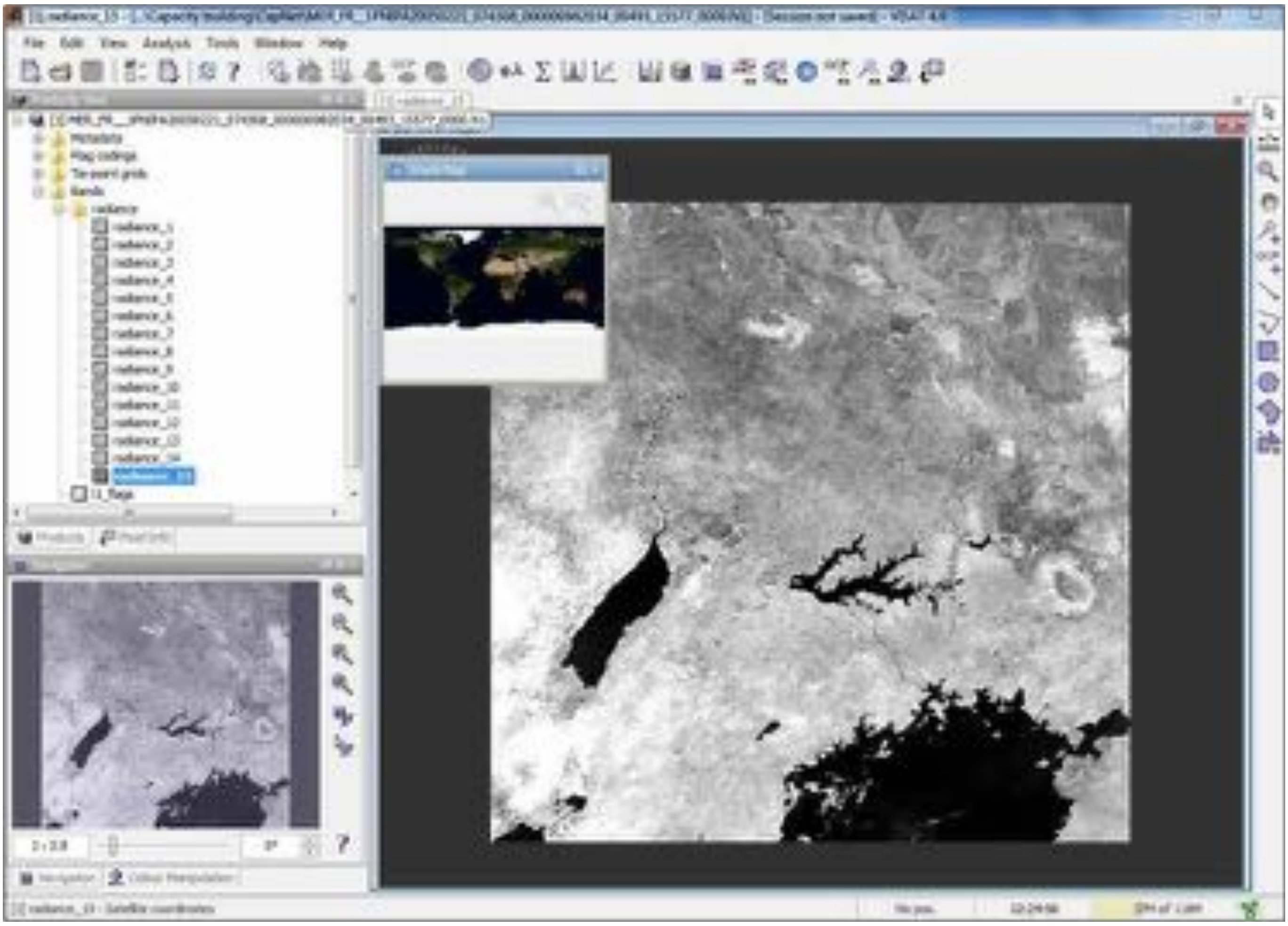
Objectives

1. Learn how to work with beam Visat;
2. Perform atmospheric correction on the image using C2R and the other variations of it;
3. Derive water quality variables;
4. Interpret the result and understand the spatial variation of water quality variables;

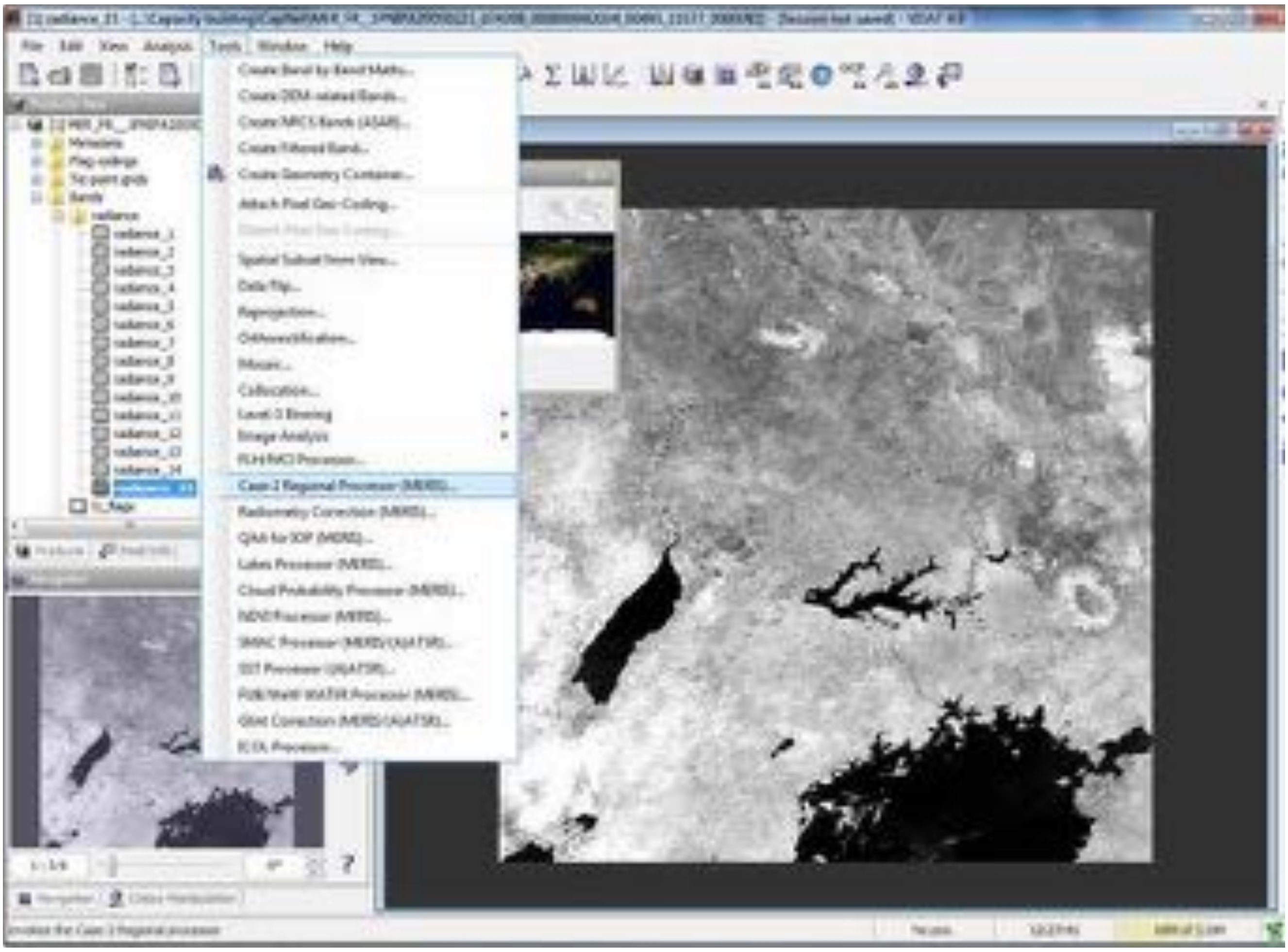
Tasks

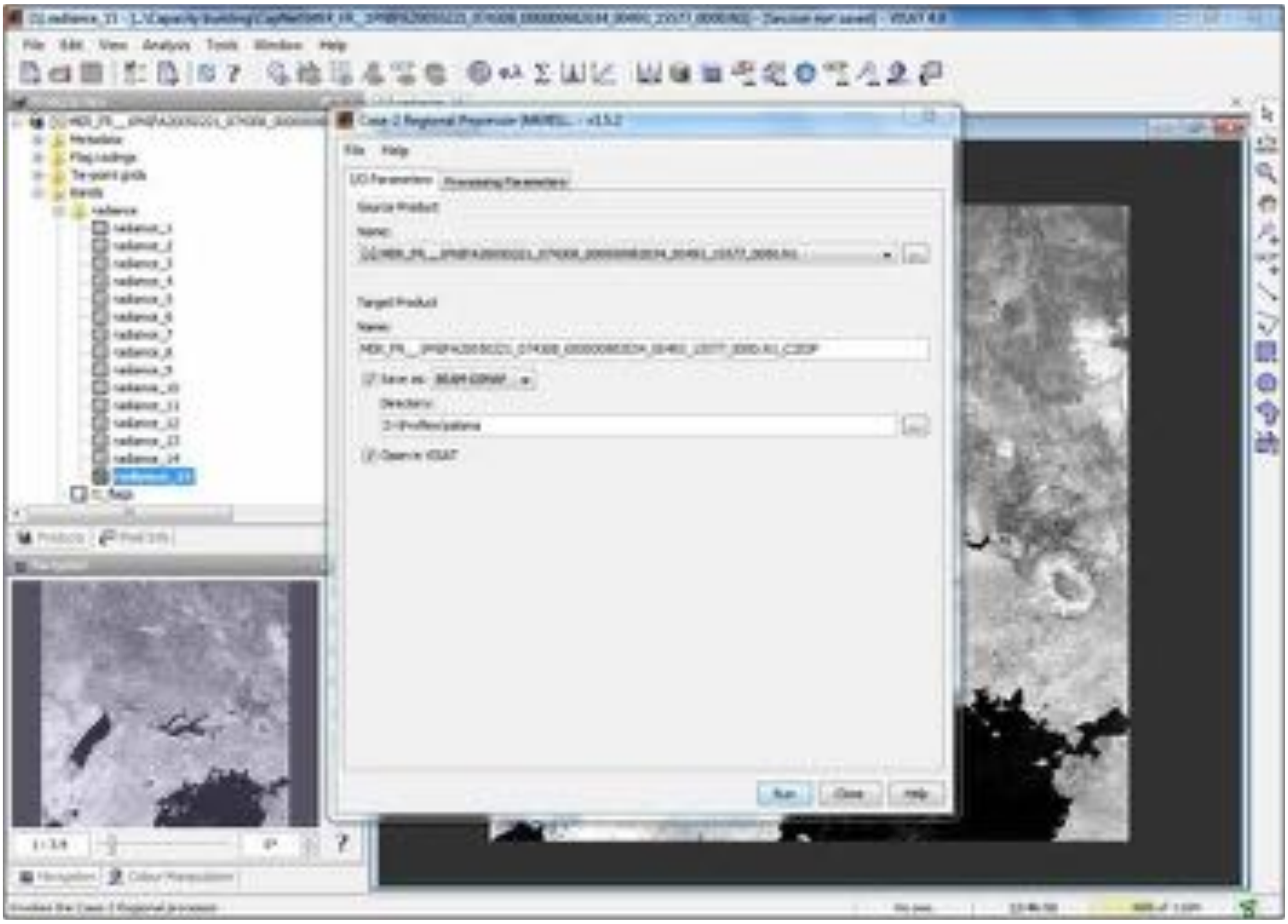
Load MERIs image in beam Visat;

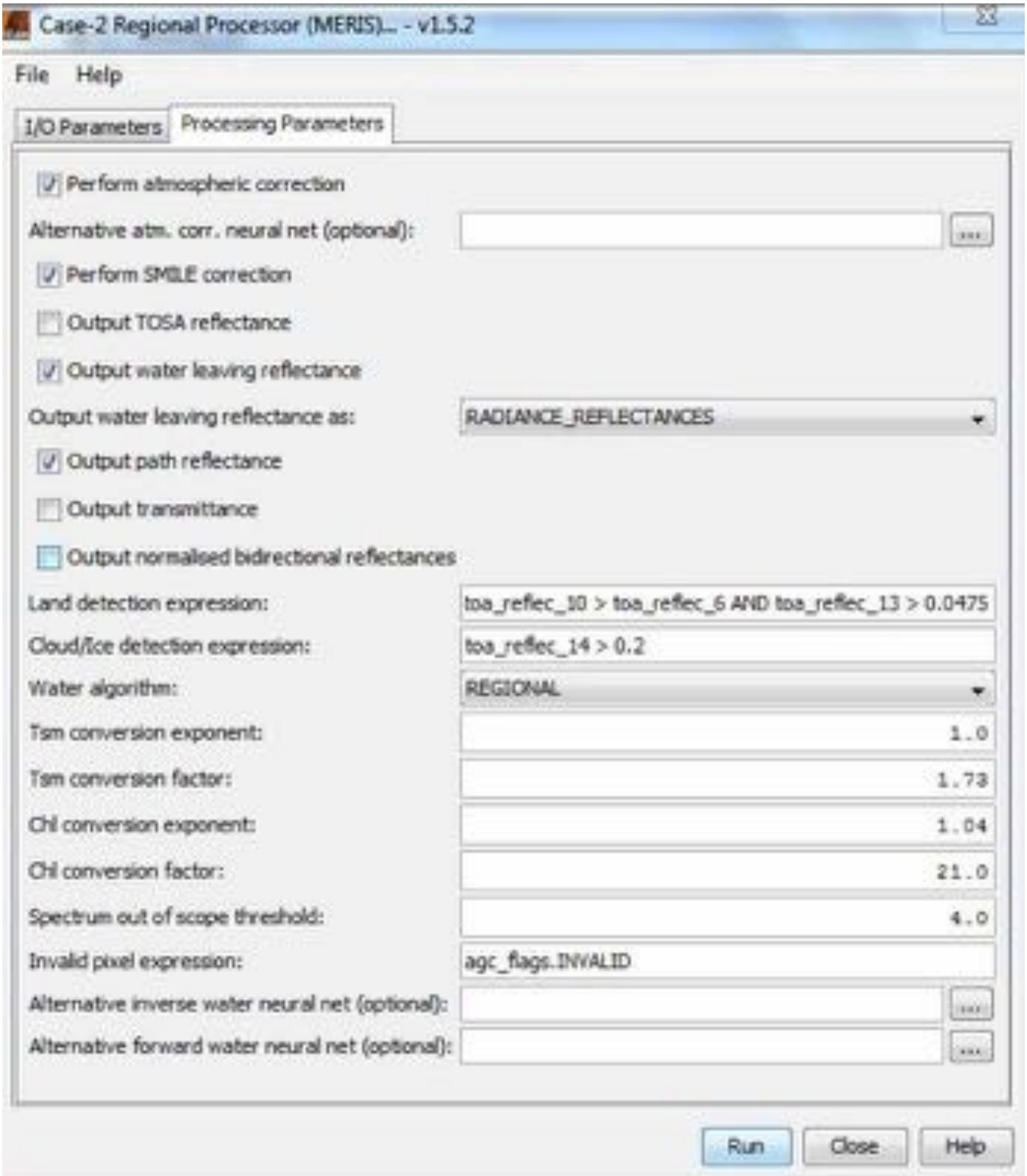
Explorer MERIS image: What is the acquisition date? Where are the Lat long data, etc?



Explore the parameters of C2R;

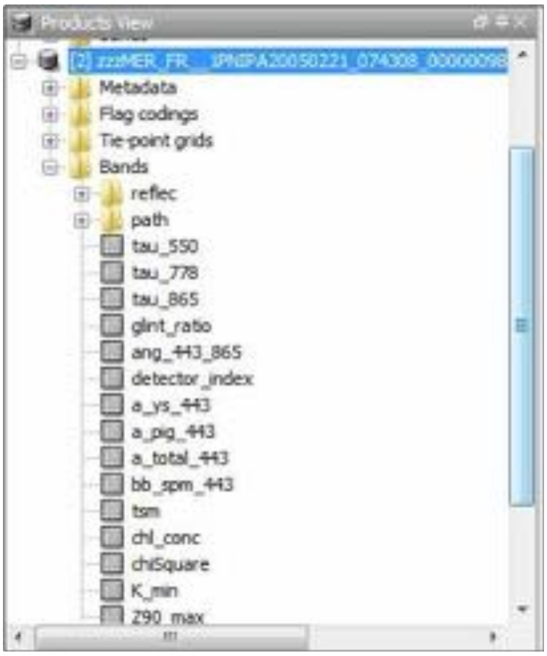




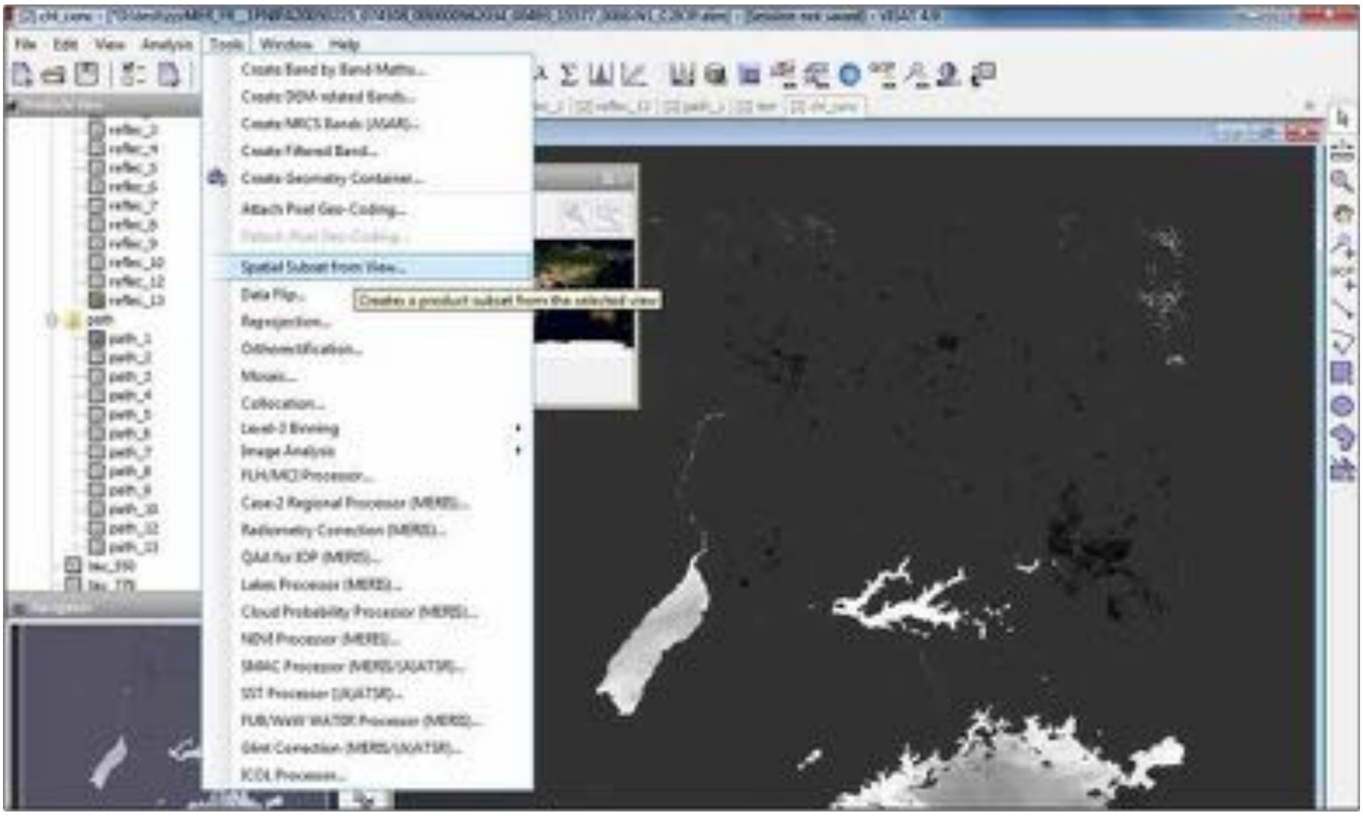

Case-2 Regional Processor (MERIS)... - v1.5.2
File
Help
I/O Parameters
Processing Parameters
Perform atmospheric correction
Alternative atm. corr. neural net (optional):
Perform SMILE correction
Output TOSA reflectance
Output water leaving reflectance
Output water leaving reflectance as:
RADIANCE_REFLECTANCES
Output path reflectance
Output transmittance
Output normalised bidirectional reflectances
Land detection expression:
toa_reflec_10 > toa_reflec_6 AND toa_reflec_13 > 0.0475
Cloud/Ice detection expression:
toa_reflec_14 > 0.2
Water algorithm:
REGIONAL
Tsm conversion exponent:
1.0
Tsm conversion factor:
1.73
Chl conversion exponent:
1.04
Chl conversion factor:
21.0
Spectrum out of scope threshold:
4.0
Invalid pixel expression:
agc_flags.INVALID
Alternative inverse water neural net (optional):
Alternative forward water neural net (optional):
Run
Close
Help

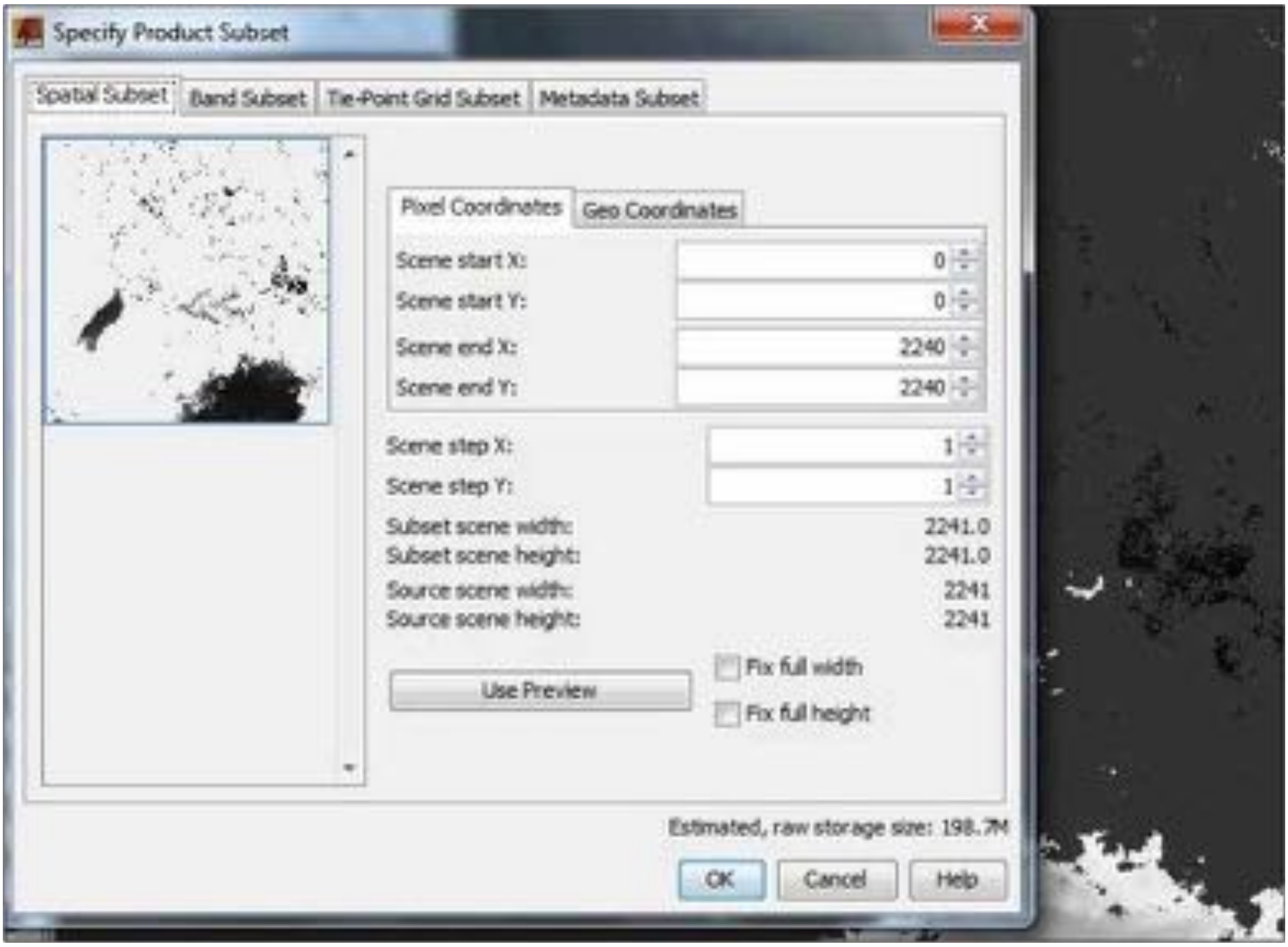
R un C2R;

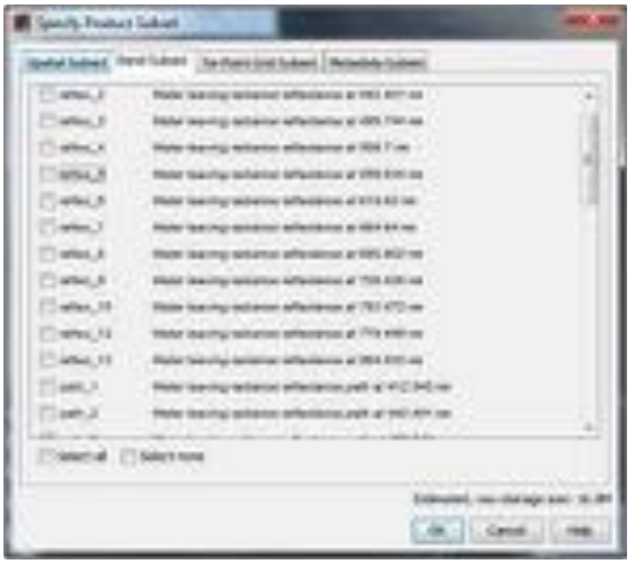
Explore C2R outputs;



Subset the data, spatially and spectrally

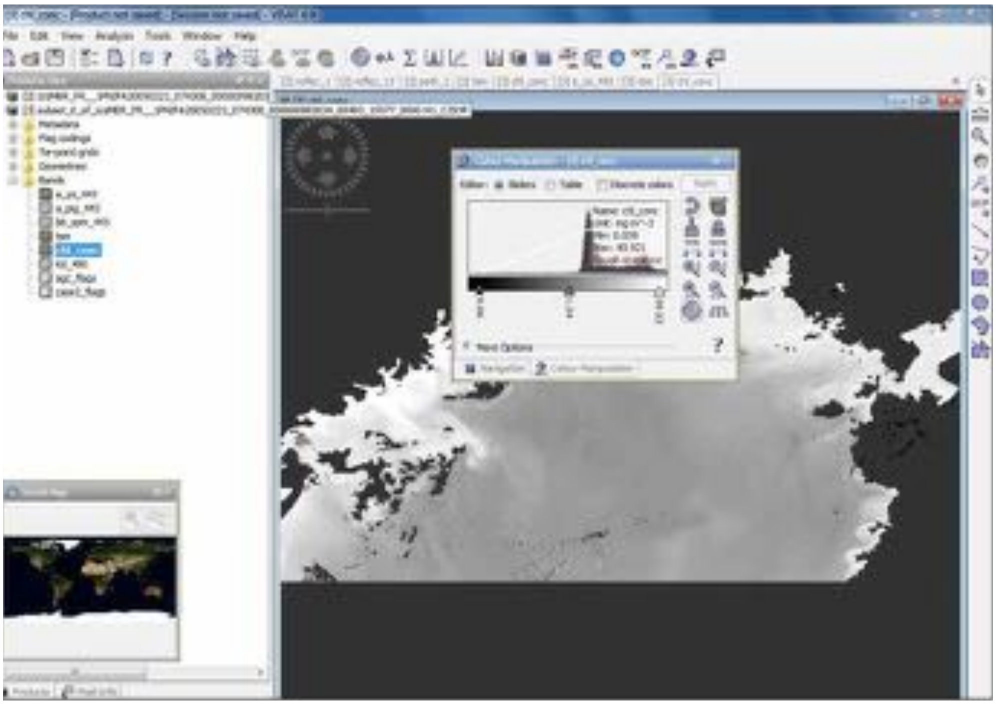


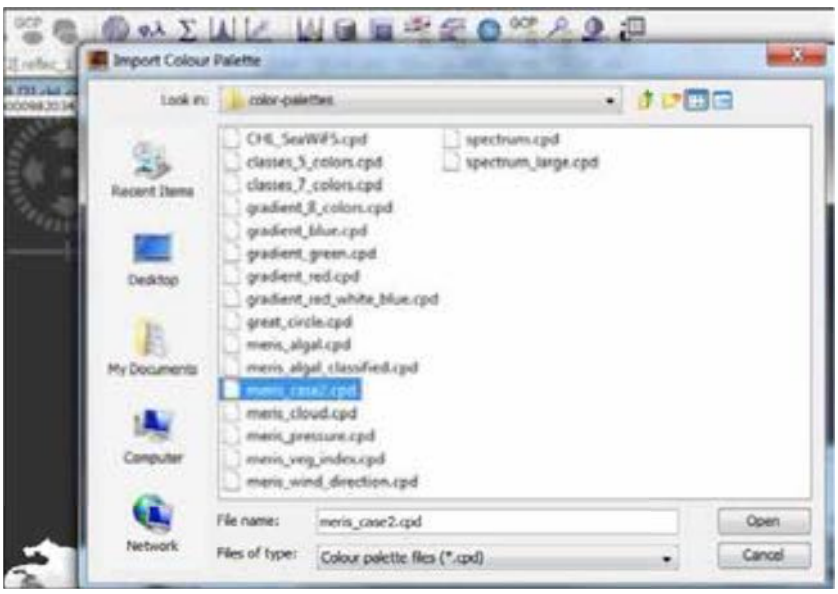




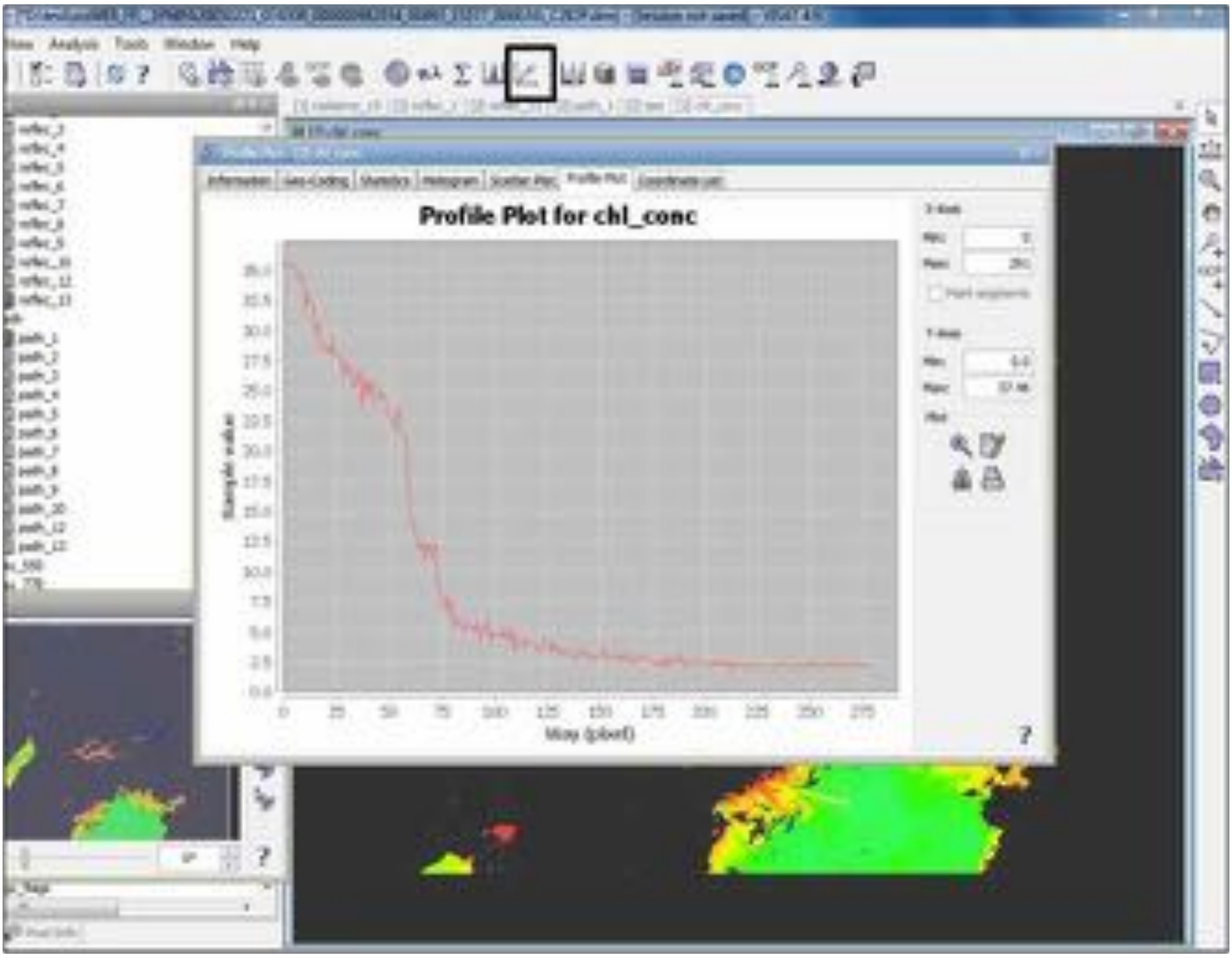
Select the water quality bands only;

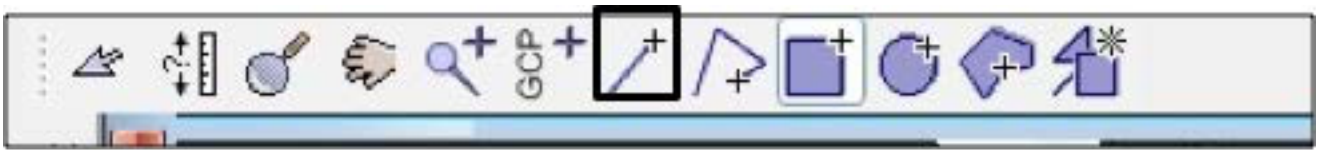
Change the color;



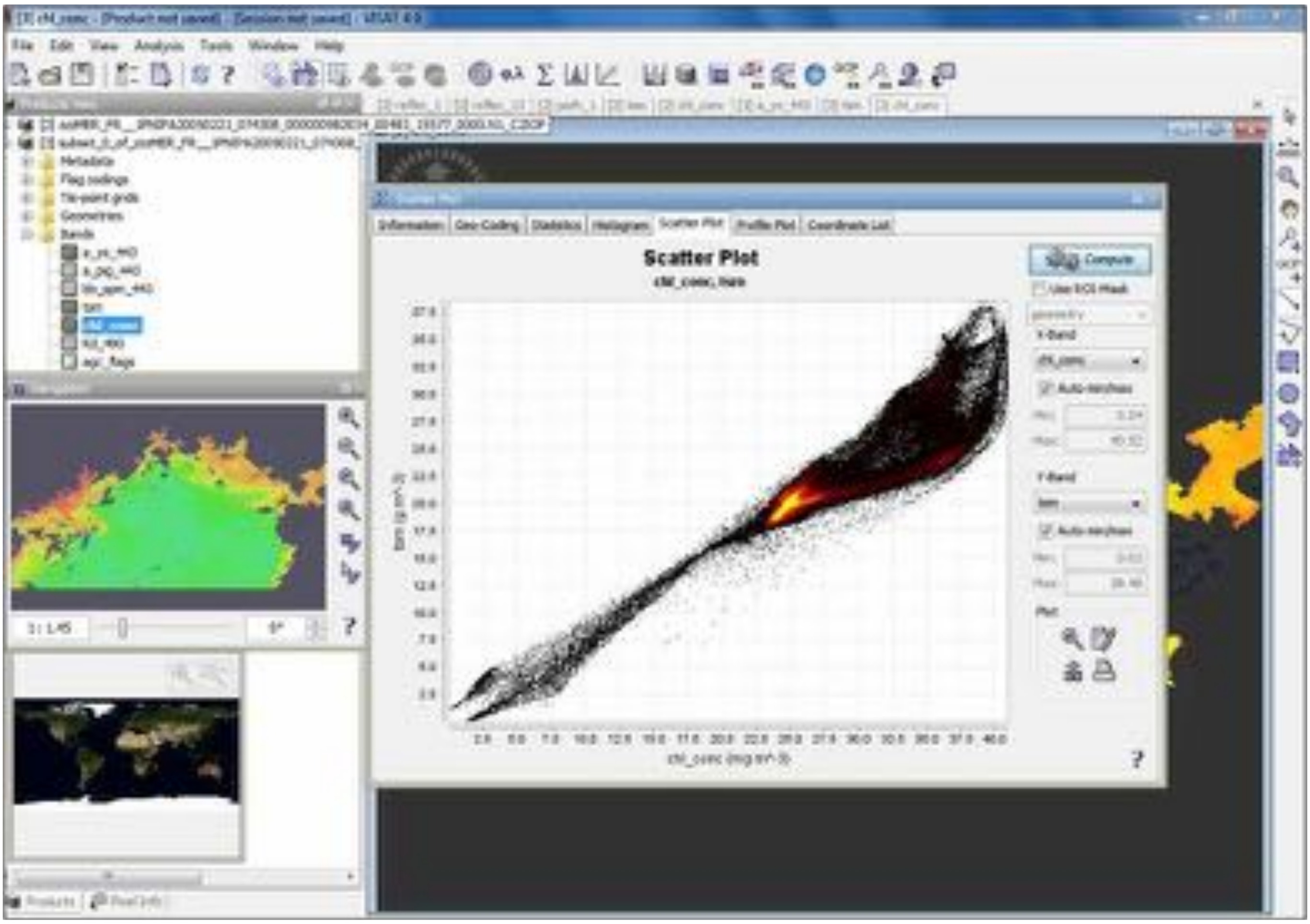


Analyze the spatial variability of the IOP by taking section and plotting the profile; : use the geometry tools to create new transect and then call profile plot:



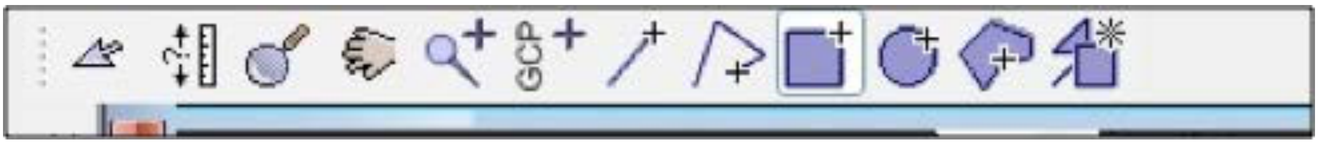


Scatter plot CDOM against SPM and Chl-a and Chla against SPM;

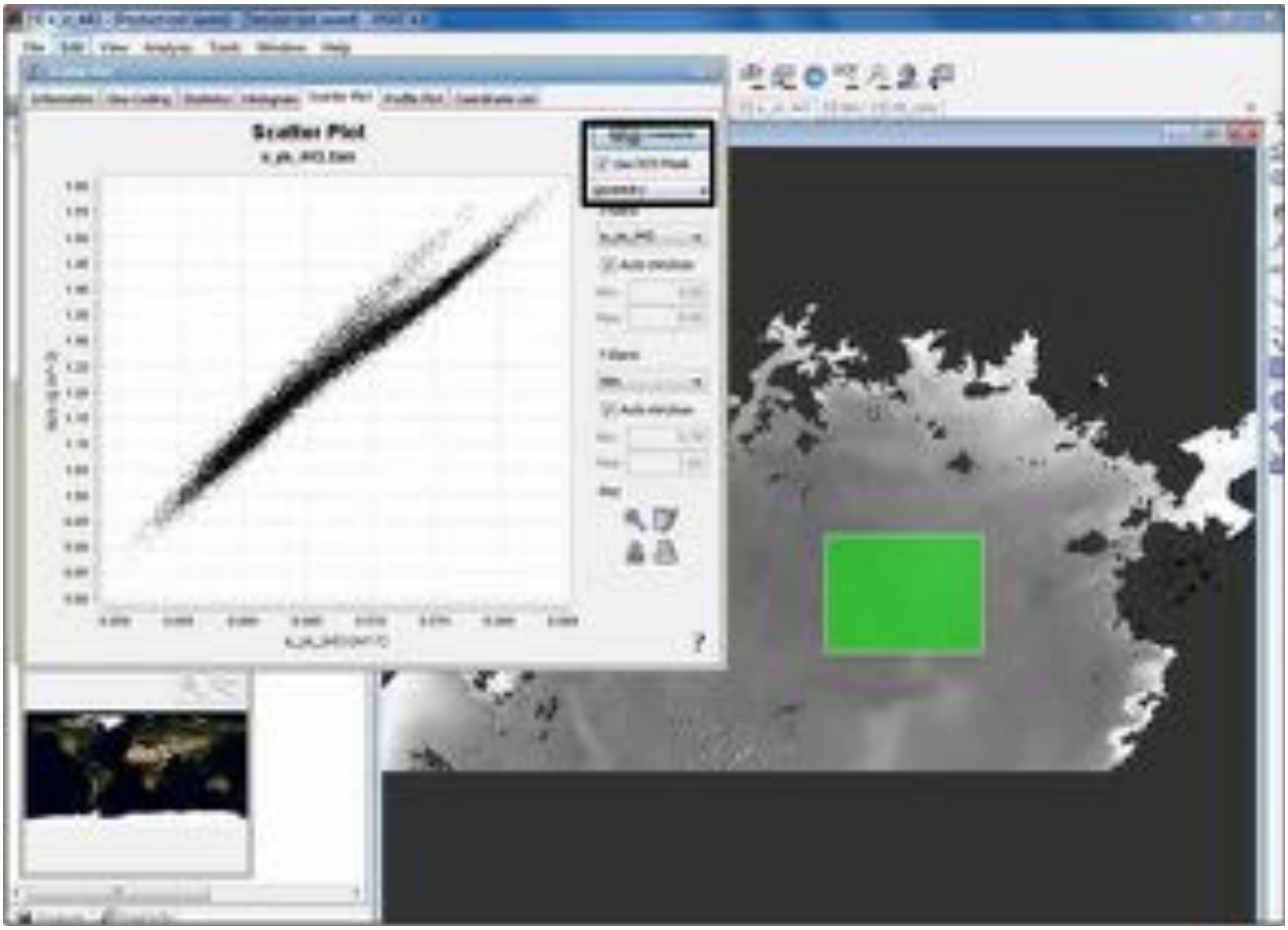


Do you see clustering, if yes why? What they represent?

For that, create a region of interest: use the geometry tools to create new geometry

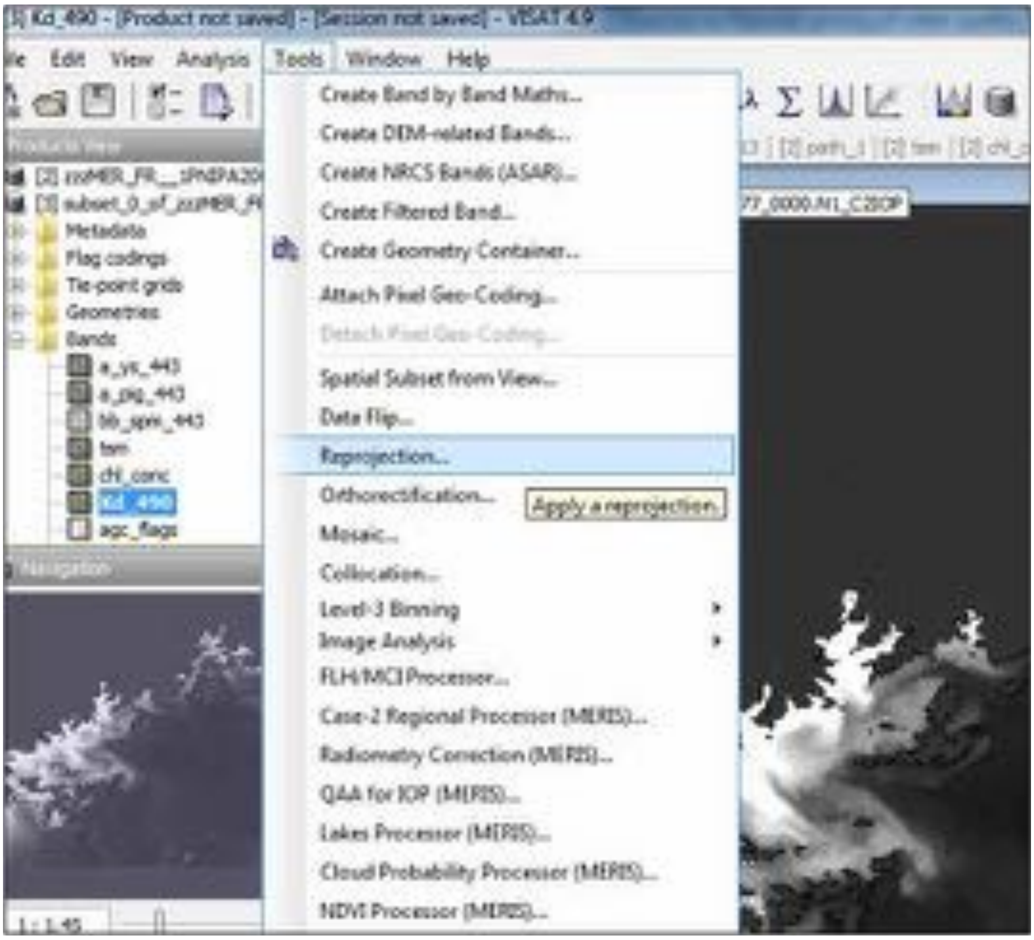


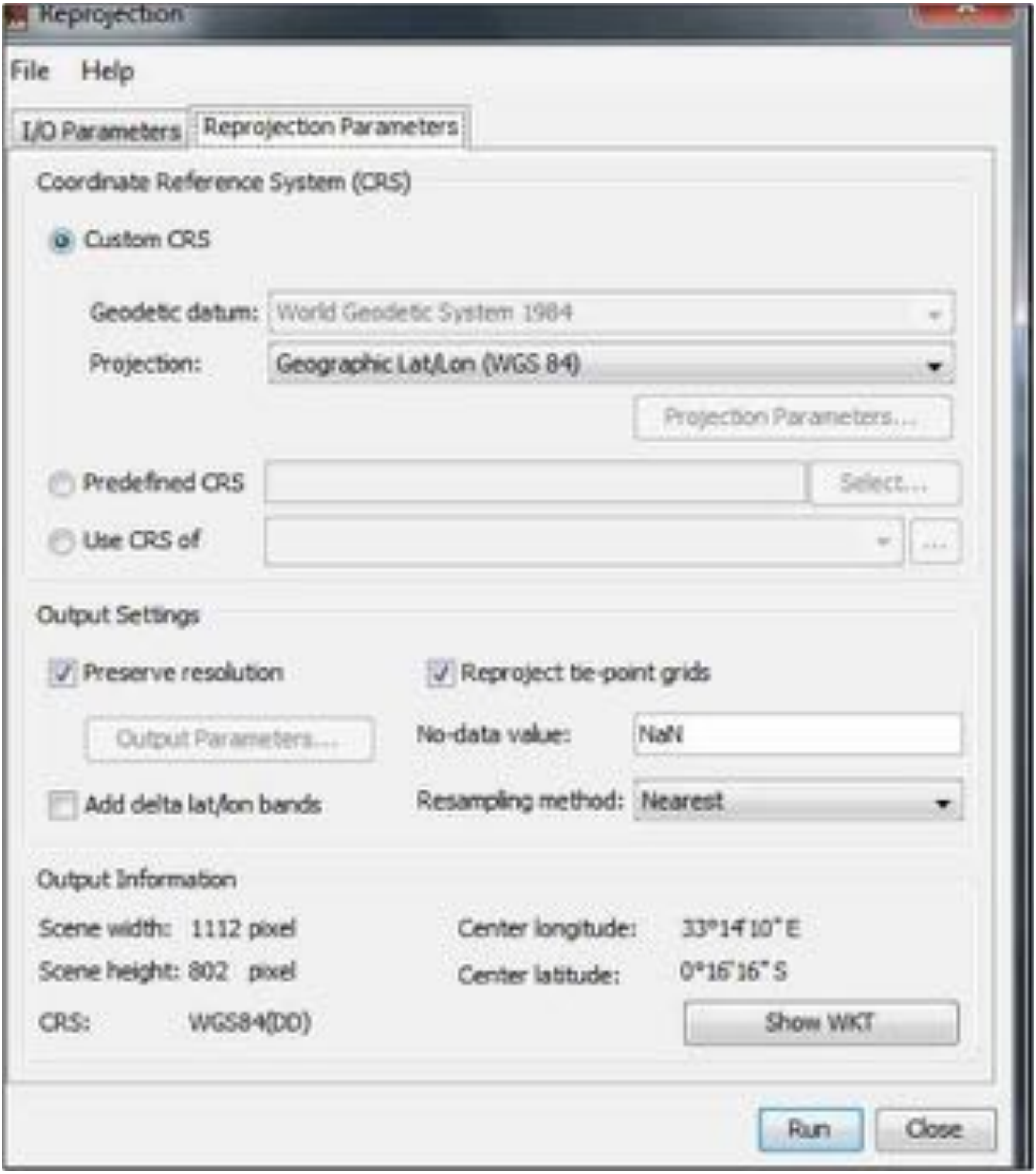
Compute the statistics (and histogram) of each water quality variable;



What do you notice from the histogram?

Project the image;





Keep the parameters as they are;

Produce a map with a color bar.

END OF EXERCISE

EXERCISE 2: INVERSION USING SPECTRAL OPTIMIZATION IN EXCEL

Dataset

In this exercise we will use:

1. MERIS image< MER_FR 1PNIPA20050221_074308_000000982034_00493_15577_0000.N1>
2. Provided Excel sheet GordonModel_xls_final.xls.

Objectives

1. Learn how to work with forward modeling;
2. Build the updated-GSM model and its parameterization;
3. Perform inversion using spectral optimization;
4. Retrieve water quality variables form the image spectra;
5. Interpret the result and perform inter-comparison between updated-GSM and C2R.

Tasks

Read the GSM model (Maritorena et al 2002, Salama et al., 2009) in appendix;

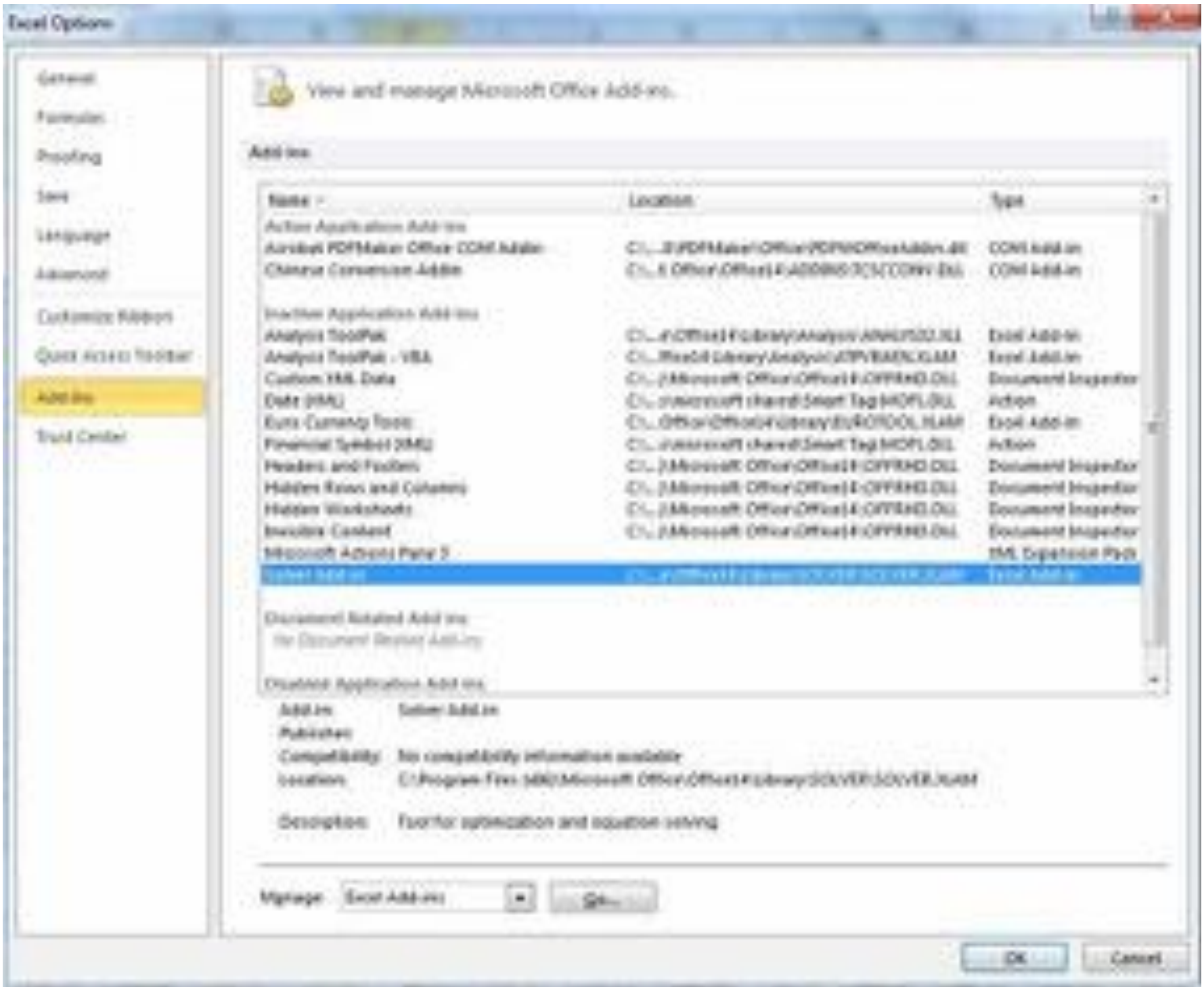
Use the provided excel sheet to build the forward model;

Create the parameterization to go from a reference wavelength to multi wavelengths;

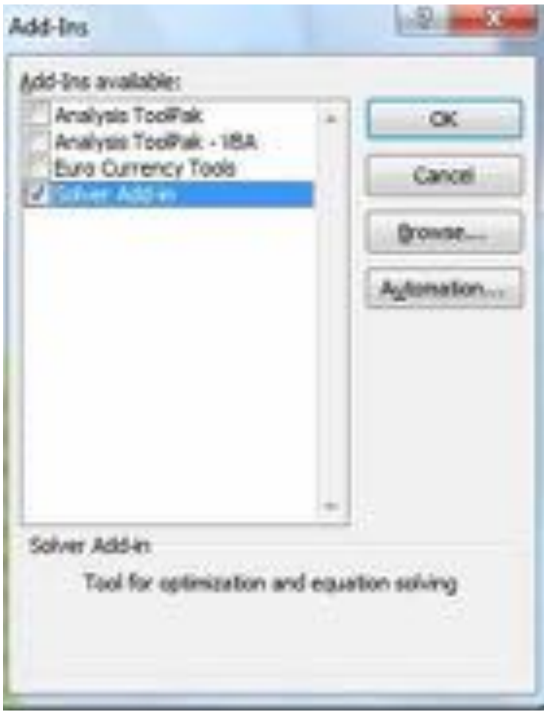
Do the inversion using the sliding buttons, provided within the excel sheet; For this task us the provided spectra in Rrs_IOCCG and their IOP in the sheet known_IOP. These data are taken from the 30 degree sun zenith simulated data (Lee et al. 2006, http://www.ioccg.org/groups/software.html).

Do the inversion using the automatic inversion method of excel (add analysis to your excel);

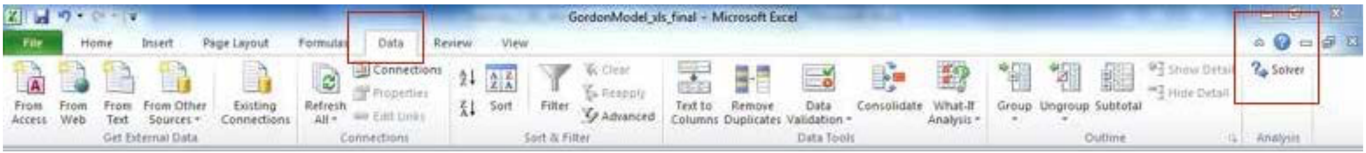
Go to option: "Select Adds-Ins and then Solver Add-in. Click "Go";



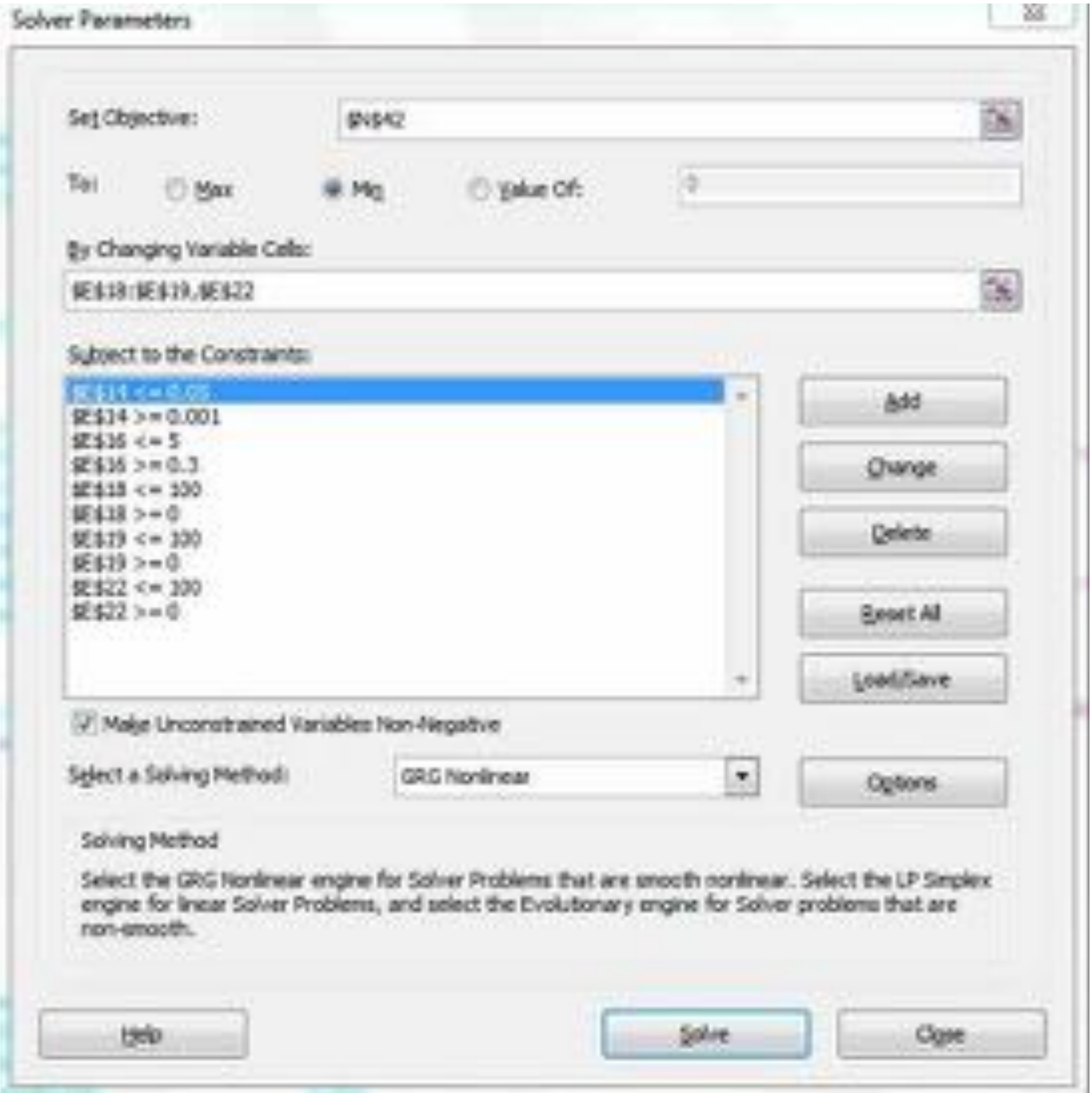
Then select Solver and press OK;



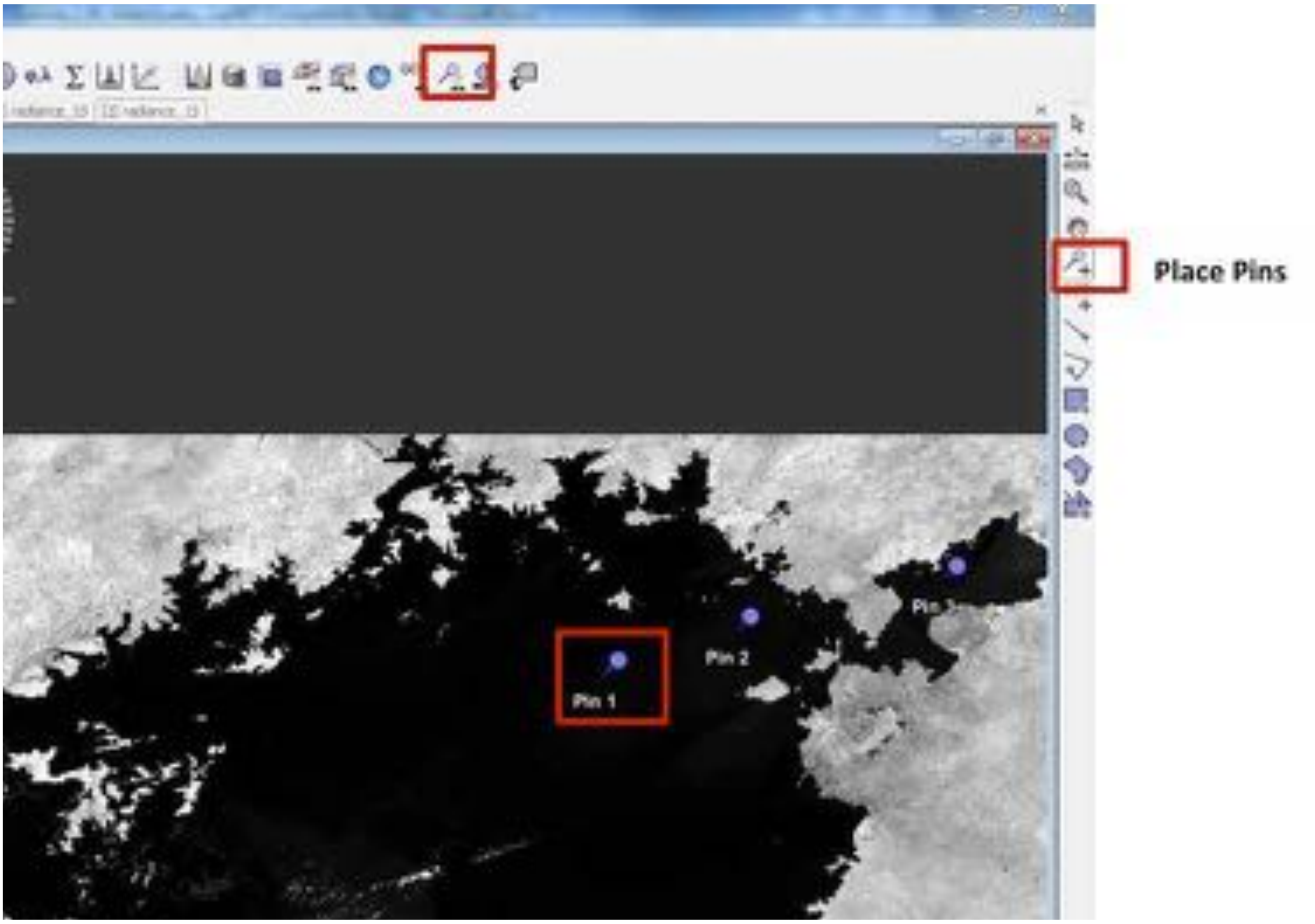
The solver is now under the tab Data;



Click on the Solver:



Pick up a few pins from MERIS image;



PIM Manager: selects the pins and save them to text file

Invert the retrieved pins using the updated-GSM model;

Compare the results with those of C2R and comment on the results.

APPENDIX: UPDATED GSM MODEL

$$R_{rs}(\lambda) = \frac{t^2}{n_w^2}\sum_{i=1}^{2} g_i \left(\frac{b_b(\lambda)}{b_b(\lambda)+a(\lambda)}\right)^i$$

Rrs (Ʌ) is the remote sensing reflectance leaving the water surface; g1=0.0949, g2 =0.0745, are subsurface expansion coefficients due to internal refraction, reflection and sun zenith; t = 0.95 and nw =1.34 are the sea air transmission and water index of refraction, respectively. The parameters b(Ʌ) and a(Ʌ) are the bulk scattering and absorption coefficients of the water column (subset of the water inherent optical properties IOP). These IOP characterize the optical behaviour of the medium and are directly related to the concentrations of water constituents.

The light field in the water column is assumed to be governed by five optically significant constituents, namely: water molecules, chlorophyll-a (phytoplankton green pigment, Chl-a), colored dissolved organic matter (CDOM), detritus and suspended particulate matter (SPM).

The bulk absorption and backscattering coefficients are modeled as being the sum of the constituent's absorptions and backscatterings. The absorption coefficient of water molecules is assumed constant and tabulated in the excels heet. The variation of water absorption with temperature is neglected. The scattering coefficient of water molecules is estimated from tabulated value provided in the Excel sheet. The absorption coefficient of chlorophyll-a is approximated following:

$a_p(\Lambda)=(\alpha+\beta\ln\ [a_p(0.44)])a_p(0.44)$

α, β are wavelength dependent empirical parameters, can be found in the excel sheet.
The absorption coefficient of colored dissolved organic matter and detritus is modeled with unknown spectral dependency exponent s:

$a_{dg}(\Lambda)=a_{dg}(0.44)\exp[-s(\Lambda-0.44)]$

The scattering coefficient of suspended particulate matters is parameterized as function of scattering at 550nm and unknown spectral dependency exponent (y).

$b_{spm}(\Lambda)=b_{spm}(0.55)(\frac{0.55}{?})y$

Four IOPs are thus parameterized as a function of five variables yet to be retrieved:

$[a_p(0.44)\quad a_{dg}(0.44)\quad b_{spm}(0.55)\quad s\quad y]$

Chapter 11

Watershed Delineation and Characterisation

The chapter is based on the notes from Dr. Ben H.P. Maathuis, Department of Water Resources, ITC, January 2006

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Learning Objectives

- To facilitate the appreciation of the need for watershed delineation and characterisation
- To learn the main basic functions in the ILWIS DEM Hydro-processing module

11.1 INTRODUCTION

Information is required to carry out rainfall-runoff modelling, and part of the necessary model input can be obtained through processing and analysis of a Digital Elevation Model (DEM) in combination with information extracted from other remote sensing images of a selected area. One of the most recent near global elevation data sets is the one recorded during the 11 day Shuttle Radar Topographic Mission based on a C-band interferometric radar configuration. This information, representing the radar reflective surface (which may be vegetation, man-made features or bare earth), was collected in 2000 and is now available at a horizontal spatial resolution of 90 metres (averaged from 30 by 30 metres) at vertical increments of 1 metre. The data can be downloaded freely (http://srtm.usgs.gov), unzipped, mosaiced and processed. As for arid and semi-arid areas the reflective surface mostly represents the actual ground surface. The main limitations of the dataset are often small areas having data voids which need to be corrected prior to further processing. Other data sources to produce a DEM include existing contour or point elevation, optical stereoscopic, LIDAR or other interferometric based remote sensing instruments.

ITC has developed a DEM hydro-processing module to support further DEM processing in order to obtain a full raster and vector based (including topology) schematization of the (sub) catchments and drainage network.

11.2 DEM HYDRO-PROCESSING

There are several routines developed to support DEM Hydro-processing, e.g. Flow Determination, flow modification etc.

11.2.1 Flow Determination

This set of routines facilitates the necessary pre-processing steps to derive a hydrological consistent flow network. The Deterministic-8 model formed the basis for this routine. The flow extraction process allows the occurrences of undefined areas, representing e.g. closed basins, glacial lakes, depressions (sinkholes) within a limestone area or manmade features like reservoirs. These areas are therefore not modified during the fill sink routine. The flow accumulation computation stops at these locations and at a later stage, manually, the topology can be adapted to represent proper flow connection. Relevant features that represent actual topology can be extracted from satellite images (through screen digitizing) and the DEM may be adapted at these locations.

11.2.2 Flow Modification

To obtain a hydrological consistent raster based elevation representation, additional modifications are often required as the elevation value assigned to a pixel is an averaged representation only. Furthermore, due to raster resolution in relation to the drainage network or valley width (land surface discritisation does not allow representation of features smaller than the pixel size) or intrinsic properties of the sensor that acquired the DEM (reflective surface instead of the actual ground surface as is the case with active sensors derived raw elevation models) hence additional pre-processing is necessary. To overcome the resolution problem more detailed elevation raster data can be obtained from larger scale aerial photographs or optical stereo satellite images (Aster or Spot-5 HRS). Well established photogrammetric principles can be applied for parallax based elevation extraction.

Despite these approaches the bathymetric information of the stream network and lakes is often still not available. A DEM optimization routine, similar to the Agree-DEM method (Maidment et al, 2000, 2002) is therefore used here as well. General values for all segments or linkage of the drainage segments (extracted through satellite image interpretation) with a table containing the width and depth parameters according to e.g. Strahler order can be used for DEM modification purposes.

Topological Optimization is another option where topological consistency can be obtained for those areas having undefined DEM values (representing lakes or a reservoir). A (straight) line can be constructed from e.g. the lake inlet to outlet in a down flow direction, along this line the down flow pixels are added to the flow direction map and the drainage pixels will be added to the basic drainage network map during a later stage. For flat areas the satellite image based drainage can be extracted and through this manual intervention, the parallel drainage line occurrences in flat areas can be corrected as well.

First a default network can be generated. This can be superimposed on a satellite image. A comparative analysis shows the areas require manual adaptation. The flow modification routines are therefore fully utilizing the remote sensing information that is mostly at disposal to the analyst in order to overcome some of the imperfect areas in an elevation model.

11.2.3 Variable Threshold Computation

Packages that allow hydro parameter extraction (e.g. the Hydro-tools and TauDem Arcgis extensions, Rivertools, Arcviews HEC-GeoHMS extension3) use a fixed flow accumulation threshold. Once this threshold value is exceeded a drainage line is identified resulting in a rather homogeneous drainage network. In DEM Hydo-processing, a different approach is adopted by considering the type of geology and soil in a basin. If a geological or a soil map is available the units of this map can be reclassified to represent flow accumulation threshold values; units with coarse grained sandy soils overlaying deeply weathered sandstones can be assigned higher thresholds compared to thin soils occurring over shales (reflecting the lower permeability and little resistance to erosion).

A number of script based routines are provided in case only an elevation model is available. After computation of the internal relief, with selectable rank order kernel size, up to five upper threshold boundaries can be selected. Through these scripts the threshold classes are quickly generated and generalized (using a selectable majority filter size) that can be used during the boolean raster drainage network extraction routine. The result is that in areas with high internal relief (mountains) a lower threshold value can be assigned compared to e.g. gently undulating footslopes. Once a drainage line is identified given both approaches and subsequently an area of higher thresholds is encountered the drainage line continues but new drainage is assigned only if the given threshold condition for that area is fulfilled. Comparing the extracted drainage with a satellite image reveals if the thresholds are properly assigned. If there are still mismatches the thresholds can be easily adapted and a new variable threshold map can be computed. The

Niger rover: UN Photo/Shaw McCutcheon

provided script uses the internal relief by default; scripts can be added using the slope of the terrain if that seems to be more appropriate.

11.2.4 Network and catchment extraction

The core of the module is formed by this set of routines. The boolean raster drainage network extracted, eventually modified during the previous steps, is used as an input for the drainage network ordering routine. This results, next to a raster drainage map, in a full vector based drainage network, with associated attribute table, describing the topology as well as a number of DEM derived variables. There is an option to eventually exclude short segments based on a user defined minimum length threshold.

In the drainage attribute table, variables like upstream and downstream coordinates, their corresponding elevations are given, next to length of segment, distance between the two nodes, slope along the stream, slope taken along a straight line between the two nodes (both in degree and percentage), sinuosity (ratio between drainage length and straight distance), upstream drainage length, Strahler and Shreve order. Topology is given as linkage between upstream and downstream drainage linkage ID('s). Another variable, called StrahlerClass is provided and can be used for cartographic representation purposes, linking colour and line thickness to the Strahler order.

In the next step for each identified drainage line the corresponding catchment area is extracted. The raster and polygon based catchment maps have identical ID's compared to the drainage network and the associated table also provides a number of variables such as the catchment area, perimeter, total upstream area, longest flow path length, centre of the catchment according to a rectangular bounding box or according to half the distance of the longest flow path length. Topological linkage is given by the upstream and downstream located catchment(s). Additionally a column gives the linkage with the drainage segment.

Another option available is the catchment merge. Using Strahler or Shreve orders the lower order catchments can be merged to a higher order, which might be useful for basin scaling - data assimilation type of studies. Additionally using a point map with outlet locations the catchments situated upstream of these outlets can be extracted and the longest flow path vector can optionally

Ivindo National Park, Gabon: UN Photo/Gill Fickling

be computed. A new attribute table describing these extracted catchments is provided, having the same attributes as those given for the individual catchments. The raster and vector maps as well as the tables generated can be exported to other formats for incorporation into other software routines.

11.2.5 Compound parameter extraction

Routines are given here to compute a number of maps that are relevant with respect to watershed management, soil erosion and conservation type of studies. The overland flow length computes the distance to the river network according to the flow direction map. The wetness index sets catchment area in relation to the slope gradient by using formula $w = \ln(As / \tan(ß))$ (Beven and Kirkby, 1993). An idea of the spatial distribution and zones of saturation or variable sources for runoff generation is obtained. The stream power index is the product of catchment area and slope and could be used to identify suitable locations for soil conservation measures to reduce the effect of concentrated surface runoff. Finally, the sediment transport index accounts for the effect of topography on erosion. The two-dimensional catchment area is used instead of the one-dimensional slope length factor as in the Universal Soil Loss Equation. The equations for the indices applied are those given by Burrough and McDonnell (1998).

11.2.6 Statistical parameter extraction

A number of functions to provide relevant statistical information of the extracted river and catchment network are available. The Horton plots show the relationship between Strahler order and total number of Strahler order stream segments for a given order, average length per Strahler order and average catchment area per Strahler order, as well as the bifurcation, channel length and stream area ratio's (by means of a least square regression line). The results can be graphically displayed plotting the Strahler order on the X axis and the number of drainage channels, stream length and stream area on a log transformed Y axis. According to Horton's law the values obtained should plot along a straight line (Chow et al, 1988); this is another indicator that the parameters used for drainage extraction are properly selected. Especially when performing catchment merge operations using Strahler orders, reference to the original Horton plot might be relevant.

Next to this a number of scripts are provided assisting computation of other frequently used statistics, such as the construction of cumulative hypsometric curve for a given catchment or through a crossing operation with a classified soil or land cover map to obtain the percentage coverage of each class within a selected catchment. Also all extracted catchments can be crossed with e.g. the elevation model and aggregate statistics (mean, minimum, standard deviation, etc) are computed and appended to the catchment table. Satellite derived information can be used for hydrological parameterization too.

11.3 DEM HYDRO-PROCESSING EXAMPLES

It is not feasible, given the large number of spatial and tabular data sets that are created using this module, to show them all. Therefore the figures presented below show a selected number of results. Within the help function of the developed software the routines applied are described in detail.

A number of SRTM 1 by 1 degree tiles are imported and processed covering most of Rwanda. Figure 11.1 shows, from a subset, the results obtained when the lakes in the northern portion of the DEM are not considered and are modified using a filling operation. From the DEM it is apparent that the different geological setting warrants multiple flow accumulation thresholds and therefore the internal relief is reclassified into four threshold classes and subsequently used as an input for the drainage extraction. Based on a number of user specified outlet locations the catchments are merged and the drainage is extracted. These results can be validated using a satellite image as background. Relevant parameters given in the tables, such as centre of catchment, can be transformed into point maps and visualized. To find suitable outlet locations for catchment merging the Strahler or Shreve order merge can be performed first. Catchments are merged based on the drainage order selected; their outlets can be used for a user defined merge in a later stage ensuring that the catchments are of similar Strahler or Shreve magnitude.

Figure 11.2 demonstrates the added flow processing flexibility. Within the lake, an area that is undefined within the original elevation model, an artificial defined flow direction network is generated though the incorporation of a user defined set of digitized stream segments, the first point of the digitized segment(s) is regarded as the upstream location and the last point is the outlet location. For these added segments the flow direction map is adapted and the new drainage network extracted ensures a consistent (downstream) network and topology. Not all drainage lines identified during the default drainage extraction are extended; some only cover a very small portion of the lake basin drainage area. Furthermore the area draining directly into the lake can be extracted as well. This type of manual interference provides the user more flexibility for drainage network generation and catchment extraction. Given the fact that the DEM used has undefined values some of the attributes in the tables, especially those depending on DEM derived information, need manual adjustment.

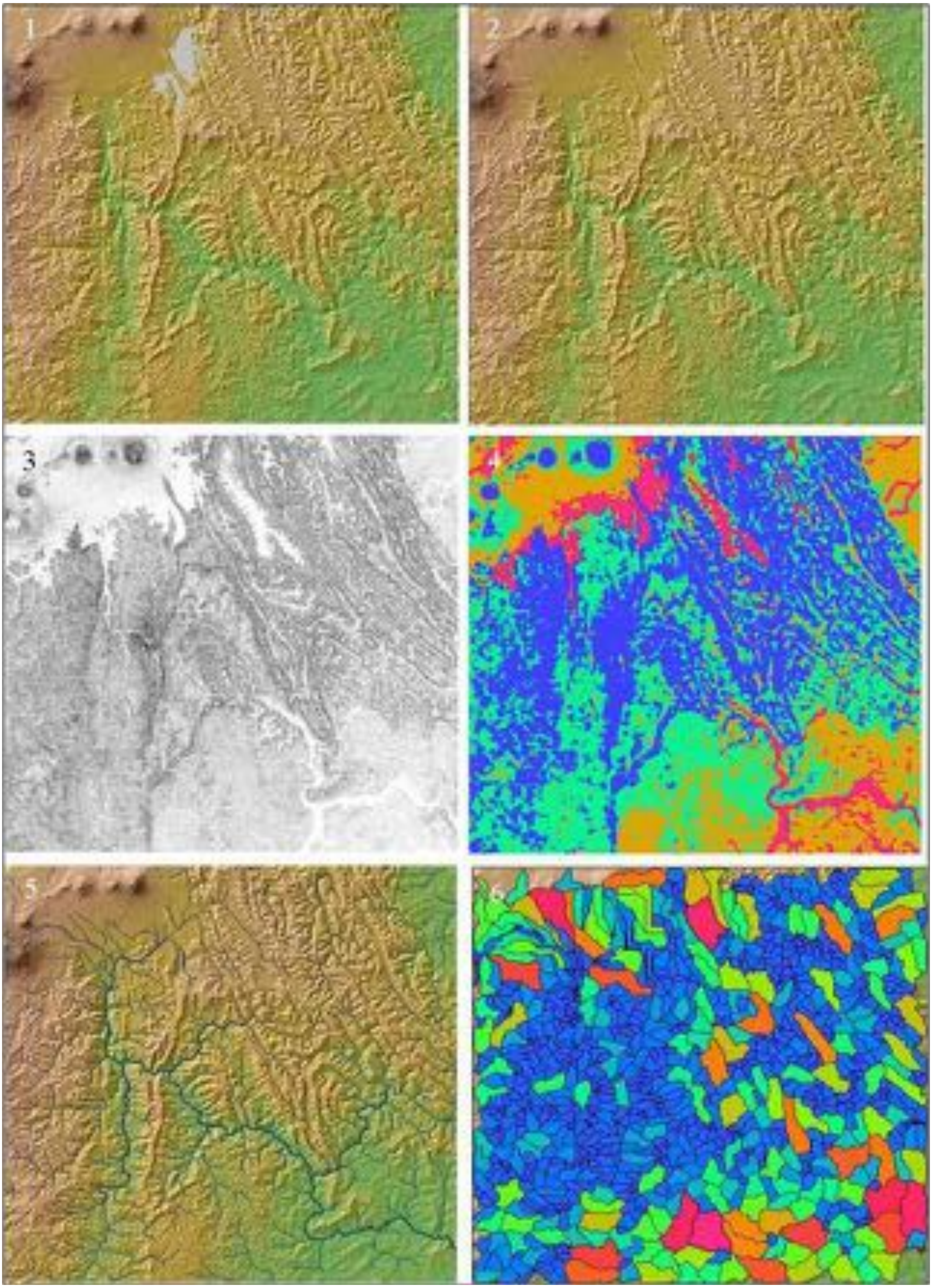

Figure 11.1 a: Hydro Processing using the SRTM DEM, example NW Rwanda

1: Original DEM (grey areas are data voids); 2: DEM obtained after kriging and internal depression filling;

3: Internal relief map (light = low internal relief / dark = high internal relief); 4: Reclassified flow accumulation threshold map; 5; Variable drainage network; 6: Associated catchment map (for 5 and 6: associated tables provide topological information and additional attributes);

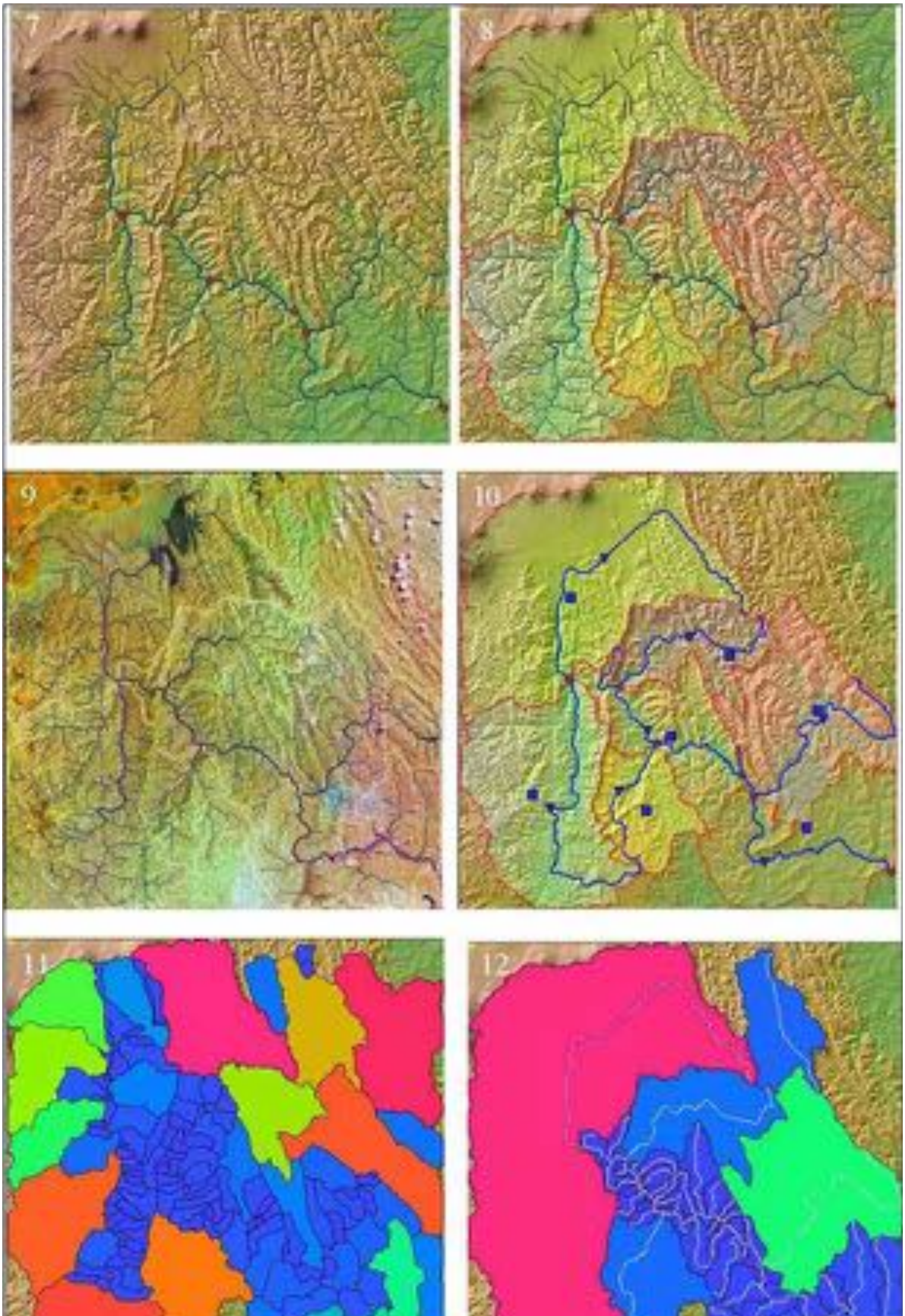

Figure 11.1 b: Hydro Processing using the SRTM DEM, example NW Rwanda

7: User defined outlet locations; 8: Extracted drainage network and merged catchments based on user defined outlet locations; 9: Validation of results using Landsat TM satellite image; 10: Longest flow path, centre of catchment according to bounding box and half of the flow path length; 11: Catchment merge till 3rd Strahler order; 12: Catchment merge till 4th Strahler order and longest flow path.

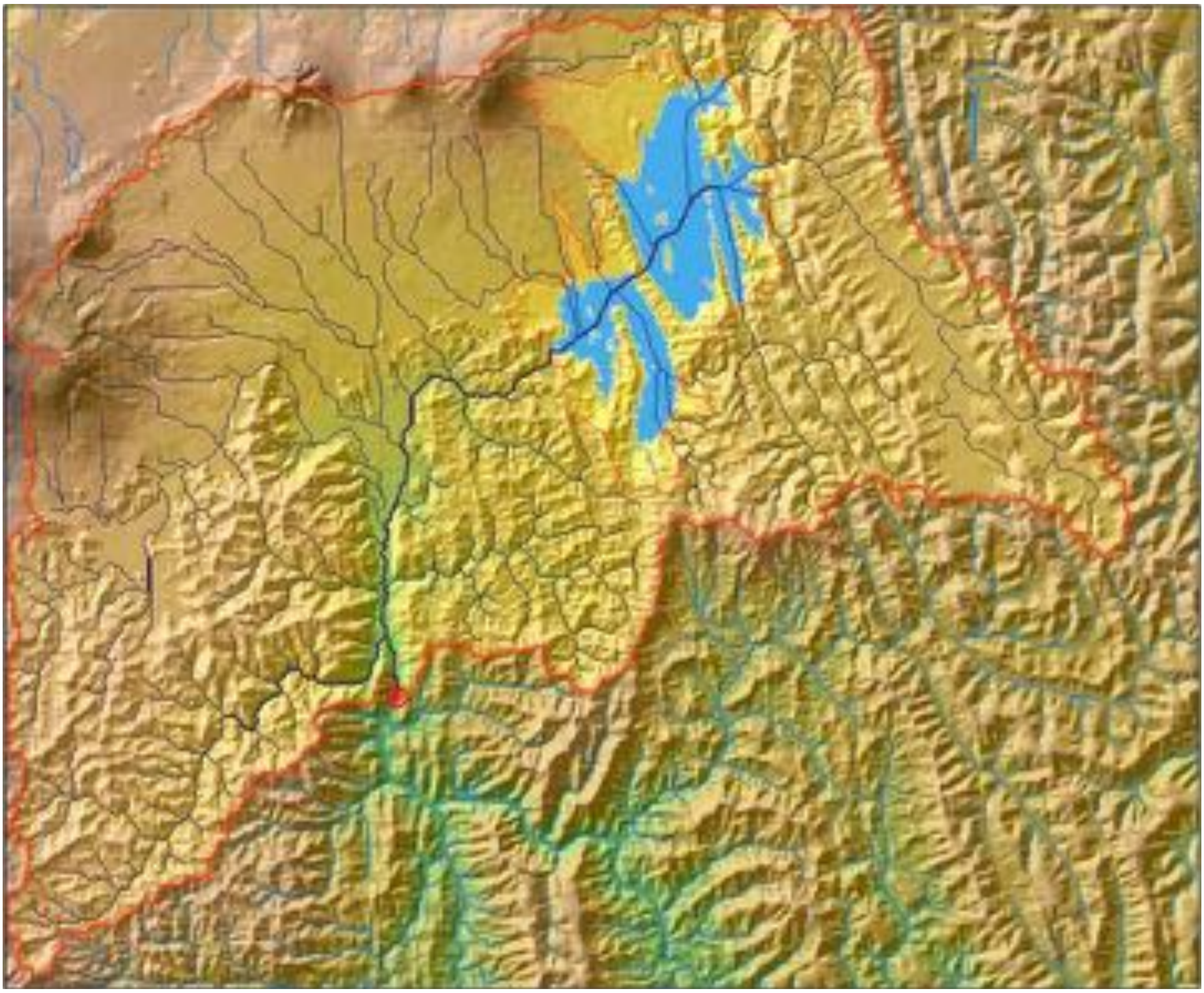

Figure 11.2: Manual flow adaptation through lakes

A number of SRTM 1 by 1 degree tiles are imported and processed covering most of Rwanda. Figure 11.1 shows, from a subset, the results obtained when the lakes in the northern portion of the DEM are not considered and are modified using a filling operation. From the DEM it is apparent that the different geological setting warrants multiple flow accumulation thresholds and therefore the internal relief is reclassified into four threshold classes and subsequently used as an input for the drainage extraction. Based on a number of user specified outlet locations the catchments are merged and the drainage is extracted. These results can be validated using a satellite image as background. Relevant parameters given in the tables, such as centre of catchment, can be transformed into point maps and visualized. To find suitable outlet locations for catchment merging the Strahler or Shreve order merge can be performed first. Catchments are merged based on the drainage order selected; their outlets can be used for a user defined merge in a later stage ensuring that the catchments are of similar Strahler or Shreve magnitude.

Figure 11.2 demonstrates the added flow processing flexibility. Within the lake, an area that is undefined within the original elevation model, an artificial defined flow direction network is generated though the incorporation of a user defined set of digitized stream segments, the first point of the digitized segment(s) is regarded as the upstream location and the last point is the outlet location. For these added segments the flow direction map is adapted and the new drainage network extracted ensures a consistent (downstream) network and topology. Not all drainage lines identified during the default drainage extraction are extended; some only cover a very small portion of the lake basin drainage area. Furthermore the area draining directly into the lake can be extracted as well. This type of manual interference provides the user more flexibility for drainage network generation and catchment extraction. Given the fact that the DEM used has undefined values some of the attributes in the tables, especially those depending on DEM derived information, need manual adjustment.

Figure 11.4 is based on information derived from the produced tables and a number of attributes are used to produce for a small upstream catchment, using the SCS unit hydrograph approach, a storm hydrograph. This information can be directly used to define boundary conditions needed as input within other models.

11.4 CONCLUSION

The DEM hydro-processing module described is offering new features enhancing the flexibility to extract a full topologically based hydrologic network and relevant associated attributes. Through the use of multiple drainage thresholds, eventually verified using a satellite backdrop image, a realistic hydro-network can be produced. Through the added option of topological flow modification also hydrological more complex areas might be handled. Aggregation can be performed using Strahler or Shreve orders as well as through user defined outlet locations. The spatial and tabular data can be imported / exported to a number of common used data

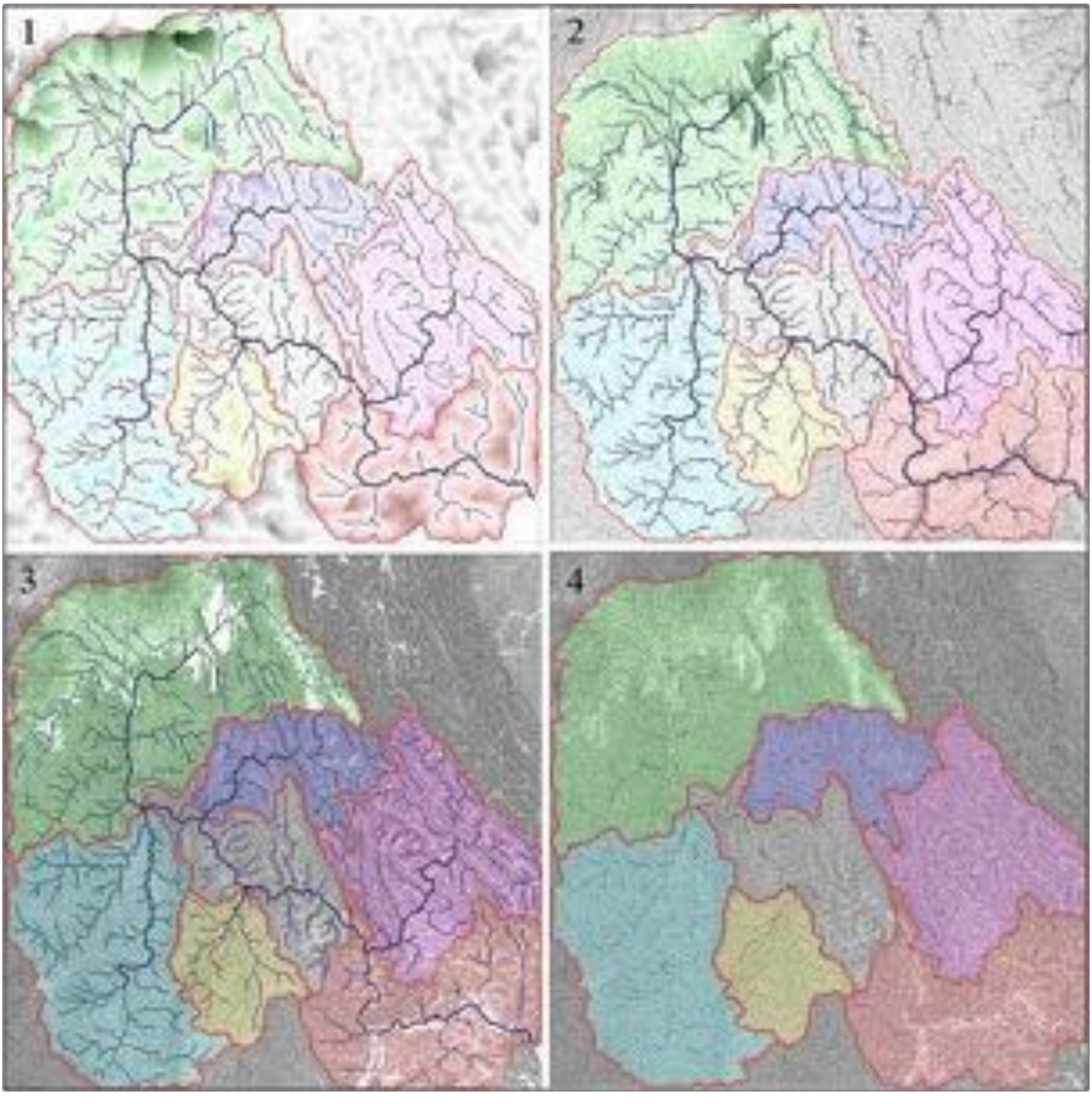

Figure 11.3: Compound DEM derived parameters

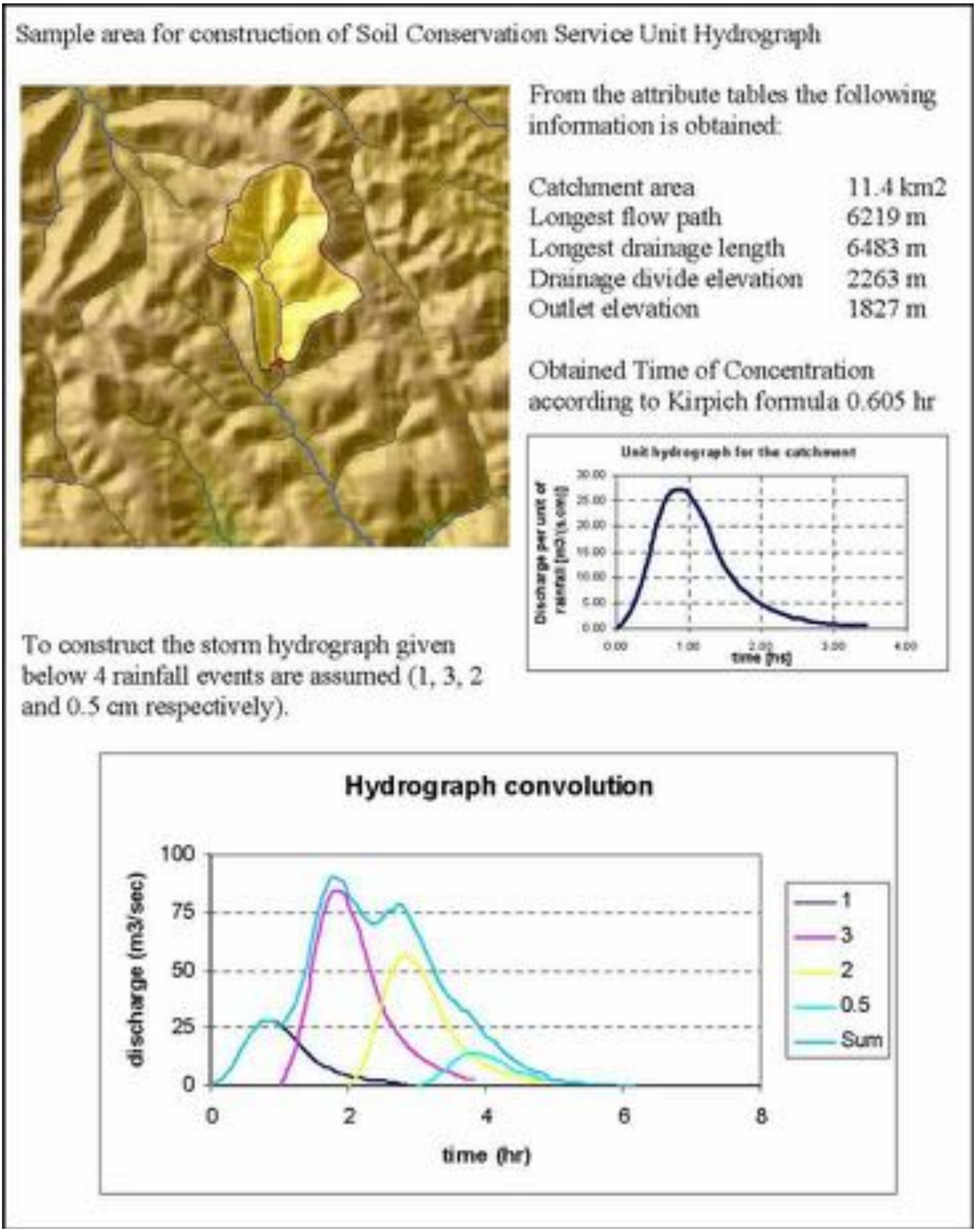

Figure 11.4: Hydro parameterisation for setting boundary conditions

formats facilitating easy parameterisation of hydrological models. As the SRTM DEM has a near global coverage the routine allows efficient hydro parameterisation for those areas as well. Distortions of the elevation model have to be corrected prior to the hydro-processing. Within the ILWIS package, one of the most common shortcomings, the data voids, can be handled. Next to this, relevant land cover related elevation uncertainties can be adapted using elevation correction factors based on classified satellite image land cover maps. The pre-processed elevation model can then be used as input for the hydro-processing module.

Although some of the routines implemented are computational intensive, great effort was made to efficiently use available resources to ensure shortest possible processing time, but the fill-sink operation and the drainage network ordering routine still take some time.

11.5 REFERENCES AND SUGGESTED READINGS

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Internet-references: Arc Hydrotools, Hec-GeoHMS, Rivertools, TauDem

Arc Hydrotools: http://www.crwr.utexas.edu/gis/archydrobook/ArcHydroTools/Tools.htm

Hec-Geo-HMS: http://www.hec.usace.army.mil/software/hec-geohms/

Rivertools; http://rivix.com/intro.htm

TauDem: http://hydrology.usu.edu/taudem/taudem5.0/index.html


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Chapter 12

Hydrologic Data from Earth Observation Systems: A Tutorial

Learning Objectives

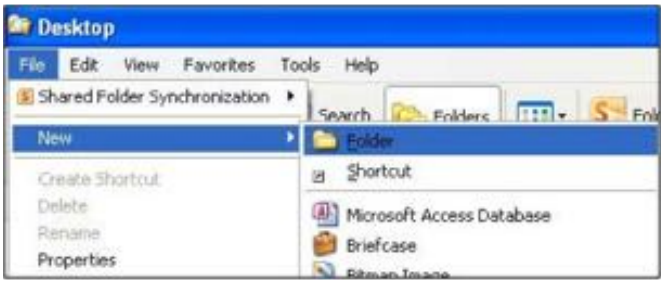
- To enable the users to access and use the wide variety of earth observation tools that provide hydrological data and apply them to integrated water resource management.
- The tutorial will direct users in locating, downloading the data and importing the data into the relevant software. Data categories include Rainfall, Digital Elevation Models, Global Land Cover and Soil Moisture.

GO BACK TO TABLE OF CONTENTS

12.1 DATA PREPARATION

Files will be created and stored in an EO_Tools folder. Here are the steps for creating said folder:

1. Right click on Start' and select 'Explore'
2. Click on 'Desktop'
3. On the menu bar at the top of the window click File | New | Folder
4. Name the folder EO_Tools
5. All instructions are for Mozilla Firefox web browser and ArcGIS 10.1. Users with alternative browsers or ArcGIS versions might encounter small differences.

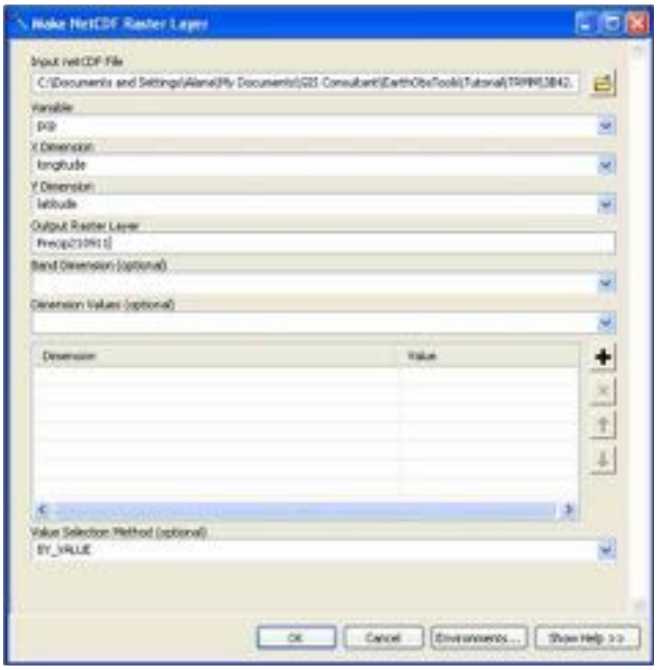


12.2 PRECIPITATION DATA

Precipitation data is available global for most countries. However collected measurements are not uniformly distributed globally with the tropics being woefully underrepresented. The launch of TRMM – Tropical Rainfall Measuring Mission serves to fill this gap by measuring the minute amounts of microwave energy emitted by the Earth and its atmosphere to quantify the water vapor, the cloud water, and the rainfall intensity in the atmosphere. TRMM provides data on a global 0.25° x 0.25° grid over the latitude band 50° N-S. These are the steps to accessing and using TRMM data. For this tutorial we will be downloading TRMM product 3B42: 3-Hour 0.25 x 0.25 degree merged TRMM and other satellite estimates.

1. Open ArcMap by clicking on Start | All Programs |ArcGIS | ArcMap
2. N.B. You cannot add a NetCDF file to ArcMap by clicking the Add Data button
3. Open the ArcToolbox Window if it's not already open by click on the Toolbox icon on the top centre window
4. Click on Multidimension Tools
5. Double click on 'Make NetCDF Raster Layer' to open the tool window

6. Under 'Input NetCDF File' click on the browse button and navigate to EO_Tools folder and click on the '3B42_daily.2011.12.03.7.nc' file
7. Click the 'Variable' drop down arrow and select 'r'
8. Leave 'lon' and 'lat' in the X and Y Dimension boxes
9. In the 'Output Raster Layer' box type in 'R03122011'
10. Click OK



11. Though the TRMM layer is displayed it is not a permanent layer until exported.

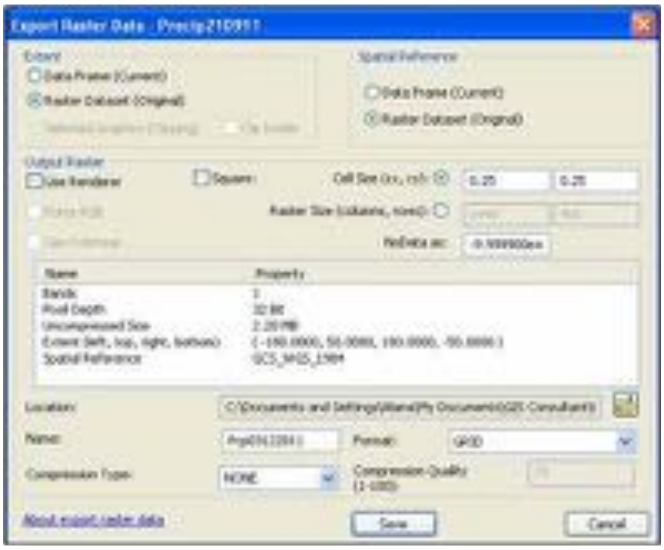
12. In the Layers panel right click on the TRMM layer and select Data | Export Data

13. Under 'Location' click on the Browse icon and direct it to the EO_Tools folder. N.B. you are NOT naming the file here. You are just selecting the EO_Tools folder

14. Under 'Name' type TRMM03122011

15. Under 'Format' select GRID

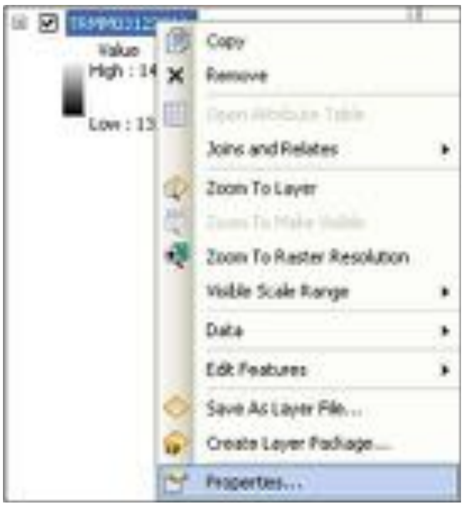
16. Click Save



17. When asked "Do you want to add layer to the map" click YES to verify that the data was created correctly.

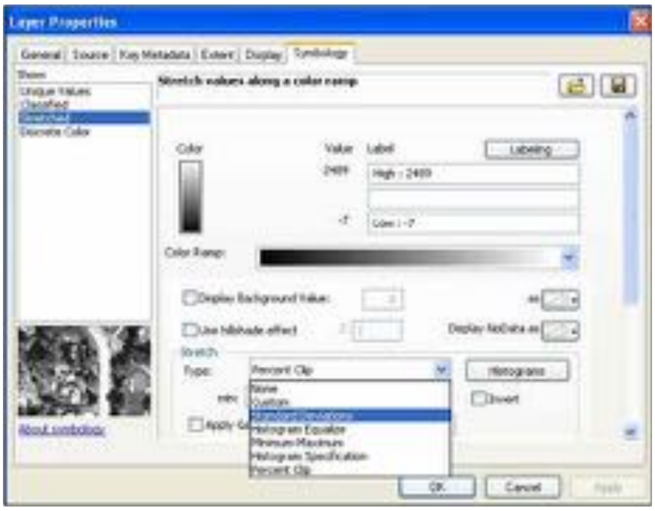
18. Once verified, right click on the 'Pcp03122011' file and delete it

19. Right-click on the TRMM03122001 layer and selected 'Properties'



20. Click on 'Symbology'

21. Ensure that under 'Stretch' section, 'Standard Deviation' is selected and n: 2.5



22. Remaining in the Layer Properties window, click on the drop arrow under 'Color Ramp' and select the elevation colour scheme. The names of each colour scheme can be viewed by right-clicking on the Color Ramp box and unchecking 'Graphic View'

23. Select Spectrum-Full Bright

24. Click 'Invert'

25. Click OK

26. Before adding the world map to the map you need to set the projection for the file

27. Open ArcCatalog by clicking Start | All Programs | ArcGIS | ArcCatalog

28. Click on the 'Connect to Folder' button

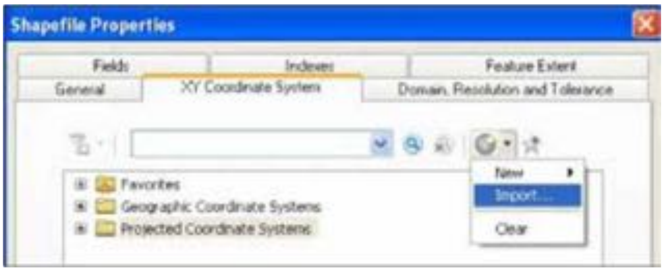
29. Navigate to the EO_Tools folder and Click OK.

30. The files and folders within the EO_Tools folder should now be visible.

31. Right-click on the 'World' shapefile.

32. Click on 'Properties' and then on XY Coordinate System

33. To ensure compatibility between the World shapefile and the NetCDF file we will assign the same projection to them both



34. Click on the drop arrow next to the 'Add Coordinate System' globe icon and click 'Import'

35. Navigate to the EO_Tools folder and click on the TRMM03122001 file and click 'ADD'

36. Click OK

37. You can now add this world map to the TRMM data.

38. Maximize the TRMM ArcMap window 

39. Click on the 'Add Data' button

40. Navigate to the EO_Tools folder and click on the 'World' shapefile

41. On the Layers window to the left, right-click on the 'world' layer name and select 'Properties'

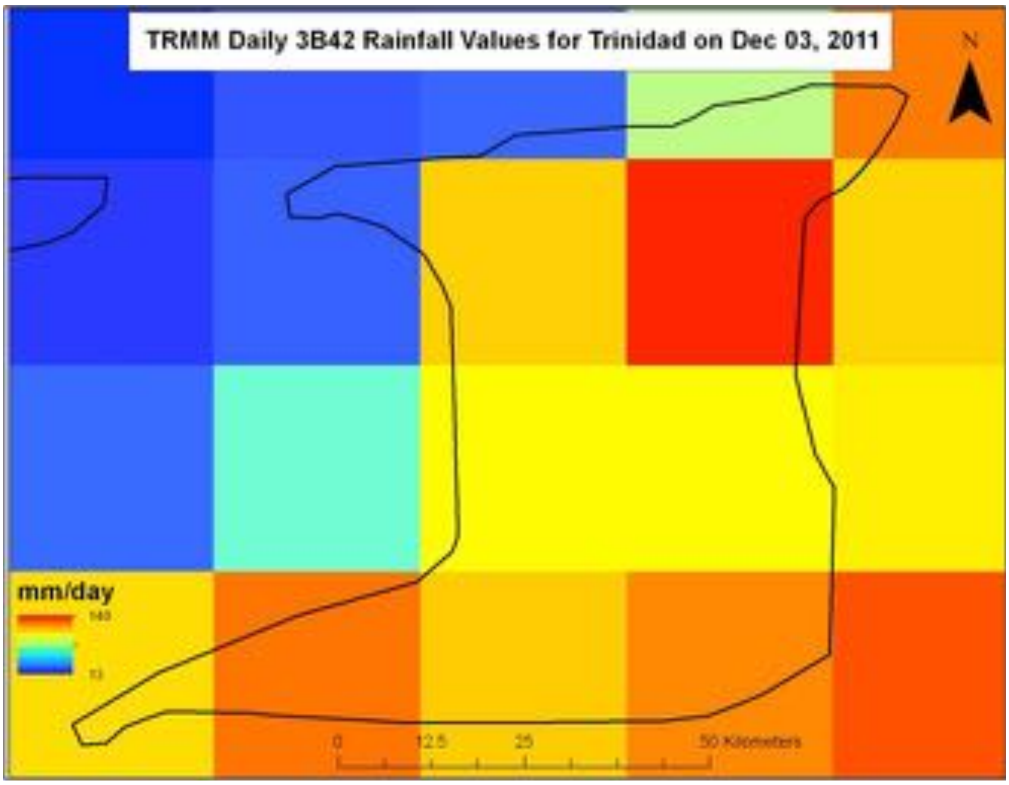
42. Under 'Symbol' click on the coloured square and select 'Hollow'

43. Click 'Ok'

44. The World shapefile is now added above the TRMM data layer. Note that the TRMM data does not cover the entire globe.

45. Zoom in to Trinidad

46. If wanted, the north arrow, legend and scale bar can be added by clicking Insert from the main menu



12.3 ELEVATION DATA

Elevation data are fundamental in understanding the hydrology of any region. It allows for watershed delineation, flow modeling, disaster planning and a host of other water resource management functions. Historically elevation measurements were painstakingly by surveyors using benchmarks and triangulation but with the rise of earth observation satellites, global elevation data are now freely available allowing for hydrological analysis of even the most remote areas .For this tutorial we shall detail how to source, download and display Digital Elevation data for Trinidad.

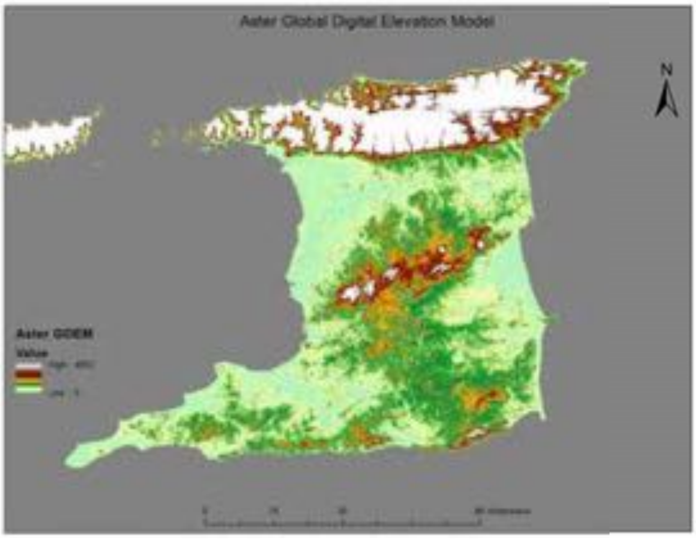
12.3.1 SRTM DEM

1. Click Start | All Programs |ArcGIS |ArcMap
2. Click on the Add Data icon
3. Under 'Look In' use the drop arrow to find the EO_ Tools folder, click on 'srtm_24_10.tif' and click 'Add'
4. The DEM for the entire tile is displayed in grey-scale and without any visual stretch
5. To improve visual analysis, in the 'Table of Contents' window right click on 'srtm_24_10.tif' and then click on Properties.

6. Ensure that the 'Symbology' tab at the top of the window is selected.
7. Under 'Stretch' click on the drop arrow and select 'Standard Deviation' from the list.
8. Ensure that '2.5' is written in the 'n:' box

9. Remaining in the Layer Properties window, click on the drop arrow under 'Color Ramp' and select the elevation colour scheme. The names of each colour scheme can be viewed by right-clicking on the Color Ramp box and unchecking 'Graphic View' 10. U s e the Zoom In button to select and zoom into Trinidad

10. Users familiar with ArcGIS might wish to clip the SRTM DEM file but this is not mandatory



12.3.2 HydroSHEDS

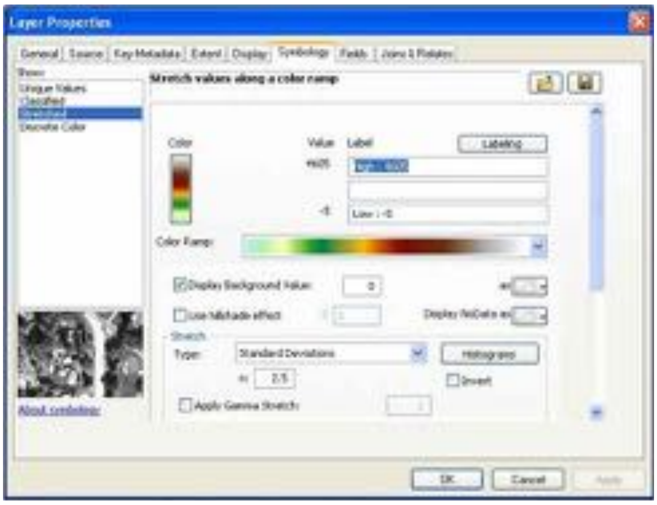
There are several products available from the USGS HydroSHEDS website including river networks, watershed boundaries, drainage directions, and flow accumulations. For this tutorial we shall use the Drainage Directions map for Trinidad.

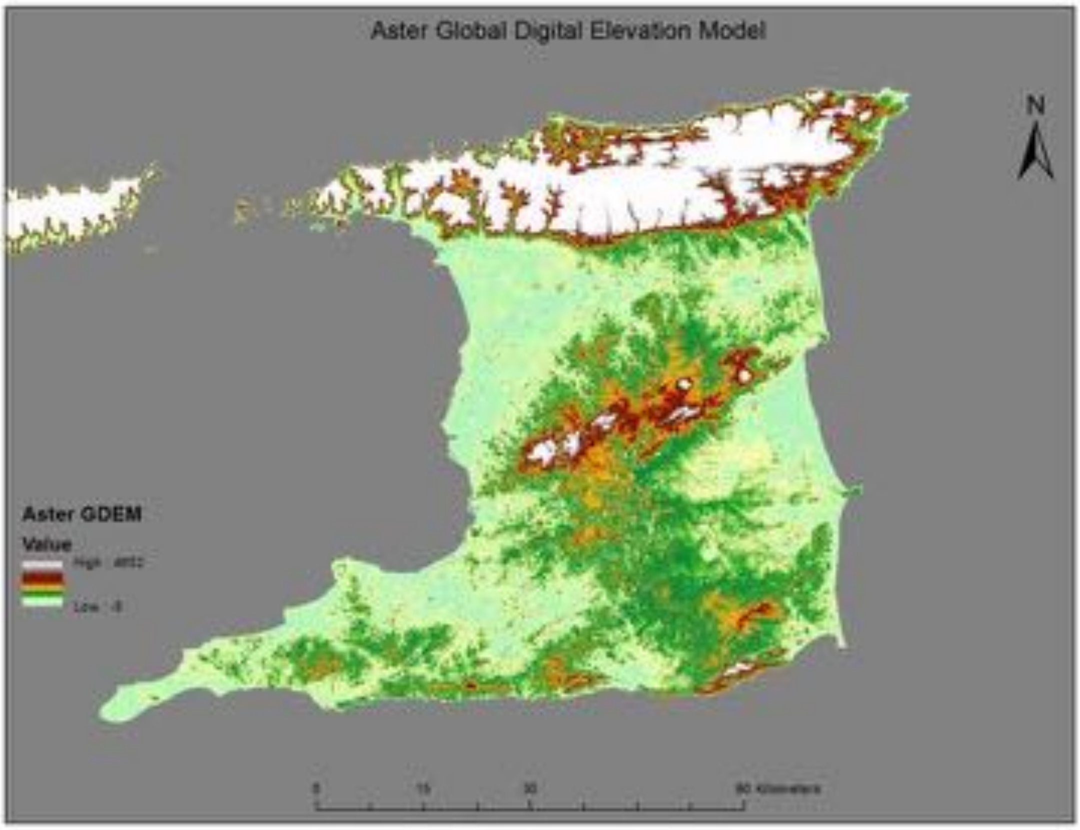
1. Open ArcMap by using Start | All Programs | ArcGIS | ArcMap
2. Click on Add Data 
3. Navigate to the EO_Tools folder and click on the N10W065_dir file
4. Use the Zoom In to zoom to Trinidad 

12.3.3 ASTER GDEM

The Advanced Spaceborne Thermal Emission and reflection Radiometer (ASTER) provides high-resolution images of the Earth in 15 different bands. On 29 June 2009, the Global Digital Elevation Model (GDEM) was released to the public, becoming the most complete mapping of the earth ever made, surpassing SRTM's extent and covering from 83°N to 83°S. Unlike SRTM's 90 m global resolution ASTER offers 30 m resolution worldwide as well as seamless scene download. These are the steps for downloading and displaying ASTER data:

1. Open ArcMap by clicking on Start | All Programs | ArcGIS | ArcMap
2. Click on the Add data icon and navigate to the EO_ Tools folder
3. Click on the Aster TIFF file '20121019083417_1771568388.tif'
4. Under "Table of Contents" right click on the file name and select "Properties"
5. Click on "Symbology" and under "Stretch" select "Standard Deviations" and ensure 2.5 is listed under "n"
6. Under the Color Ramp select the Elevation colour ramp
7. Click "Ok"
8. Save and close ArcMap





12.4 LAND COVER

The Global Land Cover Facility, funded by NASA and hosted by the University of Maryland provides a central location for the access of land cover data from a variety of satellite. We will be using it to access MODIS, AVHRR and Landsat data for this tutorial.

12.4.1 MODIS

In addition to supplying individual scenes, MODIS (Moderate-resolution Imaging Spectroradiometer) is also used to create a variety of land cover layers. For this tutorial we will download and display the MODIS Continuous Vegetation Cover which exist in three formats – bare, herbaceous and trees and add up to 100% of any land surface. The three layers can also be used in a multiple-band image or they can be displayed individually as done here.

1. To display the file in ArcMap first the projection must be set in ArcCatolog

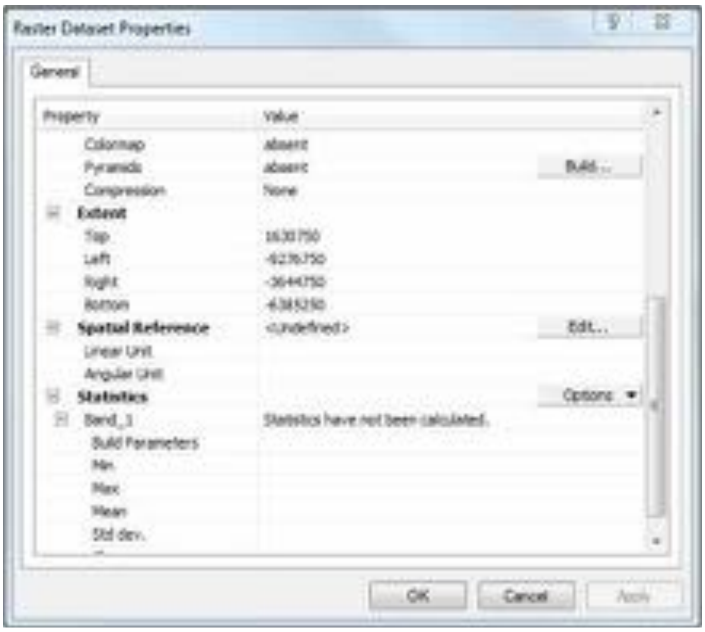
2. Open ArcCatalogby clicking on Start | All Programs | ArcGIS | ArcCatalog

3. To connect the EO_Tools folder click on the 'Connect Folder' icon

4. Navigate to theEO_Tools folder and click 'OK'

5. All the files in the EO_Tools folder are now visible. Right-click on the "Goodes.SA.2001.Tree" file and click on 'Properties'

6. Under the "Spatial Reference" click on "Edit

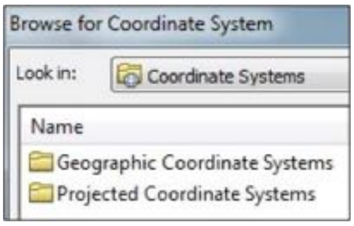


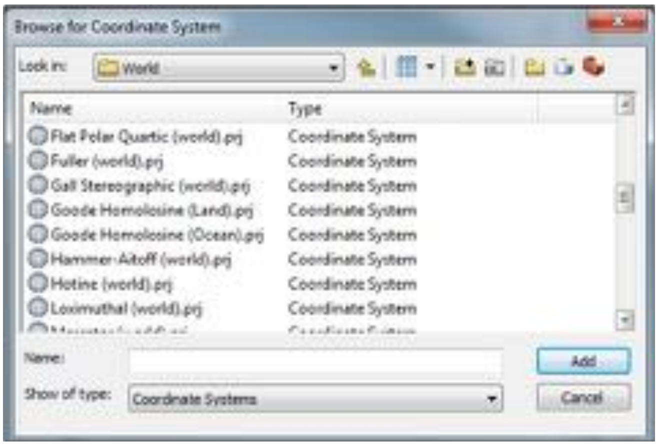
7. The projection for this file is given in the name and is 'Goode'. In the Spatial Reference Properties window click on "Select"

8. Double click on Projected Coordinate Systems

9. Scroll down and double click on "World"

10. Scroll down and click on "Goode Homolosine (Land) projection





11. Click Add

12. Close ArcCatalog

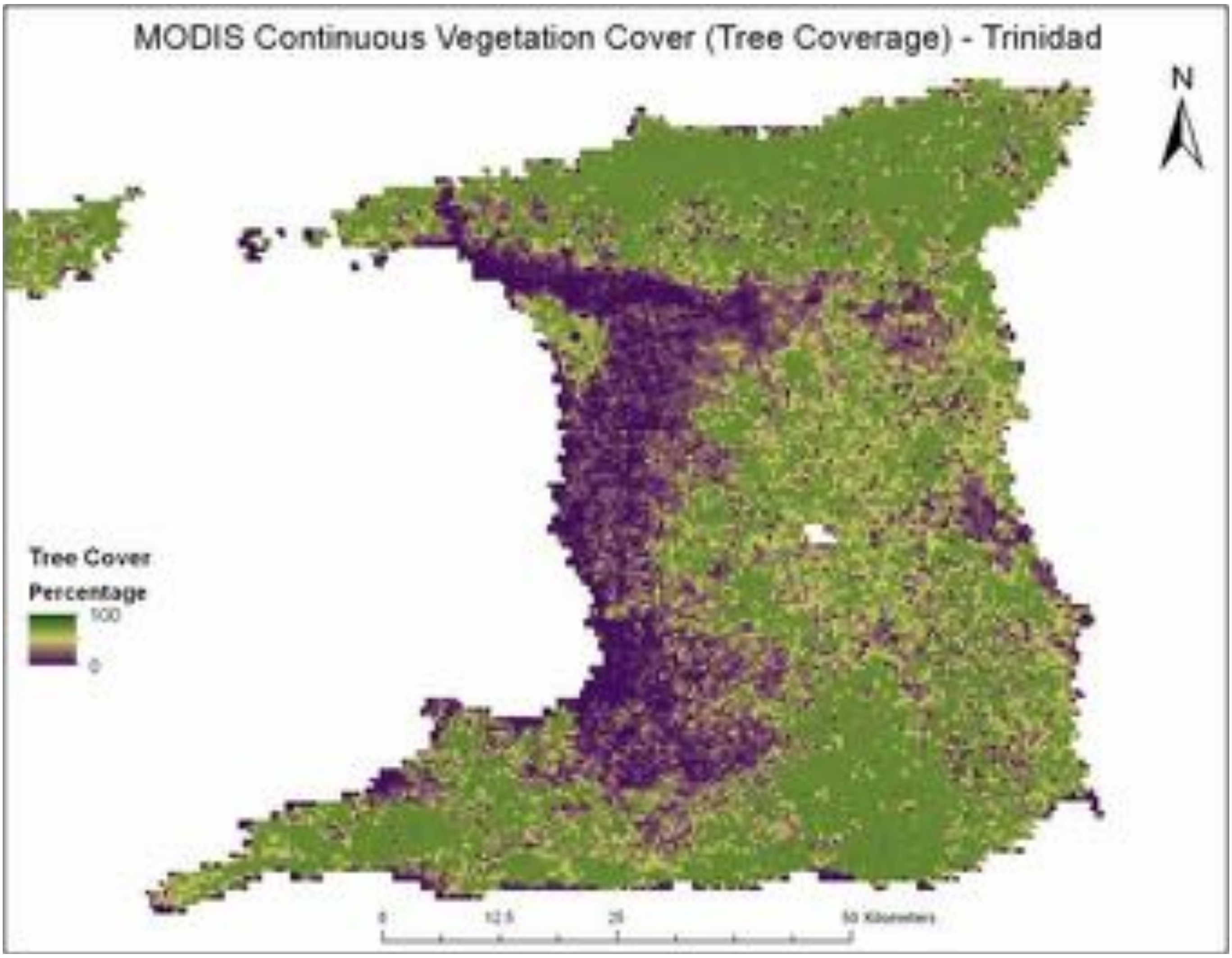
13. Open ArcMap by clicking on Start | All Programs | ArcGIS | ArcMap

14. Add the TIFF file by clicking on the Add Data icon and navigating to the EO_Tools folder

15. Zoom in to Trinidad

16. Right-click on the file name on "Layers" and select "Properties"

17. Click on Symbology and Select the Green-Purple colour ramp and click OK


MODIS Continuous Vegetation Cover (Tree Coverage) - Trinidad
N
Tree Cover
Percentage
100
0
0
12.5
25
50 Kilometers


AVHRR 1km resolution Land Cover - Trinidad
N
0
12.5
25
50 km

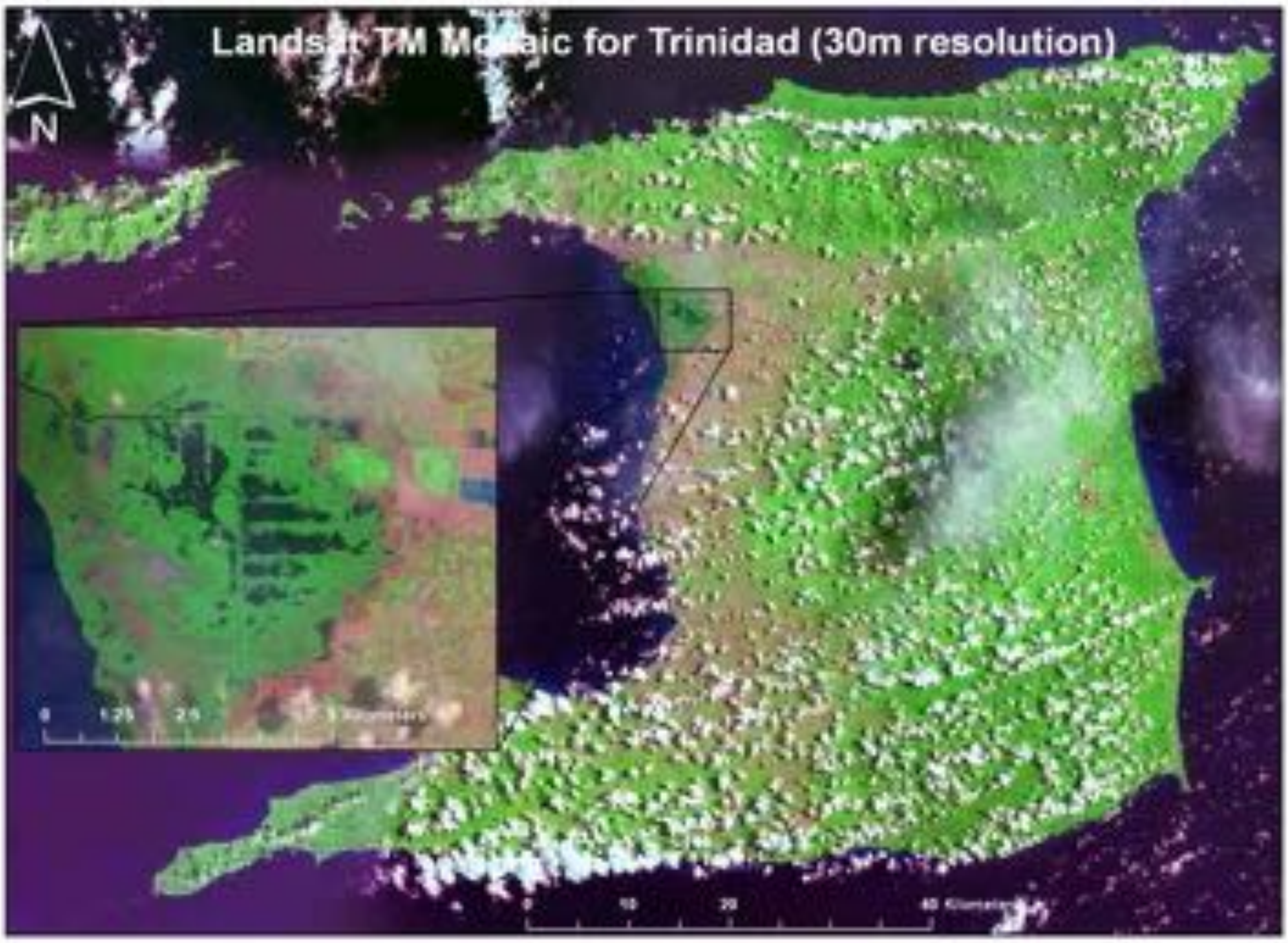
12.4.2 AVHRR

The Advanced Very High Resolution Radiometer (AVHRR) is used to produce a global land cover map for the globe that's classified into 14 classes. In this tutorial we will cover the directions on downloading and displaying this map for the island of Trinidad (previous page)

1. Open ArcMap by clicking Start | All Programs | ArcGIS | ArcMap
2. Click on 'Add Data' and navigate to the EO_Tools folder
3. Click on the AVHRR_1km_LANDCOVER_1981_1994.GLOBAL.tif file
4. Use the recommended USGS colour scheme for land cover as a guide for the colour of each category http://www.shadedrelief.com/shelton/c.html

12.4.3 Landsat

1. Open ArcMap by clicking Start | All Programs | ArcGIS | ArcMap
2. Click on the "Add Data" icon and navigate to the EO_Tools folder and add the N-20_10_loc.tif file
3. Use the Zoom icon to zoom in to Trinidad 



12.5 Soil Moisture

For this section of the tutorial we will demonstrate how to source, download and display data from the Essential Climate Variable: Soil Moisture database. Soil moisture data is also available from the Soil Moisture and Ocean Salinity (SMOS) satellite but interested parties must first submit a proposal before being given access.

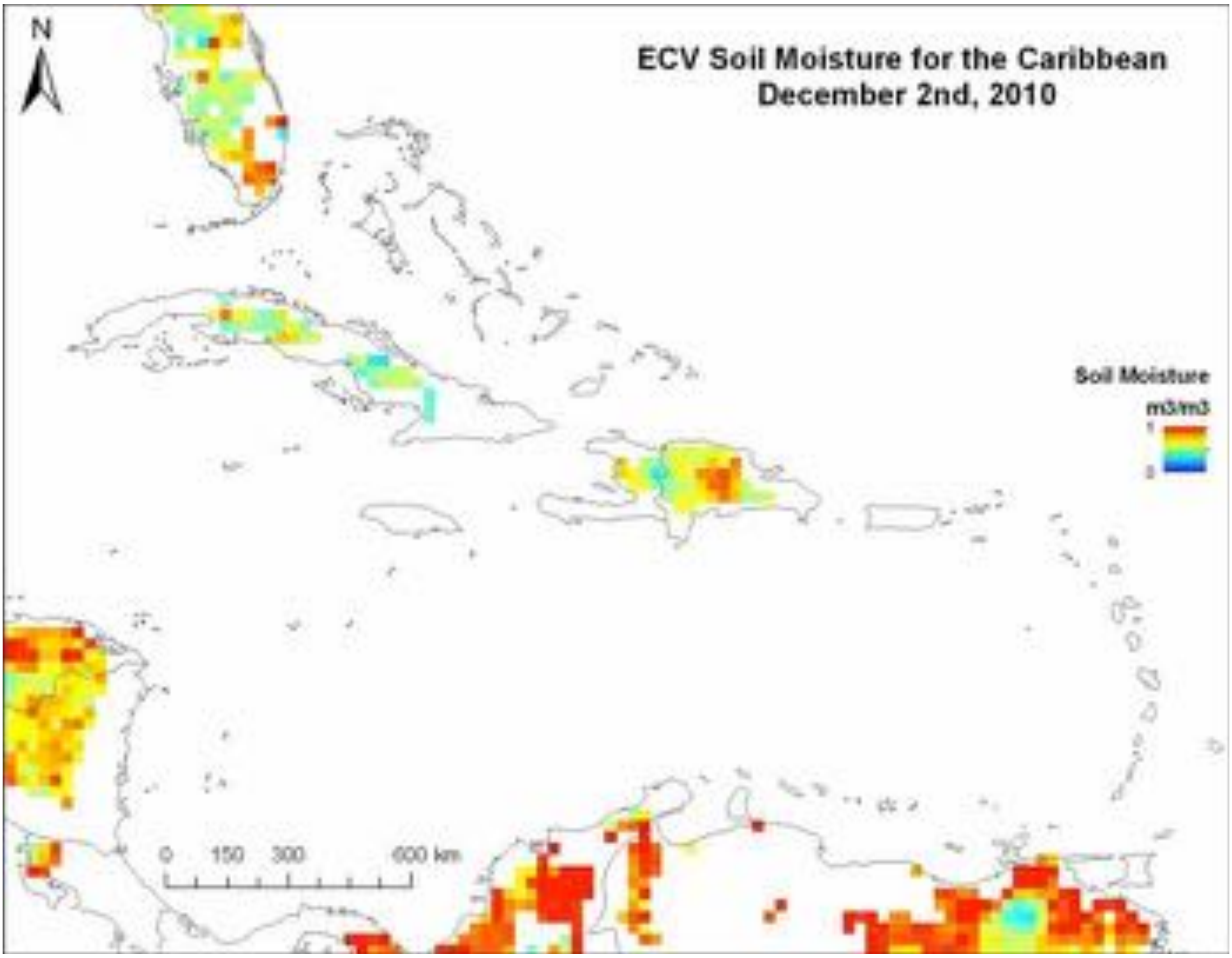
1. Open ArcMap by clicking Start | All Programs | ArcGIS | ArcMap

2. N.B. You cannot add a NetCDF file to ArcMap by clicking the Add Data button

3. Open the ArcToolbox Window if it's not already open by click on the Toolbox icon on the top centre window

4. Click on Multidimension Tools

5. Double click on 'Make NetCDF Raster Layer' to open the tool window



6. Under 'Input NetCDF File' click on the browse button, navigate to the EO_Tools folder and click on the ESACCI-L3S_SOILMOISTURE-SSMV-MERGED-20101202000000-fv00.1.nc file

7. Leave the defaults for Variable, X and Y dimension

8. Under Output Raster Layer type SM20101202

9. Click OK

10. Click on the Add Data icon

11. Navigate to the EO_Tools folder

12. Click and on the World shapefile

13. Click Add

14. On the Layers window to the left, right-click on the 'world' layer name and select 'Properties'

15. Under 'Symbol' click on the coloured square and select 'Hollow'

16. Click 'Ok'

17. Zoom in to Trinidad

18. Note that there is no soil moisture data available for Trinidad.

19. Zoom out to the Caribbean. The larger islands have some data. Areas with dense vegetation, strong topography, ice cover, extreme desert or large fractional coverage of water are typically unavailable in soil moisture datasets.

12.6 APPENDIX - DATA DOWNLOAD INSTRUCTIONS

12.6.1 Precipitation data (TRMM)

1. Go to the NASA Mirador website: http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=TRMM&dataGroup=Gridded&CGISESSID=568b0eec5ca9c160d7eced94a3fc50be

2. Scroll down to the bottom of the Gridded data products list and click on “TRMM 3B42 daily.007

3. On the year/month calendar select December 2011

4. On the month/date calendar select the 03rd

6. Click ‘Save’

7. Navigate to the EO_Tools folder and click ‘Save’

To effectively view the data a shapefile of the world is needed as an overlay.

1. Go to http://aprsworld.net/gisdata/world/

2. Click on the world.zip link

3. Navigate to the EO_Tools folder and click ‘Save’

4. This downloads a zipped file which requires a decompression program such as WinRAR (http://download.cnet.com/WinRAR-32-bit/3000-2250_4-10007677.html).

5. Navigate to the EO_Tools folder and double click on the 'World' zipped file to decompress it. This will automatically open WinRAR.

6. Click 'Extract To' and verify that the Destination Path leads to the EO_Tools folder.

7. Click Ok

8. Close WinRAR

9. Click on "Click here to begin Search" 

10. On the results page click on 'Data Download (HTTP)

11. The file will download as a zipped file that needs decompression software such as winzip or winrar to decompress.

12. Save and extract the file to the EO_Tools folder.

12.6.2 SRTM DEM

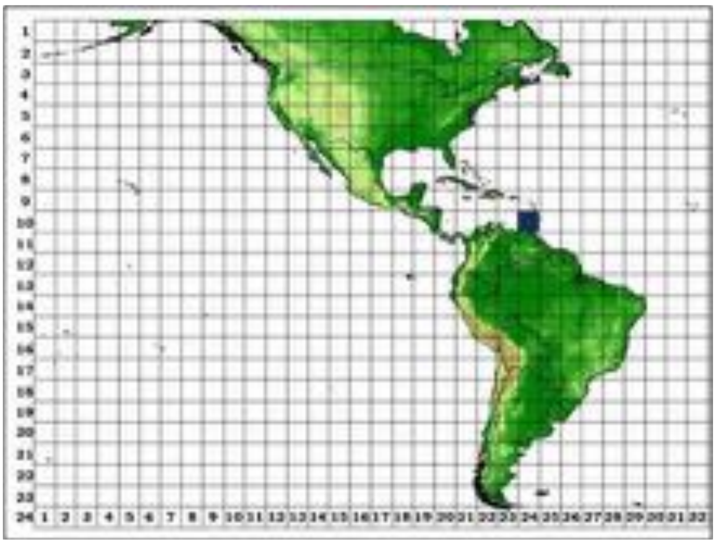
1. Go to the CGIAR SRTM download webpage http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp

2. For '1. Select Server' ensure 'CGIAR-CSI (USA)' is selected

3. For '2. Data selection method' ensure that 'Multiple Selection' is selected

4. For '3. Select File Format' select 'GeoTiff'.

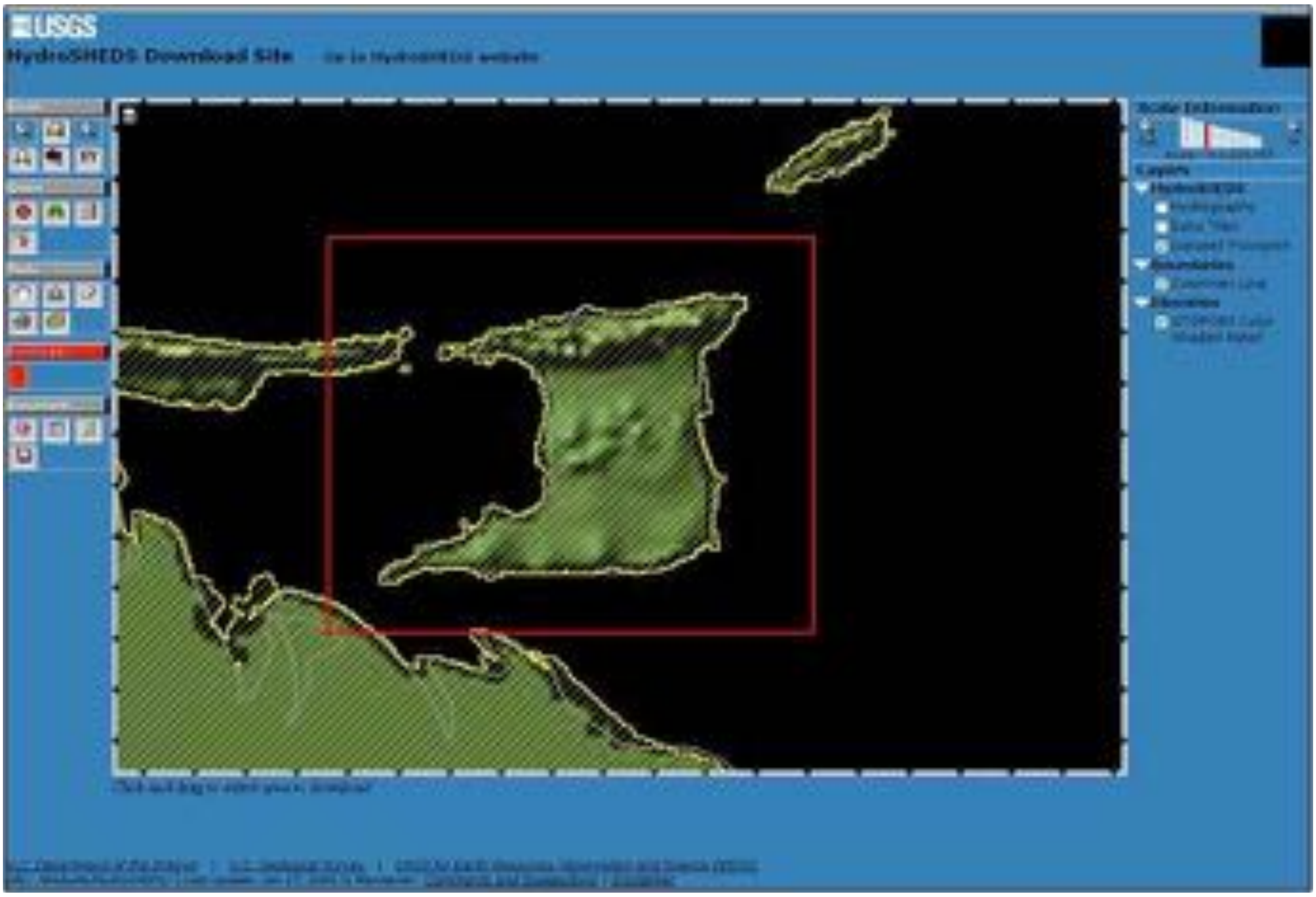
5. Click on the tile covering Trinidad. It will then be highlighted in dark blue



12.6.3 Hydrosheds

1. Go to the USGS HydroSHEDS download website: http://gisdata.usgs.gov/website/HydroSHEDS/
2. For greater detail than provided in this tutorial regarding the download site, users can click on “View User Instructions”
3. For the purposes of this tutorial, click on “Launch HydroSHEDS Download Site Viewer”
4. Use the “Zoom in” icon to zoom to Trinidad
5. Under ‘Downloads’ click on the red “Define Tiles Download Area” icon

6. Draw a rectangle around Trinidad. This immediately prompts the opening of a download page with the available data options



7. click on the checkbox next to n10w065_dir_grid
8. On the left, under “Available datasets”, click on “3sec GRID, Drainage Directions

9. At the bottom of the page click on “Retrieve Bundle” 10.

Files in bundle	Est. bundle Size (MB)	Start Download	Remove Bundle
n10w065_dir_grid	7	Retrieve Bundle	

10. Save the zipped file and then decompress and extract it using WinZip or WinRAR to the EO_Tools folder

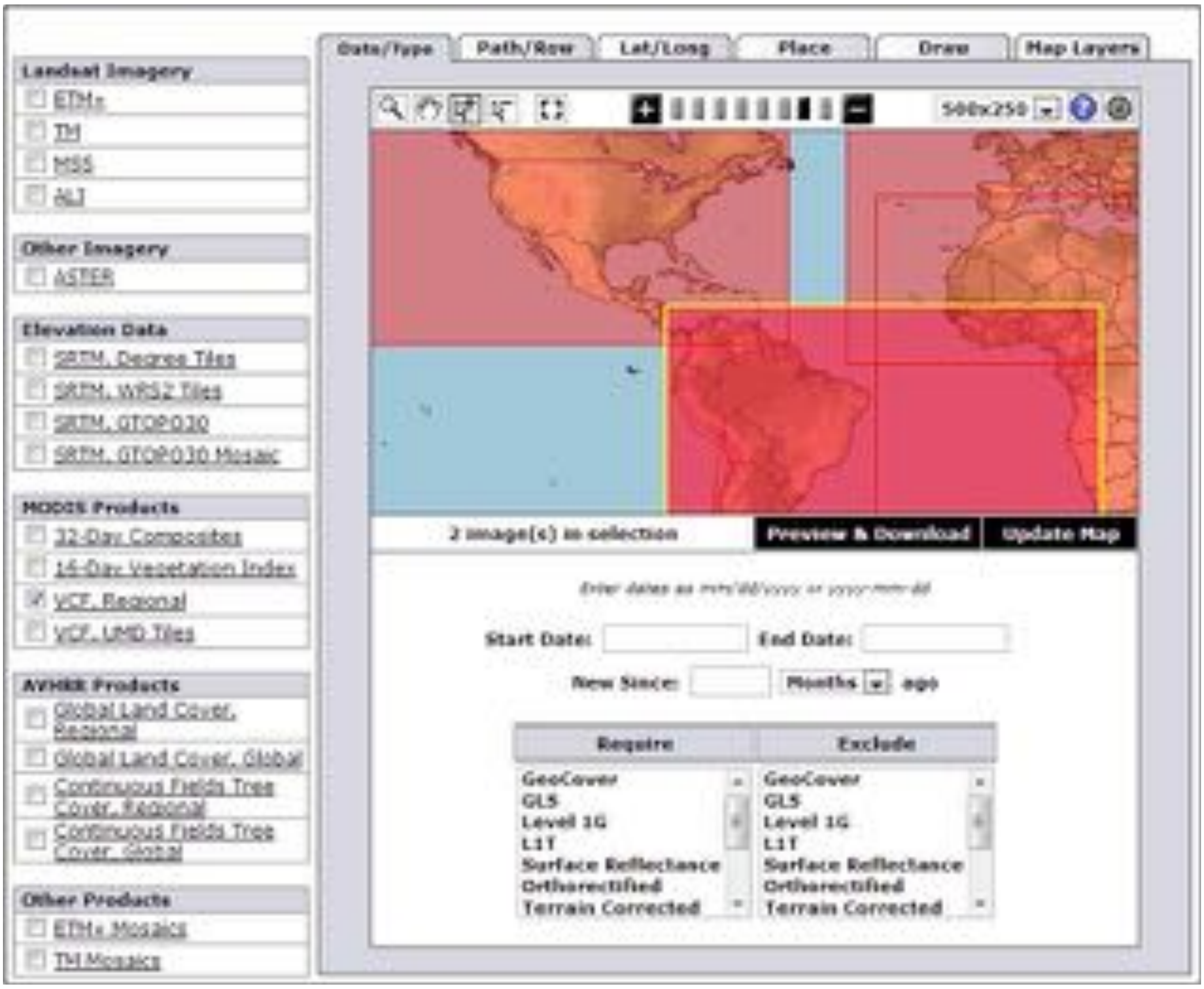
12.6.4 Aster GDEM

1. Go to the USGS Data Explorer site: http://gdex.cr.usgs.gov/gdex/
2. You must be logged in to download any data from the Data Explorer site so first create an account by clicking on “Sign In” and then on “Create an account”. N.B. When creating your account under “Receive order notifications” select “Always”
3. Use the Zoom In and Pan icons to zoom to Trinidad
4. Use the ‘Define Rectangle Area’ tool to select Trinidad
5. Click on the “Download Data for Defined Area” icon
6. In the Download box that opens, select “ASTER Global DEM V2” under “Product”

7. Ensure that “GeoTIFF” is selected under “Format”
8. Projection should be Lat/Lon
9. Enter your Research Area
10. Click “Submit”
11. On the Data Preview window click “Download”. Don’t be worried if the preview looks very dark, that will be addressed when we display the file in ArcMap
12. Select “Save File” and click “Ok”
13. 13. Navigate to the EO_Tools folder and click “Save”

12.6.5 MODIS

1. Go to the Global Land Cover Facility download site: http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp
2. Click on Map Search
3. N.B. The Vegetation Cover Fields are supplied by continent.
4. On the left side of the page under 'MODIS Products' click VCF Regional
5. Click on the 'Select' icon at the top of the Map window
6. Trinidad is contained within the South American continent scene so click on Trinidad and note that all of South America is highlighted
7. Click on "Preview and Download"



8. Click on the '028-060' file and then click 'Download'
9. Note that on the Download page you can download each layer individually or you can download the "AllFiles" zipped file
10. Click on "Goodes.SA.2001.Tree.tif.gz"
11. Navigate to the EO_Tools folder and click on "Save"
12. Use WinZip or WinRAR to decompress the file

12.6.6 AVHRR

1. Go to the download site at http://glcf.umiacs.umd.edu/data/landcover/
2. Click on 'Download via web page with links to FTP Server'
3. Click on 1 Kilometer pixel resolution, Geographic projection, GeoTIFF
4. Navigate to the EO_Tools folder and click "Save'
5. Use WinZip or WinRar to decompress the file


AVHRR Global Land Cover Classification

Global Coverage Data Sets

1 Degree pixel resolution	Geographic projection, binary (BSQ)
1 Degree pixel resolution	Geographic projection, GeoTIFF
8 Kilometer pixel resolution	Goodes projection, binary (BSQ)
8 Kilometer pixel resolution	Geographic projection, GeoTIFF
1 Kilometer pixel resolution	Goodes projection, binary (BSQ)
1 Kilometer pixel resolution	Geographic projection, GeoTIFF

12.6.7 Landsat

1. Go to the GLCF Data & Products website: http://glcf.umiacs.umd.edu/data/
2. Under "Products Derived from Satellite Imagery" click on "Landsat Mosaics"

3. On the Landsat GeoCover Mosaics page click on "Download via FTP Server"
4. Scroll down and click on N-20
5. Click on "79 N-20-10.Landsat_Mosaic-EarthSat-GeoTIFF"
6. Click on "N-20-10_loc.tif.gz". N.B. Due to the relatively high resolution of Landsat images (30m) the files are rather large and will take a while to download depending on your connection speed

7. Select “Save File” and click “Ok”

8. Navigate to the EO_Tools folder and click “Save”

9. Extract the file using WinRAR or WinZIP

12.6.8 Essential climate Variable: Soil Moisture

1. Download of Soil Moisture data from the ECV database requires free registration. Approval may take more than a day. Registration is done here: http://www.esa-soilmoisture-cci.org/dataregistration

2. Once registration is approved you will be sent an email with your account information and the ftp link for data download.

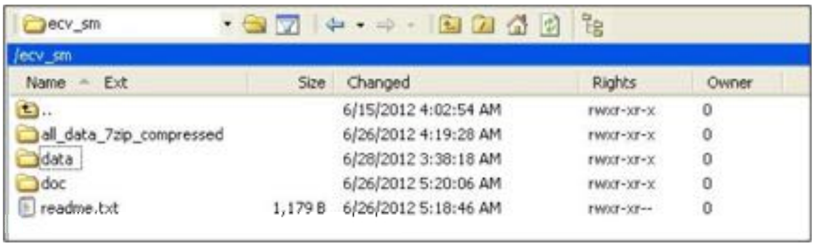
3. Access to the secured database can only be done using an SFTP software such as WinSCP. Go to http://winscp.net/eng/download.php#download2, download and install the software.

4. Open WinSCP by clicking Start | All Programs | WinSCP | WinSCP

5. Under ‘Session” click “New” and then enter the information given in the ECV SM Product: Access Confirmed email that you received

6. Click “Save” and then click “Login”

7. Once successfully logged in double-click on “Data” in the folder list



9. File names end with the year/month/day that they represent. You might need to expand the Name column to see the entire file name

10. Scroll down and right click on “ESACCI-L3S_SOILMOISTURE-SSMV-MERGED-20101202000000-fv00.1.nc”

11. Click “Copy”

12. Click “Browse” and navigate to the EO_Tools folder and click “Ok”

13. Click “Copy”

Chapter 13

Information Management

Learning Objectives

- To provide an appreciation of how information management supports effective water management in a river basin;
- To provide an understanding of the information management process and know some of the tools used in information management;
- To identify important information management outputs and how they are disseminated locally or regionally

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13.1 INTRODUCTION

Spaceship earth is a complex system of systems, and hence a global, coordinated, comprehensive and sustained system of earth observing systems providing access to all earth observation data in a standard interoperable format is crucial.

13.1.1 Information Management Process

- The first step is to decide on 'what' and 'how' to capture the desired information.
- There is a need to identify and decide on 'how' and 'where' to stored the captured information.
- To define and decide on the level of processing, methods and quality desired.
- To decide on the procedures and methods that will be used to retrieve the stored information.
- To decide on the frequency of updating and methods to be used to update in order to have most updated information.
- To decide on the level of security for each type of information.
- To decide on the type of information to be shared and methods for sharing
- Develop and implement the information management plan

13.1.2 Types of Information

Integrated water resources management requires the collection and manipulation of a wide range of datasets converting it into information which is required for management, planning and development. For a river basin organisation these include material on the biophysical environment of the basin focusing on each of the following subjects:

- Geography - focusing on the physical environment of the basin includng geomorphology, landcover and mineral reserves.
- Climate and weather - including principles of meteorology, climate specific to the basin and the concept of climate change.
- Hydrology - exploring the balance and use of water as well the water cycle, surface and groundwater in the region with specific focus on the basin.
- Water quality - providing an overview of the state of the waters of the basin and factors influencing this, impacts of human activities, mining and groudwater.
- Ecology and biodiversity - including aquatic ecology and ecosytems factors affecting them, wetlands and biodiversity.

Other information includes:

- History and water-related culture – providing the history of the people in the basin and their cultures – with a special focus on water. General concepts of indigenous traditional knowledge. Traditional stories provide authentic impressions of the cultures in the basin and their relationship to water.
- Socio-economics in the basin – providing an overview of relevant human development issues and indicators as well as socio-economic portraits of the basin.

The other information is related to resource management and includes:

- Water demand - including perspectives on demand management, regulation, major demand sectors, conservation and re-use;
- Water infrastructure - including bulk transfers, dams, small scale supply and groundwater, infrastructure for irrigation and development and maintenance;
- The value of water - including a discussion of economic valuation of water, an overview of virtual water, comments on the future outlook and environment costs; and
- Resource monitoring - including the importance of monitoring, existing monitoring infrastructure and programmes, information systems, data and information for decision-makers and a discussion of gaps in data and information necessary for integrated water resources management.
- Dams and infrastructure, rivers and streams

Box 13.1: The Orange-Senqu River Awareness Kit

The Orange-Senqu River Awareness Kit (Orange-Senqu RAK) is an on-line and DVD-ROM-based tool designed to support capacity development in ORASECOM and raise awareness for transboundary water issues in southern Africa. This central focal point for knowledge related to the Orange-Senqu River basin serves as a hub for information management and dissemination for ORASECOM. The structure of the Orange-Senqu RAK (themes and chapters) was defined through participatory processes involving stakeholders from all four basin states of the Orange-Senqu River basin.

13.2 SOURCES OF EO DATA AND INFORMATION

How does one go about obtaining EO data products for use? The answer depends on the type of EO data needed. For example ESRIN is a European Space Agency establishment located in Frascati, near Rome. This centre was created in 1966. One of its chief tasks consists of the utilisation of the telesurveying data obtained through the earth observation mission performed by ESA's own satellites and those of other countries through the Earthnet programme. To carry out this task, ESRIN operates ground infrastructures consisting of some 30 data reception stations scattered all over the world. Once the data have been obtained, they are processed and filed before distribution to the final users, which is effected partly on a commercial basis, thus also generating economic returns.

Most of the ESA earth observation datasets are available on the internet free of charge. Access is granted after user registration through the Earth observation principal investigator portal (http://eopi.esa.int/esa/esa) , which also provides the detailed content of the free datasets.

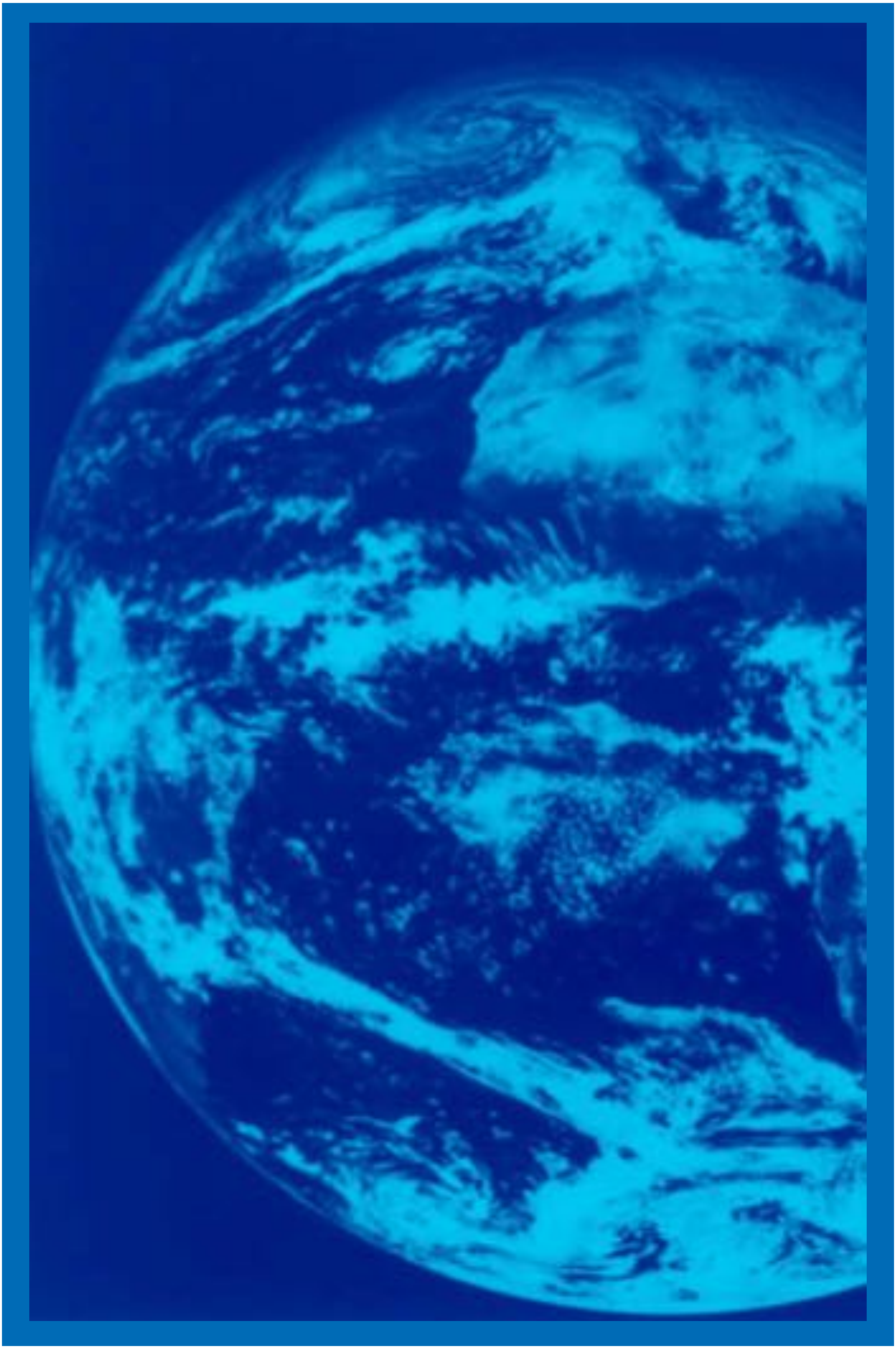
Some data products are generated only after specific user requests, as ESA may not have the capacity to generate all possible products systematically and make them all available online (e.g. SAR data). This group of datasets is called the 'restrained dataset', which is provided free of charge. Potential users must first provide a project proposal, allowing ESA to define a product/ programming quota.

The Multi-mission Earth Observation Portal (http://earth.esa.int/) functions as an authoritative one-stop access point for a wide variety of Earth observation resources. It features a directory to locate projects, services and datasets and provides direct access to satellite data as well as map servers and cartographic material.

Many of the users of remotely sensed data need the information during a crisis and therefore require "near-real time turnaround". Turnaround time is less demanding for those involved in hydrologic modelling, calibration/validation studies, damage assessment and planning.

13.3 A PLAN FOR REGIONAL AND LOCAL ADAPTATION

Guided discussion and presentation by participants on replication and adpatation of the training module on the use of EO as tool in IWRM at regional and local level. Participants are expected to devise a way forward based on the assessment of regional and local needs, identifying target groups, partners and anticipated impact of training interventions.



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