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Dilip Kumar
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Spatial Information Technology for Sustainable Development Goals

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The new agenda is a promise by leaders to all people everywhere. It is a universal, integrated and transformative vision for a better world. It is an agenda for people, to end poverty in all its forms. An agenda for the planet, our common home. An agenda for shared prosperity, peace and partnership. It conveys the urgency of climate action. It is rooted in gender equality and respect for the rights of all. Above all, it pledges to leave no one behind.

—UN Secretary-General BAN Ki-moon

Preface

The future of the planet and of life on Earth is explored in Rachel Carson's book *Silent Spring*, published in 1962, which begins with a 'fable for tomorrow', presenting the true story of the use of DDT that had caused damage to wildlife, birds, crops, agricultural livestock, domestic pets and even human beings. In 1968, Garrett Hardin published a paper titled 'The Tragedy of the Commons' which summarised the population problem, unrestricted use of resources and environmental pollution. The international NGO The Club of Rome, founded in 1967, has dedicated itself to the study of the 'world problematique'. The term describes political, social, cultural, environmental and technological problems from a global, multidisciplinary and long-term perspective. It attracts scientists, researchers, business people and heads of state from around the globe. In 1972, researchers from the Massachusetts Institute of Technology (MIT) presented a model, 'Limits to Growth', published under the auspices of The Club of Rome, which explained the ecological limits to economic and demographic growth. It was the result of mathematical simulations conducted on predictions of demographic and economic growth correlated with the exploitation of natural resources and forecasted up to 2100. They investigated five major trends of global concern, such as accelerating global industrialisation; rapid world-population growth; widespread malnutrition caused by poverty; dependence on non-renewable resources and their accelerated depletion; and the deteriorating environment. The MIT researchers concluded with three major points:

1. If the present growth trends in world population, industrialisation, pollution, food production and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on Earth are satisfied and each person has an equal opportunity to realise his or her individual human potential.
3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success.

The conclusions of 'Limits to Growth' were controversial, but the report contains a message of hope that 'Man can create a society in which he can live indefinitely on Earth if he imposes limits on himself and his production of material goods to achieve a state of global equilibrium with population and production in carefully selected balance.' This was the first movement toward a definition of the foundations of a development mode that we qualify today as sustainable.

In 1972, The United Nations Conference on the Human Environment took place in Stockholm, Sweden, which for the first time explored ecological issues of global concern. The conference concluded with a declaration of principles and an action plan to fight pollution. In 1984, the United Nations Assembly gave Gro Harlem Brundtland the mandate to form and head up the World Commission on Environment and Development. The commission's mandate was to recommend means to the international community to preserve the environment through improved cooperation between developing and developed nations, while considering existing relationships between peoples, resources, the environment and development. In 1987, the work of the World Commission on Environment and Development produced a report entitled 'Our Common Future', also known as the Brundtland Report. She wrote in the foreword to the Report:

> 'A global agenda for change'—this was what the World Commission on Environment and Development was asked to formulate. It was an urgent call by the General Assembly of the United Nations:
>
> - to propose long-term environmental strategies for achieving sustainable development by the year 2000 and beyond;
> - to recommend ways concern for the environment may be translated into greater cooperation among developing countries and between countries at different stages of economic and social development and that lead to the achievement of common and mutually supportive objectives that take account of the interrelationships between people, resources, environment and development;
> - to consider ways and means by which the international community can deal more effectively with environment concerns and
> - to help in defining shared perceptions of long-term environmental issues and the appropriate efforts needed to deal successfully with the problems of protecting and enhancing the environment, a long-term agenda for action during the coming decades, and aspirational goals for the world community.

In 1972, the UN Conference on the Human Environment brought the industrialised and developing nations together to delineate the 'rights' of human society for ensuring a healthy and productive environment. A string of such meetings followed regarding the rights of people to adequate food, housing and access to safe water.

The present decade has been marked by a revival of social concerns. Scientists are drawing our attention towards urgent and complex problems bearing on human survival: a warming globe, threats to the Earth's ozone layer and the desertification of agricultural land. We respond to these problems inappropriately at the local level and by assigning the problems to institutions ill-equipped to cope with them. Environmental degradation was first seen as mainly a problem of the rich nations and a side effect of industrial wealth, but currently it has become a survival issue for developing nations. It is part of the downward spiral of linked ecological and economic decline in which many of the poorest nations are trapped. Despite official hopes expressed on all sides, no trends are identifiable today and no programmes or policies offer any real hope of bridging the growing gap between rich and poor nations.

In 1992, The Earth Summit, held at Rio de Janeiro, Brazil, also popularly known as the United Nations Conference for Environment and Development (UNCED), gave rise to the Rio Declaration on Environment and Development and articulated an action plan called Agenda 21 for sustainable development. The World Summit on Sustainable Development, also known as Rio+10, held in 2002 in Johannesburg, South Africa, focused on the renewal of global commitment which was defined in the Rio Declaration and Agenda 21. The World Summit also included among its targets the elimination of poverty; changes to consumption patterns and non-viable production; and the protection and management of natural resources. The Johannesburg Declaration focused on:

> the indivisibility of human dignity which is resolved, through decisions on targets, timetables and partnerships, to speedily increase access to such basic requirements as clean water, sanitation, adequate shelter, energy, health care, food security and the protection of biodiversity. We will work together to help one another gain access to financial resources, benefit from the opening of markets, ensure capacity-building, use modern technology to bring about development and make sure that there is technology transfer, human resource development, education and training to banish underdevelopment forever... give priority attention to the fight against the worldwide conditions that pose severe threats to the sustainable development of our people, which include: chronic hunger; malnutrition; foreign occupation; armed conflict; illicit drug problems; organised crime; corruption; natural disasters; illicit arms trafficking; trafficking in persons; terrorism; intolerance and incitement to racial, ethnic, religious and other hatreds; xenophobia; and endemic, communicable and chronic diseases, in particular HIV/AIDS, malaria and tuberculosis... (18–19)

On 8 September 2000, the United Nations General Assembly adopted the United Nations Millennium Declaration. Among other aspects of the Declaration, the General Assembly adopted the eight Millennium Development Goals (MDGs), most of which were anticipated to be achieved by 2015, such as the eradication of extreme hunger and poverty; universal primary education; gender equality and the empowerment of women; reduction of child mortality; improvement to maternal health; combatting HIV/AIDS, malaria and other diseases; ensuring environmental sustainability; and developing a global partnership for development. In 2012, Rio+20, the United Nations Conference on Sustainable Development (UNCSD) held at Rio de Janeiro, Brazil, marked the twentieth anniversary of the Rio conference. The main objective for Rio+20 was to secure a renewed political commitment for sustainable development along with assessing progress and bridging the gaps in the implementation of sustainable development efforts; and addressing new and emerging challenges.

Ambitious action plans for people, prosperity and the planet were accepted in 2015 to achieve the agenda for sustainable development by 2030. There are 17 sustainable development goals (SDGs), including eradicating poverty, strengthening universal peace through collective partnership, and promoting eco-growth, social inclusivity and environmental sustainability.

Spatial information technology is not only providing information on the Earth's resources but it is also useful for managing them in an integrated, inclusive and sustainable manner in order to achieve SDGs. The present book is an effort to develop knowledge about spatial information technology for contributing towards the UN's SDGs among students, researchers, professionals and laypeople. This book is organised in order to facilitate understanding of spatial databases and how to extract information from them for planning purposes. It describes the basic fundamental concepts concerning advanced techniques for spatial data management and analysis. It also discusses the methodology to proceed practically in a systematic manner. The text then presents the basic concepts underlying geographic information systems (GIS), remote sensing and global positioning systems (GPS) for resource and infrastructure planning and their management with the aim of developing these skills among students and young researchers. Geo-scientists can also enhance their knowledge through the use of this technology. The chapters of this book are systematically arranged in such a way that readers can easily understand the conceptual background and do their hands-on practice with GIS software.

Part I discusses the fundamental concepts in eight chapters and Part II deals with their application as case studies from different disciplines. Chapter 1 discusses the requirements of spatial information technology by incorporating descriptions of what is meant by remote sensing, GPS and GIS as well as linkages between them, the fundamental technological requirements, components and types of GIS. Chapter 2 explains the database structure considered to be the backbone of a GIS environment. Various types of spatial and non-spatial databases are explained in it. Chapter 3 presents the fundamental concept of remote-sensing technology as one of the major sources of spatial databases. Chapter 4 describes GPS technology used to acquire locational information about the Earth's surface, which is very useful for fieldwork and ground verification. Chapter 5 deals with the basic concept of a geo-referencing system which is a necessary process to provide a real coordinate system for spatial databases and discusses the projection system. Chapter 6 deals with workflow for development of spatial databases needed to finalise the map. The main purposes of the previous chapters are to prepare the final map for resource management, which is discussed in Chap. 7. It describes different methods of spatial database analysis. Finally, Chap. 8 discusses the map visualisation process and different forms of GIS output with the use of geospatial technology. Part II discusses the applied aspects by presenting five case studies (Chaps. 9–13) representing different challenging areas such as the land-use model for agricultural sustainability, flood-inundation mapping, watershed characterisation and prioritisation, infrastructure assessment and crop modelling in order to contribute towards SDGs.

Chapter 14 discusses the application of spatial information technology in other SDGs with suitable examples. Concluding remarks are given in Chapter 15 where global initiatives and the national perspective are discussed.

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New Delhi, India

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Introduction

Spatial information technology is a transformative tool universally available to empower individuals to advocate and innovate for our common future. The technology includes remote sensing, global positioning systems (GPS) and geographic information systems (GPS). These technologies enhance our ability to assess and monitor complete socio-bio-physical characteristics of the Earth such as geomorphology, climatology, oceanography, natural resources, disasters, settlement, agriculture, economy and many more to manage and preserve its ecosystems. Thus, this technology has huge potential to help us realize the following sustainable development goals (SDGs) by 2030:

1. No Poverty: End poverty in all its forms everywhere
2. Zero Hunger: End hunger, achieve food security, improved nutrition and promote sustainable agriculture
3. Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages
4. Quality Education: Ensure inclusive and equitable quality education for all and promote lifelong learning
5. Gender Equality: Achieve gender equality and empower all women and girls
6. Clean Water and Sanitation: Ensure access to water and sanitation for all
7. Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable and modern energy for all
8. Decent Work and Economic Growth: Promote inclusive and sustainable economic growth, employment and decent work for all
9. Industry, Innovation and Infrastructure: Build resilient infrastructures, promote sustainable industrialisation and foster innovation
10. Reduced Inequalities: Reduce inequality within and among countries
11. Sustainable Cities and Communities: Make cities inclusive, safe, resilient and sustainable
12. Responsible Consumption and Production: Ensure sustainable consumption and production patterns
13. Climate Action: Take urgent action to combat climate change and its impacts
14. Life Below Water: Conserve and sustainably use the oceans, seas and marine resources
15. Life on Land: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss

16. Peace, Justice and Strong Institutions: Promote just, peaceful and inclusive societies
17. Partnerships for the Goals: Revitalise the global partnership for sustainable development

The present book aims to improve scientific understanding regarding spatial information technology to help communicate the United Nations' SDGs to faculty members, students, researchers, professionals and laypeople. The book describes the basic fundamental concepts and techniques of spatial data management and analysis together with methodological advancement. GIS, remote sensing and GPS are presented in an integrated manner for the planning of resources and infrastructure.

Chapter 1 introduces background information about spatial information system requirements in the day-to-day life of human beings that can address questions such as what, where and when. It also describes the locations, conditions, trends, patterns, modelling of natural resources and occurrences of phenomena. Basically, GIS integrates the components of computer hardware, software, databases, procedures and trained people in order to capture, compile, store, update, manipulate, analyse and display geographically referenced spatial data together with non-spatial information. The development of computer technology has enhanced the concept of map-making (cartography) in the GIS environment as well as increased the capability of decision-making by using huge databases for multidisciplinary applications. The major applications of GIS include mapping, monitoring, measurement and modelling of databases of varied forms. Chapter 2 presents the concept of databases in GIS that play a major role in spatial information technology. Basically, two types of database are used: spatial and non-spatial. These databases consist of the Earth's features converted into the different layers, along with their non-spatial data. These thematic layers may be rendered as raster or vector data models. The vector data store the information as pairs of x–y coordinates while raster data are represented in cells. The non-spatial database is stored in alpha-numeric tabular form. Types of non-spatial database include network, hierarchical and relational and these interact with spatial databases by means of a common key such as a unique identification number. The various sources are available in the form of spatial and non-spatial databases such as analogue maps, remote-sensing imagery (both digital and photographic), GPS data, field surveys, census data and primary as well as secondary tabular data.

Chapter 3 specifically deals with remote sensing, a technique to acquire data remotely that employs a multidisciplinary approach to the handling of imagery. There are several mechanisms involved, ranging from the source of energy to the supply of end-product to the user. Remote sensing can be accomplished through three platforms: groundborne, airborne and spaceborne. The product of remote sensing may be in the form of photographs or digital imagery. Electromagnetic energy is the medium by which different sensors acquire information about the Earth's surface. The limited portion of the electromagnetic energy available for remote sensing is known as an atmospheric window. In the atmospheric window, energy interacts with the Earth's features and is reflected back to the upper atmosphere where a deployed sensor records that energy to form an image. The interaction of energy with Earth material such as soil, vegetation and water depends on the nature, properties and configuration of features. The interacted electromagnetic energy is reflected back to the atmosphere where sensors receive it and transmit it to the ground station. The reflectance behaviour of the feature is assessed from the reflectance curve displayed in a computer monitor. There are various Earth-resource observation remote-sensing satellites in orbit, starting with Landsat, one of the pioneers in satellite observation, followed by European and Indian satellites, launched to acquire information about the Earth’s surface. The imagery received from the satellite is not directly usable by the user community, thus digital image processing is applied to provide geometric and radiometric correction as well as enhancement techniques to increase the interpretability of the imagery in digital classification and visual interpretation with the help of a photo or image interpretation key. The checking of the classified or interpreted satellite imagery finally needs assessment for accuracy and when completed these classified images can be used as thematic maps. Satellite imagery, once classified, can also be used as input in a GIS environment to create a database as a base layer. Thus, remote sensing provides the base information as well as thematic information to integrate with a GIS environment. The field verification and fieldwork need an accurate information system like GPS, an instrument that provides the precise location of a particular point. Generally, GPS refers to the services provided by the US NAVSTAR (Navigation Satellite Timing and Ranging) satellite network, but GLONASS (Global Navigation Satellite System) and IRNSS (Indian Regional Navigation Satellite System) are also providing positional information from Russian and Indian satellite constellations, respectively. There are space, ground and user segments in GPS. Ground segments control the spaceborne satellites to monitor their operations. The GPS receiver acts as a user which is installed in a road–rail–air–water navigation system. With the help of four satellite signals, a receiver determines the 3-dimensional position on Earth. To enhance the positional accuracy, a differential global positioning system (DGPS) can be used, where a minimum of two GPSs are required, one acting as a base station and another as rover. GPS is widely applied for navigational purposes.

Without a coordinate system, the purpose of spatial data is not fulfilled. In geo-referencing of the spatial database it is therefore most important to understand the location of a particular feature and phenomenon on the Earth’s surface. Given its huge size, the Earth is modelled as a globe, with its true shape, distances and directions reproduced at the appropriate scale. The Earth's coordinates comprise a reference system which is used for mapping 3-dimensional aspects on a 2-dimensional plane. GIS software uses two types of coordinate system—a geographic and another planar system that uses data to locate the precise position, since the shape of the Earth is spheroid due to flattening at the poles. There are two types of data used while mapping: one is geocentric and the other local. There are various projection systems, available from the families of cylindrical, conical and azimuthal projection, to represent various locations on the Earth’s surface. In India, polyconic, Lambert Conformal Conic (LCC) and Universal Transverse Mercator (UTM) projections are widely used to represent small-scale to large-scale maps. The proper planning of the project is the most important aspect of creating the digital database in a GIS environment. There are various input sources to convert analogue data into digital data, such as scanning of maps, digital remotely-sensed data, digital data from secondary sources and GPS data. The conversion of digital raster data into vector data is done through an onscreen digitisation process. During vectorisation, various errors occur and these are corrected by identifying dangles, nodes, sliver polygons and duplicate features. Sometimes, the errors occur while joining two adjacent maps which need an edge-matching process. The updating of a map can also be corrected by using editing tools available in the software. Topology is the most important feature of GIS, as it illustrates the relationships of connectivity, contiguity and containment between features for spatial analysis purposes. The non-spatial data can also be created in a GIS environment by using GIS software and other software such as Microsoft Excel and dBase. It is attached to spatial data through the common field in both spatial and non-spatial data in the GIS software. The database can also be used to create another data set by a data linkage process in the same coordinate system. It can be classified into two parts, one exactly matching and another non-exactly matching. In exact matching, it is known when the spatial feature is matched and both the data set and attributes are appended in a new data set. Non-exact matching, also classified as hierarchical and fuzzy matching, involves merging the data sets to create a new one in a hierarchy, appending different data sets not matching each other. After creating a digital database it can be used for cartographic mapping and spatial analysis.

Spatial analysis is the most important feature of the GIS software that enhances the decision-making process. It has a wide application in understanding the environment around us and when planning the allocation of resources. Various functions and methods of spatial analysis in different GIS software packages are available and depend critically upon the ability of the GIS engineer to utilise and develop them in a GIS environment. Basically, spatial analysis can be single- or multi-layer, with queries ranging from simple to complex. It is very useful for the quantitative measurements of point, line and polygon to understand the dimensions of features. It also includes the transformation process from single layer to multiple layers such as when creating a buffer zone around the point, line and polygon features as well as when analysing two layers with different features such as *line in polygon* and *polygon in polygon* overlay analysis. The spatial interpolation technique is also utilised to identify an unknown value from known characteristics of the spatial data; methods include Thiessen's polygon interpolation method, the triangular integrated network (TIN) and the digital elevation model (DEM). The spatial data can also be manipulated through the aggregation and merging of data sets to form a new data set. These spatial analysis methods are very useful for the geographical analysis of the data set. The output of the various spatial analyses can also be used for mapping and act as input for other purposes. The overall conceptual road map of conversion of real-world features into digital or analogue mapping is known as visualisation. Map visualisation includes all the steps for decision-making regarding global resources and phenomena. It includes all activities, ranging from thinking about the problems and hypothesis generation to final analysis of results and their presentation by exploring, analysing, and synthesising the facts. The desired output can be represented by cartographic and non-cartographic methods of representation. In this way, spatial information technology is helpful in map-making and decision-making processes.

This book also includes case studies focusing on land-use modelling, morphometric analysis, flood-inundation mapping, infrastructure mapping, crop modelling and applications relating to other SDGs. Spatial information technology employs land-use modelling and suggests various alternate scenarios in such a way that no land should be kept as wasteland; this will help bring about prosperity and environmental enhancement. Another application that includes the calculation of morphometric parameters proves that spatial information technology is an efficient tool in drainage delineation and analysing characteristics for morphometric analysis. The morphometric parameters of different aspects like linear, areal and relief show the different characteristics of the watershed. These characteristics can be used to interpret the geological conditions responsible for the hydrology of the drainage basin. The ten morphometric parameters—drainage density, stream frequency, texture ratio, bifurcation ratio, watershed shape factor, overland flow, circularity ratio, elongation ratio, form factor and compactness ratio—are used for prioritisation of the watershed in high, medium and low categories. The land and water resource development plan should be applied on the basis of priority of the watershed. The applications of spatial information technology are very helpful in the management of flood-inundated areas. The remote-sensing-based analysis reveals that floods in the study area occur in low-lying zones alongside the rivers from September to November, which affect the *kharif* (monsoon season) crops and sometimes also the *rabi* (dry season) crops. The overlay analysis in the GIS provides the statistical assessment of flood-inundated areas in the watershed. In the rural and urban environments, infrastructure is the crucial parameter to assess development. The case study of infrastructure development shows the capability of information technology to identify gaps in the provision of infrastructural facilities such as education, health care, drinking water, transport, communication technologies (i.e. postal service, telephone) and, electrification that are not uniformly available. Spatial information technology can also be applied in crop management and its modelling by incorporating other software extensions in a GIS environment. The last case study shows that there are possibilities to increase the productivity of the soil by utilising geospatial components such as remote sensing, GIS, GPS and simulation models like InfoCrop and QUEFTS in an integrated manner for planning optimal productivity and exploring resource and input management options. The present study provides inputs for policymakers and other agencies for planning the best use of the available resources in order to improve the socio-economic and environmental conditions of the region as well as developing new policies and strategies for sustainable development.

Part I

Conceptual Background and Fundamentals of Spatial Information Technology

1 Spatial Information Technology: Definitions, Types and Linkages

Abstract

For readers with a basic understanding of geography and resource allocation, this chapter provides an introduction to the following aspects of spatial information technology:

- Linkages between remote sensing, GPS and GIS
- Meaning and definition of GIS
- Components of GIS
- Capabilities of GIS
- Evolution of GIS
- Types of GIS
- Brief applications of GIS

Keywords

Spatial information technology · Remote sensing · GPS · Monitoring · Modelling

1.1 Spatial Information System

In our day-to-day lives, various questions arise regarding the allocation of basic necessities and planning of future development. Geography, as a discipline, helps us in our roles as producers and consumers. The food producer has many questions regarding agriculture, while the agricultural scientist has to undertake suitability analysis for different crops and future predictions. The meteorologist analyses weather systems and climatic phenomena. The regional and town planner has to plan where to site the residential area to optimise quality of life. Industrialists think about the optimal localisation of industry to obtain cheap raw materials, labour and a nearby market to sell the finished product. The consumer has to decide from which market he or she gets the cheapest and most desired product. The government has to plan for infrastructure and utility development and research the optimum locations for educational institutions ranging from primary schools to colleges of further education; medical facilities such as health centres at various levels; fire stations; police stations; transportation and communications hubs; pipeline network for various uses. Ultimately, we are looking to provide a better quality of life by utilising the optimum capacity of resource bases. Each and every phenomenon has one or more relevant factors. If the factors are few, the less of a problem there is for decision-makers, but where factors are more numerous, there is greater complexity of data for the decision-making process. Thus, the spatial information system can play a vital role in the decision-making process. It is not only confined to a single discipline but has a wide range of applications for the community. Spatial information systems can help enhance our approach to studying one or more of

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the fundamental issues that arise when using digital information technology to examine the surface of the Earth.

Thus, spatial information technology has been developed to (1) address the type of questions it should be able to answer and (2) create formal definitions and the ability to carry out spatial operations. Fundamentally, spatial information systems can answer three general questions of 'what', 'where' and 'when', although 'where' appears to be most important; these systems are sometimes also known as the 'science of where'. The combination of these three questions describes location, condition, trends, patterns and modelling. The following questions can be answered with spatial information technology:

Question 1 What exists at a particular location?

This question identifies particular location characteristics. There are many ways to answer this question, such as place name, object or feature name, *x*–*y* coordinates etc. For example, New Delhi is a place name; agricultural land is a feature name; and 77° East longitude and 35° North latitude is an *x*–*y* coordinate. The particular location explains characteristics such as population, soil type, water condition, physiography etc.

Question 2 Where are certain conditions satisfied?

This question is the opposite of the first question and requires spatial analysis to answer. For example, identifying where certain *conditions* are satisfied such as finding the location where the area is less than 1000 m^2 with barren land; slope is less than 3°; soil is in good condition; and quality of groundwater is excellent.

Question 3 What has changed in land use during the period 1981–2011?

This question shows the *trends* of particular land use over the time period—it may be annual or decadal—depending on the availability of data. The spatio-temporal map of the same location is required to answer this question.

Question 4 What is the spatial pattern of resources or of particular phenomena?

This question determines, for example, whether waterborne diseases are found near waterlogged regions or not. Another query may be whether a wheat crop is mostly cultivated in North or South India. This type of existing spatial pattern of resources or phenomena can help us examine the distribution of waterborne diseases or wheat crop cultivation regions all over India through GIS.

Question 5 What happens in the future when certain criteria occur?

This question is posed to determine what happens when, for example, we site a sugar mill close to an agricultural field or when we change the cropping pattern of a particular region. We can also decide which area needs schools or a primary health centre. So we can use this model to decide future requirements and the management of resources. Such questions can be answered by modelling with the spatial information system.

1.2 Spatial Information Technology and Linkages between Remote Sensing, GPS and GIS

Spatial information technology aims to provide information about the Earth's surface. It includes all the tools and technologies that enable us to acquire information and provide decision-making capability towards planning and sustainable management. The most important technologies are remote sensing, GPS and GIS. Remote-sensing technology provides unbiased, near real-time remotely sensed data about the Earth's surface provided by different characteristics of satellite and sensor specifications (as discussed in Chap. 3). GPS is a tool that enables us to provide the locational information of point, line and polygon features on the Earth's surface (as discussed in detail in Chap. 4). GIS is a combination of tools that enables us to manage spatial and non-spatial data for different spatial analyses, manipulation and modelling. All these technologies, with their unique characteristics, are complementary to each other in planning and development processes of the Earth's surface resources. The remote-sensing data are useful to classify and assess the thematic information of the Earth's surface while GPS technology is useful to verify or validate this classified information in the field or in supporting the fieldwork process. GIS is a technology that provides a platform to integrate all the information which is provided by remote-sensing data, GPS, secondary as well as primary data and many other sources, and assists us with the planning process, acting as a decision-support system. Thus, all these technologies are known collectively as spatial information technology.

1.3 Meaning and Definition of GIS

The acronym GIS stands for geographic information system. It is also important to understand the literal meaning of these three words. Let's start with 'Geographic', related to geography, which is the study of the Earth. According to Hartshorne (1959): 'geography is concerned to provide an accurate, orderly and rational description and interpretation of the variable character of the earth's surface.' Geography attempts to acquire knowledge of the world in which we live, both facts and relationships, which should be as objective and accurate as possible. It seeks to present that knowledge in the form of concepts, relationships and principles that apply to all parts of the world. Finally, it seeks to organise dependable knowledge obtained in logical systems, reduced by mutual connections into as small a number of independent systems as possible. It is the way in which geography pursues these ideals that we attempt to describe its character as a field of study. It should be noted in general that our definition of the kind of knowledge of which geography is a part is based not only on what is known but also somewhat on the search for knowledge; for example, the fundamental principles governing the manner in which the unknown is to be learned. The various branches of this 'kind of knowledge' differ in the degree to which they have been able to approach the ideal state; no branch of science can claim to have attained perfect certainty or exactness of organisation and knowledge within a single system. The ideals of accuracy and certainty apply not only to the manner in which primary facts are established and to the formulation of fundamental concepts and technical terms, but also to the processes of mathematical and logical reasoning by means of which we induce relationships of observed facts and thereby deduce further conclusions. Thus geographical data describe objects in the real world in terms of their position with respect to a coordinated system; their attributes that describe the spatial data unrelated to position, such as colour, cost, pH, name etc.; their spatial interrelationships with adjacent features, which describe how they are linked together or how one can travel between them.

Information is the means by which human perception and mental processes understand and develop knowledge. One cannot expect a machine like a computer to understand or have knowledge. One can define data simply as 'records of facts,' following the pragmatic suggestion of Larner (1996). To take an example, the layout plan of a housing estate is a set of data. Individual data items associated with this example might be the pair of *x*–*y* coordinates that define the geographical position of the corner of a building or the name of the owner of the land on which the estate is constructed. In order for data to become 'information', one needs to assimilate, understand or interpret them in some fashion. To achieve this we may need to classify or organise the data in order to convey meaning. By analysing data, users extract the meaning (or arrive at an interpretation of the meaning) and obtain information. According to Nix (1990): 'Data does not equal information; information does not equal knowledge; and, most importantly of all, knowledge does not equal wisdom. We have oceans of data, rivers of information, small puddles of knowledge, and the odd drop of wisdom.' Geographic information carries some sort of geographical reference to help locate something in the form of symbolic references and numeric references.

System may be defined as any ordered, interrelated set of things and their attributes, linked by flows of energy and matter, as distinct from its surrounding environment. The elements within a system may be arranged in a series or interwoven with one another, e.g., a cooling system, political system, hydrological system etc. In a cooling system various components such as fan, pipes, water etc. are connected for the single objective of providing cool air. The lack of any component can affect the functioning of the system. A system comprises a number of subsystems. Thus there is a group of procedures which is organised in such a manner as to extract information about geographical phenomena in a logical fashion.

GIS provides the geographical perspective of the information system, the multidisciplinary information tied to a specific set of locations on Earth. It comprises a collection of computer hardware, software, databases, and procedures, is maintained by trained people, and has capabilities of capturing, storing, retrieving, manipulating, analysing and displaying the data included in the geo-referenced spatial and non-spatial databases for different user communities.

GIS is a database system in which most of the data are spatially indexed, and upon which a set of procedures operates in order to answer queries about spatial entities in the database (Smith et al. 1987). Aronoff (1989) defines GIS as 'any manual or computer based set of procedures used to store and manipulate geographically referenced data.' According to Goodchild (1990): 'Geographic Information System refers to any digital information system whose records are somehow geographically referenced. Like any information system, it combines a database with a set of procedures or algorithms that operate on the database. Because of the geographical nature of the data, the input and output subsystems must be unusually elaborate, and must rely on specialized graphics hardware such as plotters, digitizers and scanners.' Duecker and Kjerne (1989) view GIS as 'a system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth.' According to Burroughs (1986), GIS is 'a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world.' GIS is described by Cowen (1988) as a system for support of geographically based decisions, or a 'Spatial Decision Support System.' It involves the integration of spatially referenced data in a problem-solving environment. GIS has been defined by ESRI as 'an integrated collection of computer software and data used to view and manage information about geographic places, analyse spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analysed.'

In addition to these technical components, a complete GIS must also include a focus on people, organisations and standards. It provides advanced capabilities for the processing and interpretation of spatial information from the real world. It can:

1. Collect, store and retrieve information based on spatial location.
2. Identify locations within a targeted environment which meet specific criteria.
3. Explore relationships among data sets within that environment.
4. Analyse the related data spatially as an aid to making decisions about that environment.
5. Facilitate selecting and passing data to application-specific analytical models capable of assessing the impact of alternatives on the chosen environment.

6. Display the selected environment both graphically and numerically either before or after analysis.

In summary, GIS is a computer-based data processing system for collecting, manipulating, analysing and displaying geographical information.

1.4 Components of GIS

There are five components in the GIS: computer hardware, software, databases, procedures and trained personnel (Fig. 1.1).

1. Computer hardware: this basically consists of input, processing and output devices, along with memory and a storage unit(s). The central processing unit (CPU) consists of processor, motherboard, hard disk and memory card which are connected with peripheral devices such as input devices like a keyboard, scanner or mouse; output devices include a display unit such as a monitor, printers, plotters and audio system. Hardware can vary in terms of processing speed, ease of use and type of input and output facility.
2. GIS software: the GIS software package has a set of modules for performing digitisation, editing, overlaying, networking, data conversion and analysis for answering queries and generating output. GIS software can be grouped into commercial and open-source. Commercial GIS software includes ArcGIS (ESRI), Geomedia (Hexagon Geospatial), Global Mapper (Blue Marble), MapInfo Professional (Pitney Bowes), Manifold GIS (Manifold), Smallworld (General Electric), Map Viewer and Surfer (Golden Software), Idrisi (Clark Laboratories), AutoCAD Map 3 D (Autodesk), Tatuk GIS, MicroImages (TNTgis) and many more. Open-source GIS software includes GRASS, QGIS, Flowmap, GMT mapping tools, OpenJUMP GIS, SPRING and so on.
3. Database: the accuracy of the analysis depends directly on the quality of the information available in the database and it affects the results of any query or analysis. There are many data that are available which may be categorised under spatial and non-spatial. The database can be further subdivided into hardcopy map, digital map and imagery and attribute data. A digital map is a computerised representation of traditional paper-map information.
4. Procedures: The analysis requires well- defined, consistent methods to produce accurate and reproducible results.
5. Trained personnel: This is the most important component in GIS. A trained person can develop the procedures, define the tasks,

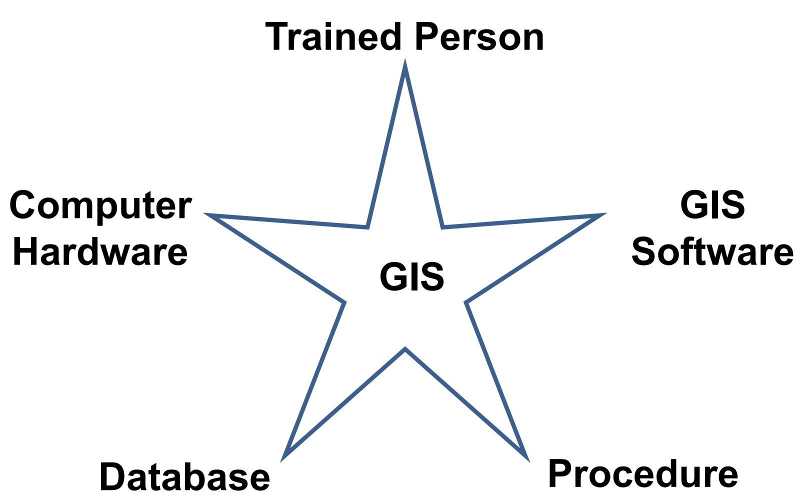


Fig. 1.1 Five components of geographic information system (GIS)

overcome problems and manage the database and other components such as hardware and software.

1.5 Capabilities of GIS

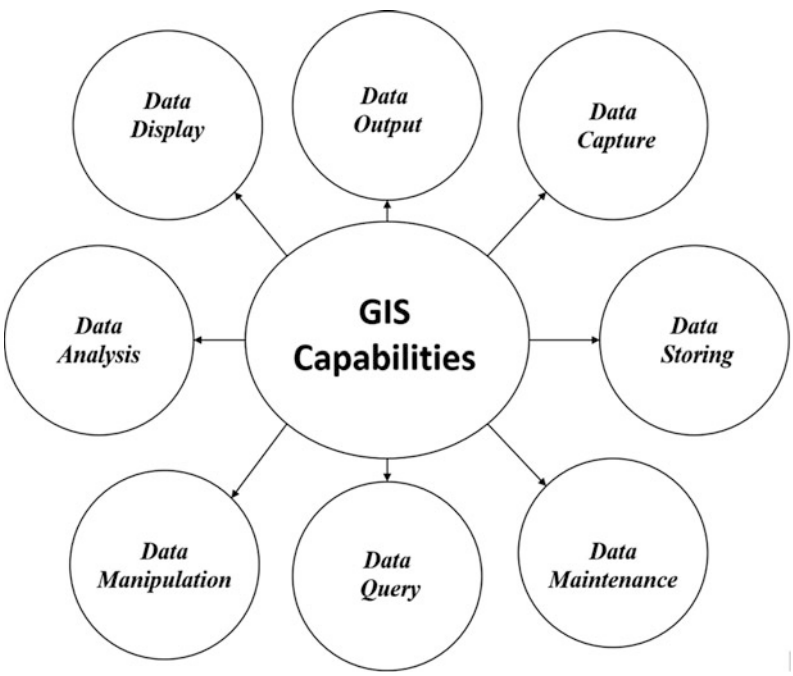
GIS has eight major capabilities (Fig. 1.2) to handle small and large databases; again, the most important component is trained personnel, who have the requisite knowledge to perform the following tasks:

1. Capturing data: GIS should provide methods for input of geographic (coordinate) and tabular (attribute) data. The more input methods available, the more powerful the GIS system.
2. Storing data: there are two basic data formats for geographic data storage: vector and raster.
3. Maintaining data: GIS has capabilities to update or maintain according to time and situation regularly.
4. Querying data: GIS should provide utilities for finding specific features based on location or attribute value as well as answer multiple queries.
5. Analysing data: GIS has the capability to analyse according to topology and find the relationship between multiple data sets.
6. Manipulating data: GIS should be able to manipulate the database to reduce the repetition of work by splitting and merging the database.
7. Displaying data: GIS has the capability to display spatial as well as non-spatial databases efficiently by using a variety of available symbology.
8. Output: GIS should be able to produce the results in a variety of formats, such as maps, reports and graphs in digital and analogue form.

1.6 Evolution of GIS

The root of GIS lies in the development of map-making or cartography. Cartography developed around the sixth century B.C., when the Greek philosopher Anaximander made the first circular map to depict the area around the Aegean Sea. Eratosthenes laid the foundation for

Fig. 1.2 Capabilities of GIS



making maps in around 200 B.C. He portrayed the world in the form of a map having transverse parallel lines showing latitude and some irregularly spaced meridians of longitude. The first printed map came into existence in 1155 A.D., after the invention of paper in China. In 1492, Martin Behaim, a German merchant and navigator, developed a globe that recorded the layout of the world, as Europeans knew it before Columbus's voyage. In 1507, Martin Waldseemüller, a German cartographer, made a world map and was the first to name the newly discovered transatlantic lands America. This map depicted North and South America separately from Asia. In 1570, Abraham Ortelius, a Flemish cartographer, published the first modern atlas called *Theatrum Orbis Terrarum*. Maps became more important with the introduction of artillery for military operations. In 1854, John Snow, a British physician, demonstrated GIS as a problem-solving tool. When cholera hit the city of London, England, he began paper-mapping cholera outbreak locations, roads, property boundaries and sources of water supply. He established that cholera cases were clustered around polluted sources of water by using spatial analysis. In the twentieth century, the arrival of new technologies, such as aerial photography, accelerated the process of map-making. In 1909, the first aerial photograph was taken, and in 1920, the technique of taking measurements from aerial photographs was developed, which was extensively used during the Second World War for making maps. In 1965, a team of scientists at the Harvard Laboratory for Computer Graphics and Spatial Analysis developed a computer-mapping package, which created maps on a line printer. Roger Tomlinson is considered to be the father of GIS and pioneered the creation of the first GIS system named the Canada Geographic Information System (CGIS) in 1966. GIS evolved further with the introduction of high-resolution photographic equipment for geological surveys. The USA began the use of such equipment with the launch of a satellite in 1966 and three satellites in the 1970s.

In 1969, Jack Dangermond and his wife Laura founded the consulting firm Environmental Systems Research Institute, Inc. (ESRI) and provided services for computer-mapping and spatial analysis to help land-use planners and land-resource managers. In 1978 MOSS (Map Overlay and Statistical System) was developed by the US Department of the Interior. It was the first broadly deployed vector-based GIS that provided integrated vector and raster processing. In 1981, ESRI had developed the first commercial GIS product known as ARC/INFO and began the evolution of ESRI into a GIS software company. As computing shifted towards Windows- and Unix-based systems, ESRI launched ARC/INFO on both platforms. ArcGIS 8.0 was released in late 1999, while ArcGIS 9.x and 10.x were released in 2004 and 2010, respectively. ArcGIS 10.6 was released in 2018.

In 1986, MapInfo developed the first desktop GIS. It was founded by Laszlo Bardos, Andrew Dressel, John Haller and Sean O'Sullivan. They wanted to develop an inexpensive mapping tool for the personal computer. MapInfo provided the mapping functionality tools for Microsoft products, branded as Microsoft Map for Microsoft Excel in MS Office 95, 97 and Microsoft Office 2000. In April 2007 Pitney Bowes entered into a merger agreement to acquire MapInfo and changed its name to Pitney Bowes MapInfo Corporation. In June 2008, MapInfo released MapInfo Professional 9.5, which included the use of a new graphics engine that allowed for translucency and anti-aliasing when displaying maps and also added CAD editing tools. Georeferenced PDF files with layer supports were added in version 10 in June 2009. Version 17.0 released in 2017 included a quick-access toolbar and mini-toolbars, enhanced layout design and improved handling of raster data.

In 1993, Web GIS was introduced by the Xerox Corporation's Palo Alto Research Center and developed a web-based map viewer. It was an experiment in allowing the retrieval of interactive information on the Web, rather than providing access to strictly static files (Putz 1994). The website provided simple map-zoom capabilities, layer selection and map projection conversion functions. This web browser demonstrated that users anywhere on the Web could use

GIS without having locally installed GIS software (Fu and Sun 2010).

In 1999, GIS Day provided an international forum for users of GIS technology to demonstrate real-world applications that are making a difference in our society. The first formal GIS Day took place 14 November, 1999. ESRI president and co-founder Jack Dangermond credits Ralph Nader with being the person who inspired the creation of GIS Day. He considered GIS Day a good initiative for people to learn about geography and the uses of GIS. He wanted GIS Day to be a grassroots effort and open to everyone to participate. Over 1200 events were held on or around GIS Day 2017 (https://www.gisday.com/).

In August 1996, Autodesk Inc. announced that it had taken 'its first step into the fast-growing geographic information systems market, as the company began shipping its first dedicated mapping and GIS product, AutoCAD MAP. It is focused on five key areas such as digital map creation, analysis, maintenance of accurate, up-to-date maps, data exchange and publishing.' In May 1997 the next version of MAP, i.e. MAP 2, running on AutoCAD R14, included layouts, the ability to import ESRI ARC/Info files and use solid fill for thematic mapping and supported raster files. In 2004, MAP 3D 2005 was released with a little mix of Civil 3D in it. It allowed point groups, surface creations, analysis and visualisation (https://map3d.wordpress.com/2010/08/09/a-history-class/). In 2018 Autodesk Inc. announced that it had taken 'its released AutoCAD 2019, which includes an industry-specific toolset with architecture; electrical design; 3D mapping; mechanical design; Mechanical, Electrical and Plumbing (MEP) design; plant 3D; and raster design. It also includes AutoCAD web app, mobile app and integrated workflows that enable smooth working across desktop, web and mobile platforms.

1.7 Types of GIS

GIS can be classified on the basis of three factors: one is based on the GIS software operating platform; the second is based on the type of database; and the third is based on the data model (Fig. 1.3). Based on the platform on which the GIS software is operating, categories can be classified as desktop-based GIS and server-based GIS. In desktop-based GIS, the software installed on a standalone computer system can be used by only one user at a time. It has excellent capabilities for making maps, visualising and exploring, querying and geographically analysing the data. There are many desktop software packages available in the market such as ArcGIS, MapInfo, AutoCAD MAP, GeoMedia, Idrisi, ILWIS, QGIS etc. Recently QGIS has become very popular among students and researchers because of its open-source nature. Palmtop is a hand-held-based software, similar to desktop GIS, which works on mobile technology and is very useful during fieldwork. This is a palm and pocket device that has the capabilities of displaying and querying analytical applications. The most important characteristic of this system is that, as all programs and data are held in memory

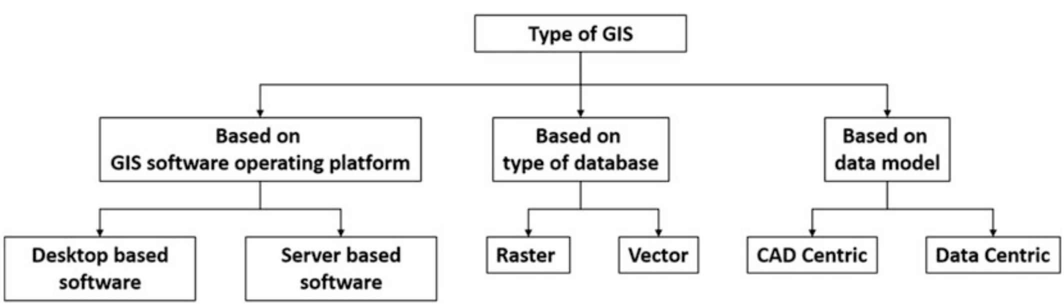


Fig. 1.3 Types of GIS

because of the lack of a hard disk, it provides fast access to the data. ESRI ArcPad and Autodesk OnSite are hand-held GIS software packages.

GIS software installed on a server computer can be accessed by multiple users. It provides the platform for developing and sharing GIS resources such as maps within a user community, whether they are sitting in the same office or across the world accessing and viewing maps on the same GIS platform through the Internet or via the company's Intranet. Web GIS is one of the examples of server-based GIS that provides access to geographic information on the Web whether you need an application that simply displays a map or a more sophisticated one that incorporates specialised GIS tools. Access to the GIS server is embedded inside the application and typically hidden from the user.

Another type of GIS is based on the type of database used and categorised as either vector-based or raster-based. Vector data focus on discrete features with precise shapes and boundaries. Vector lines are often referred to as arcs and consist of a string of vertices terminated by a node. A node is defined as a vertex that starts or ends an arc segment. Raster data, on the other hand, focus on continuous phenomena and images of the Earth. The raster data model incorporates the use of a grid-cell data structure where the geographic area is divided into cells identified by rows and columns.

The GIS can be further categorised based on whether it employs Computer Aided Design (CAD). CAD-centric systems provide much more versatility in capturing and displaying spatial features graphically, in terms of 2-dimensional and 3-dimensional displaying functions. They capture the spatial data into different layers and combine them together by different line styles and colours. CAD-centric systems have a limitation with the linking of non-spatial data to spatial graphical features to automatically assign symbology on the basis of user-defined criteria; this potentially restricts the processing of analytical tasks (Cowen et al. 1986). Here GIS and CAD are combining to assist in the management process of, for example, highway and railway track design, infrastructure design, water network planning etc. (Hassan and Akinci 2010). Data-centric GIS is an important requirement for the database management system (DBMS), which is a secure and widely accessible repository for geospatial data. It provides an analytical capability by relying upon the topological data structure that defines the relationship between arcs, nodes and polygons, which is helpful in analysis, publishing maps, tables and graphs. In GIS it is used for security, availability, scalability, archiving, querying and real-time information integration. Today, CAD and DBMS integration provides the benefits of both systems in GIS.

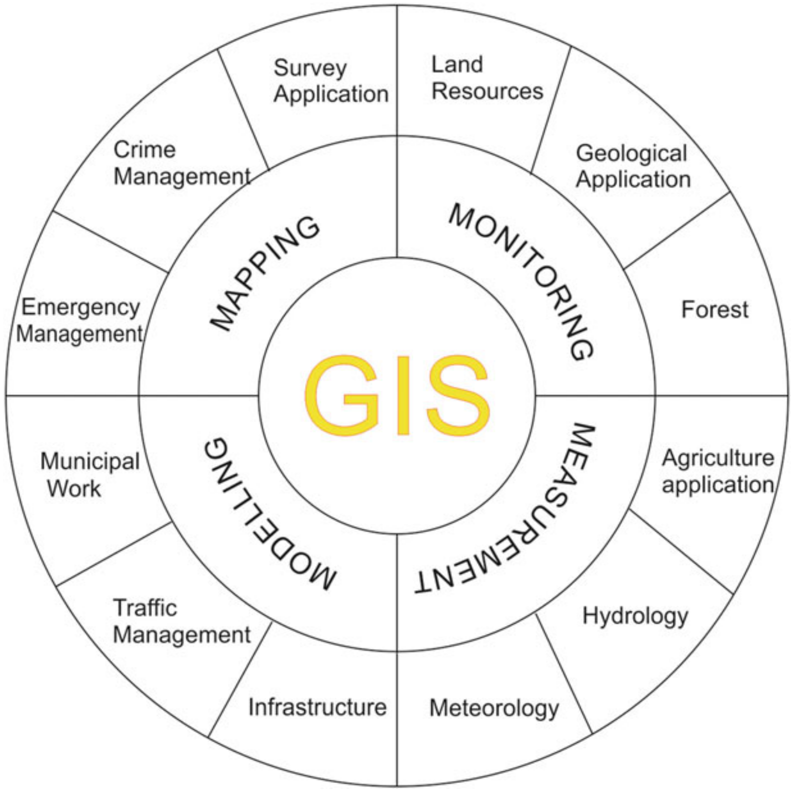
1.8 Application of GIS

Basically, there are only four major applications in GIS: mapping, monitoring, measurement and modelling (Fig. 1.4). They are widely applied in various disciplines.

1.8.1 Survey Application

There are many survey agencies widely using GIS technology, such as the Census of India, Survey of India, Geological Survey of India, Forest Survey of India etc. The Census of India widely applies GIS technology in the field mapping and monitoring of the census data. It is creating census maps at all administrative levels as well as mapping rural and urban population characteristics. The Survey of India conducts surveys of all kinds of physical environments in India and produces various types of maps. The Geological Survey of India conducts surveys about geological aspects and features in the form of maps, and the Forest Survey of India conducts all kinds of biomass studies and monitors and produces reports as well as maps.

Fig. 1.4 Applications of GIS



1.8.2 Land-Resource Management

GIS is widely used for the integration of land-resource management (Burrough 1986). The integration of biophysical and socio-economic approaches provides comprehensive information about the land that can be applied to planning purposes for different land uses such as agriculture, settlement (both rural and urban) and siting of industry etc.

1.8.3 Geological Applications

Beneath the surface of the Earth, there are limitations to viewing. Here GIS plays an important role in the field of oil and mineral exploration as well as groundwater management by monitoring indirect sources of information and inferences made. It is also useful for mapping historical geo-hazards like earthquakes and volcanoes, which can be useful for emergency planning and management of such areas, for example by the provision of seismic zone maps.

1.8.4 Forest Management

We have many sources to acquire information about forest resources. The multi-criteria spatial analysis of bio-physical and climatic information in the GIS environment can highlight the temporal changes as well as their management, such as area identification relating to forest plantation and species. Any decision on forest land diversion needs a detailed study and analysis of several critical environmental factors such as forest type, forest cover, landscape integrity, biological richness and protected area. The model can also guide timber harvesting, silviculture, habitat protection and fire-management activities.

1.8.5 Agricultural Applications

The agricultural sector widely uses this technology in applications ranging from land suitability to marketing, such as site suitability for various crops, crop production monitoring, estimation, irrigation management and market information. The sector uses geographical data for land-use planning, watershed management, agricultural sustainability and vulnerability studies, agro-meteorology, soil and water conservation etc. Spatial information technology is also used for precision studies to optimise application of inputs for plot and crop identification, in order to estimate and maximise yield. Crop modelling can also use the complete biophysical characteristics of the Earth, for example InfoCrop developed by the Indian Agricultural Research Institute.

1.8.6 Hydrology

GIS is one of the tools that assist in hydrological investigation. It is used not only to assess surface and groundwater resources, but also to deal with management aspects such as site analysis for dam construction and distribution systems as well as monitoring and modelling of water resources.

1.8.7 Meteorology

In recent years, GIS has played a significant role in meteorology and climatology for the mapping, monitoring and modelling of daily weather information. We can see daily weather reports in the media as one of the examples of GIS. Climate change phenomena are basically the outcome of GIS capability. Weather data are collected from weather stations and these data are further interpolated spatially to understand the pattern through Thiessen polygon, isoline and surface methods.

1.8.8 Infrastructure

Infrastructure development plays an important role in increasing the quality of life as well as in nation building. It includes such activities as the planning and provision of road networks, education facilities, medical facilities, drinking water, electricity development, parks, location of fire stations etc. GIS can assist with site suitability analysis to find appropriate locations for these facilities.

1.8.9 Traffic Management

GIS is useful to create databases on navigation systems such as road networks. The network analysis capability of GIS can be helpful in the planning and management of road traffic at peak hours or during any emergency route diversion.

1.8.10 Municipal Work

Municipalities can utilise high-resolution satellite imagery or aerial photography to create the base maps for areas, including land ownership, construction areas, floors in a building, street characteristics and amenities. GIS can also manage the various tasks of the municipality such as birth and death registration, property tax, land registration and bill payments etc. to provide better services to citizens.

1.8.11 Emergency Management

GIS is very useful in supporting spatial decision-making during times of extensive damage to the property and lives resulting from various natural and man-made extreme events. GIS can be helpful in identifying the best evacuation routes during emergencies, and rebuilding planning after a disaster. GIS has capabilities for mitigating natural hazards (with emphasis on the physical environment), vulnerability (with emphasis on the human environment) and risk (with emphasis on hazards and vulnerability). It can assist in the assessment and mapping of events such as avalanches and lava flows, landslides, forest fires, and earthquakes, etc. and their mitigation.

1.8.12 Crime Management

GIS also assists in the assessment and management of crime events, such as identifying crime hotspots, analysing historical events and generating future predictions. It is also useful for correlating social conditions and crime events, as well as maintaining law enforcement such as the installation of CCTV cameras, night patrolling check-posts, etc.

Fundamentally, GIS has the capability to integrate various streams of information or data for different applications as well as the creation of new relationships between various features (determining factors) for their planning and development.

1.9 Conclusion

This chapter introduced background information about GIS and its contribution to meeting day-to-day requirements in the life of human society. It can address questions of what, where and when as well as describe the locations, conditions, trends, patterns and modelling of any type of resources and phenomena. GIS can be defined as a combination of computer hardware, software, databases, procedure and trained personnel, which is capable of capturing, compiling, storing, updating, analysing and displaying geographically referenced spatial data alongside non-spatial information. Its origins and development lie in cartography (the making of maps) but the development of technologies and computer systems has increased the capabilities of GIS. Because of this it has remained not only useful for map-making but also applicable to enhancing decision-making by utilising the huge amounts of various kinds of data. There are various types of GIS systems categorised on the basis of: operating system; desktop- and server-based GIS; type of database used; vector and raster GIS; data model; CAD-centric and database-centric. The major applications of GIS are in mapping, monitoring, measurement and modelling in the multidisciplinary framework.

Questions

1. What is a spatial information system?
2. What is meant by GIS? Discuss the capabilities of GIS in resource management.
3. Discuss the different components and types of GIS.
4. Describe the applications of GIS.

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2 GIS Databases: Spatial and Non-spatial

Abstract

In this chapter, you will learn about the type and management of databases in a GIS environment. After reading this chapter you should be able to understand the following:

- Types of GIS database—spatial and non-spatial
- Representation of spatial features of the Earth's surface by vector and raster data structures (point, line and polygon)
- Advantages and disadvantages of raster and vector data structures
- Types of non-spatial data structure—hierarchical, networking and relational
- Different sources of spatial and non-spatial databases

Keywords

Spatial database · Non-spatial database · Raster data · Vector data · Analogue map · Tessellation

2.1 Introduction

The database is one of the most important components in GIS and acts as a warehouse or storeroom as well as providing a backbone of any GIS analysis. It is a collection of data stored in a structured format. In Chap. 1, we discussed how GIS can address certain questions. The GIS database may be spatial to resolve the question of *Where*, non-spatial for the question of *What* or temporal for the question *When*. So, GIS does not hold maps or pictures but it holds a database that can be displayed in graphical as well as tabular form. Thus, the GIS database is a representation of our world in the form of maps, not simply pictures, to resolve these questions. Data are defined by location in space with reference to a coordinate system and by non-spatial attributes in a particular time. A map is usually represented in two or three dimensions, according to user requirements and the nature of the database. A particular spatial feature can be thought of as a layer of data about an area. The map legend is the key, linking the non-spatial attributes with spatial entities. It may include visual aids such as colours, symbols or shades. All the functionalities of the GIS, such as multiple users, concurrent use, data integrity, query facilities, data extraction, data manipulation, modelling and visualisation depend on the type of database it holds.

2.2 Types of GIS Database

The database plays a major role in providing input in the GIS environment. The analysis and results totally depend upon these databases. In a

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real-world system, all the components and features of the Earth are integrated by a cause-and-effect relationship; for example, wheat crops require particular climate zones, seasonal patterns, elevations, soils with appropriate levels of water and micro-nutrients —among many other similar criteria—for particular customers. But in the GIS environment, we segregate them as different themes or features or as a layer for the generation of an individual database. In other words, the real features of the Earth are stored as different layers according to different features (Fig. 2.1). Theoretically, layers are individual parts or slices or strata of a real-world system which is separately represented in the legend in a map with different symbology; for example, political boundaries, road networks, land use, soil type, climate, water bodies etc. can be considered as different layers in the GIS environment. These layers may be in the form of vector or raster data formats.

Basically, two types of database are used in a GIS environment: one is a spatial database and the other is non-spatial (Fig. 2.2). The spatial database can have a vector data structure or raster data structure.

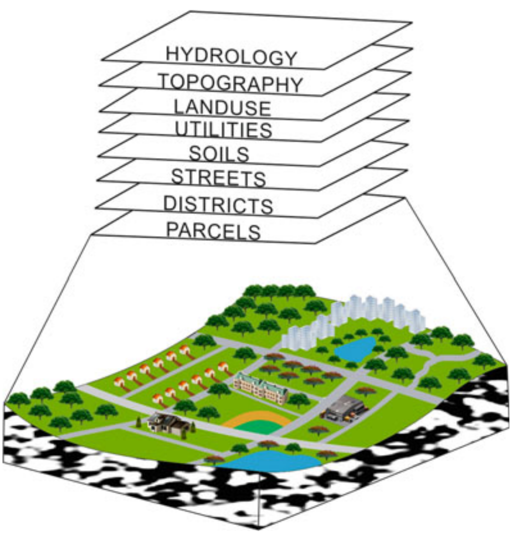


Fig. 2.1 Real-world system and layers in a GIS environment

2.3 Spatial Database

All geographical or spatial features of the world can be represented and stored in the form of a map. This is basically a set of points, lines and polygons (area). These features correspond to a uniquely defined location on the Earth's surface. Spatial data have also been described as 'any data concerning phenomena spatially distributed' in two or more dimensions. These spatial features are digitally stored in vector and raster data structures.

2.3.1 Spatial Data Representation in Vector Format

Vector data structures represent geographic data by locating x and y coordinates (longitude and latitude) and are represented in point, line and polygon features (Fig. 2.3). The vector represents the object as exactly as possible. The coordinate space is assumed to be continuous, allowing all positions, lengths and dimensions to be defined precisely.

Point feature This is defined as a dimensionless, single geometric position. It occupies a discrete location and is located by a pair of x and y coordinates such as latitude and longitude on the Earth's surface, to locate features such as elevation points, electric poles, houses, wells or towns using a unique symbology.

Line, string or polyline features These are obtained by connecting two or more points to form a second type of spatial feature called a line or polyline which is one dimension (the feature has no width) and stretches in one direction only. A line connects two points and a string or polyline is a sequence of two or more connected lines; alternatively we can call it a series of connected x–y coordinate pairs. An arc, chain and string comprise a set of x and y coordinate pairs describing a continuous complex line. A line consists of two ends known as nodes and two lines are connected by these nodes only. The straight line has fewer nodes or x–y coordinates,

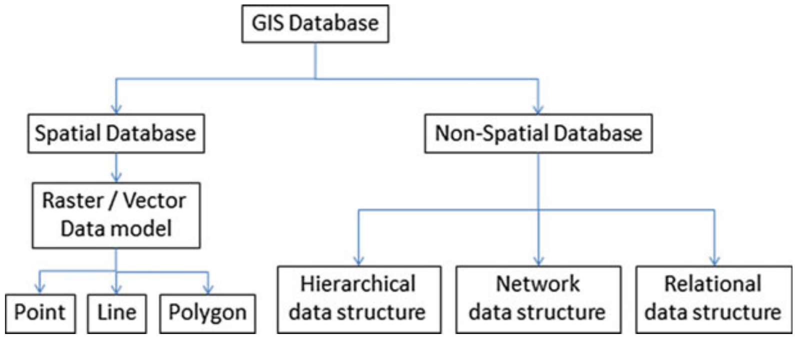


Fig. 2.2 Type of databases in GIS

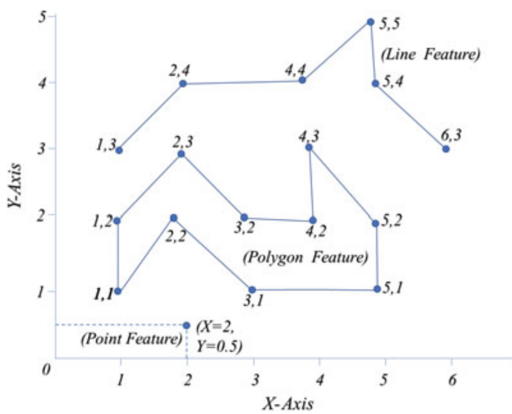


Fig. 2.3 Vector data structure in x–y coordinates

but the curve and smooth line have a large number of nodes or x–y coordinate pairs, also known as splines. These are used to represent all linear features such as road networks, railway lines, electricity distribution, water pipelines, streams, fences etc.

Polygon feature This is a series of lines, connected with nodes to form an enclosed boundary, and creates the third type of spatial feature called a polygon or area feature. It is a 2-dimensional closed homogeneous polygon feature of which the starting and end node are the same. In GIS terms, the polygon is used to designate an area feature. The area may be simple or complex. Simple areas are single polygons while a *polygon in polygon* represents more complex features such as *park contains pond* (Fig. 2.4) as well as enclosed boundaries, land parcels, ponds, river basins, forests etc.

The scale factor is very important when choosing or deciding between point, line and polygon features. According to scale, the feature can be interchangeable between point and polygon and line and polygon. Suppose you are creating a world map (small scale) and you want to locate Delhi on it, then it would be located as a point feature. But if you want to make a map of Delhi State, then it would be a polygon. The digitisation of the Ganga River on a small scale would be a line feature, but in a large-scale map, it would be a polygon (Fig. 2.5).

2.3.2 Spatial Data Representation in Raster Format

Geographical data represented by cells or grid format have two dimensions (length and breadth), and these are sometimes termed pixels or picture elements. Each pixel is referenced by a row and a column number (digital number value). This contains some values that represent the attributes of the pixel (Kumar and Kaur 2015). A point is represented by a single pixel, a line by a number of neighbouring pixels connected in a given line direction, while a polygon or an area is represented by a group or cluster of adjoining pixels (Fig. 2.6). The geographical features are generalised in terms of a uniform and regular grid. The raster representation of geographical data assumes that the Earth has a flat Cartesian surface, according to which each pixel or cell is square, associated with a square parcel of the Earth's surface.

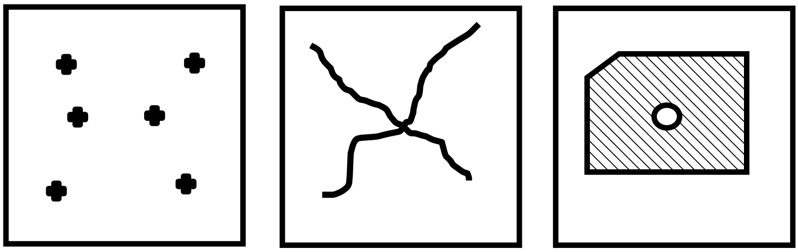
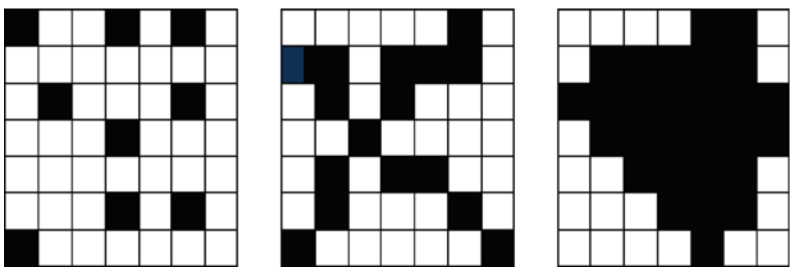


Fig. 2.4 Point, line and polygon and *polygon in polygon* features

1:20,000 scale map
Tourist map of Delhi
(large-scale map)

1:25,00,000 scale map
Road map
(small-scale map)

Fig. 2.5 Large-scale and small-scale maps (*source* Survey of India)



(a) Point (b) Line (c) Polygon

Fig. 2.6 Representation of spatial data in raster format

The resolution or scale of the raster data has a relation with the pixel or cell size and ground-feature size. If the pixel size is very small, known as high-resolution imagery, then it could be representing detailed features of the Earth's surface. For large-scale mapping, if the pixel size is larger than the feature, then it cannot represent the small features; this is known as coarse-resolution imagery (Fig. 2.7). For example, if the pixel size is 1000 m (coarse resolution) then it would not be able to represent the fountain in the garden, but if it is 0.5 m (high resolution), it can represent it very clearly in the images.

The raster data model represents phenomena or features using a tessellation approach. This is the partition of space into cells that together depict the geographical phenomena. There are regular and irregular tessellations. The regular tessellations have small shapes and sizes of cells and the values of the cells show their attributes. There are three regular tessellations—i.e. hexagonal, triangular and square (Fig. 2.8).

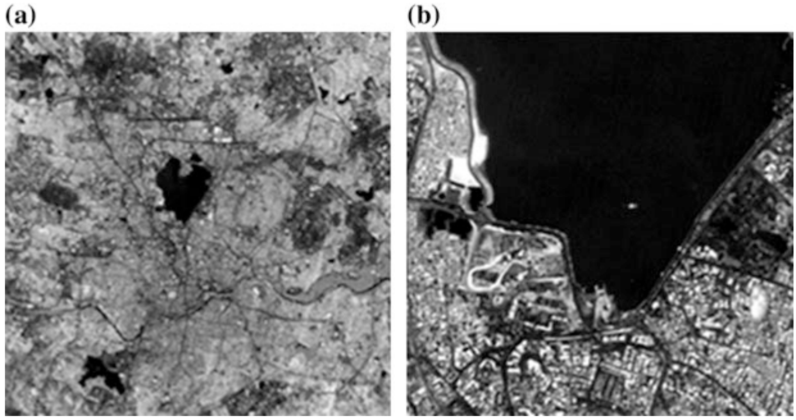


Fig. 2.7 Coarse-resolution (**a**) and high-resolution (**b**) imagery (*Source* NRSC)

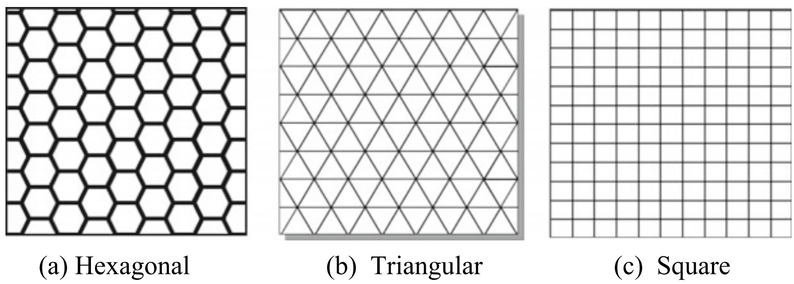


Fig. 2.8 Regular tessellation

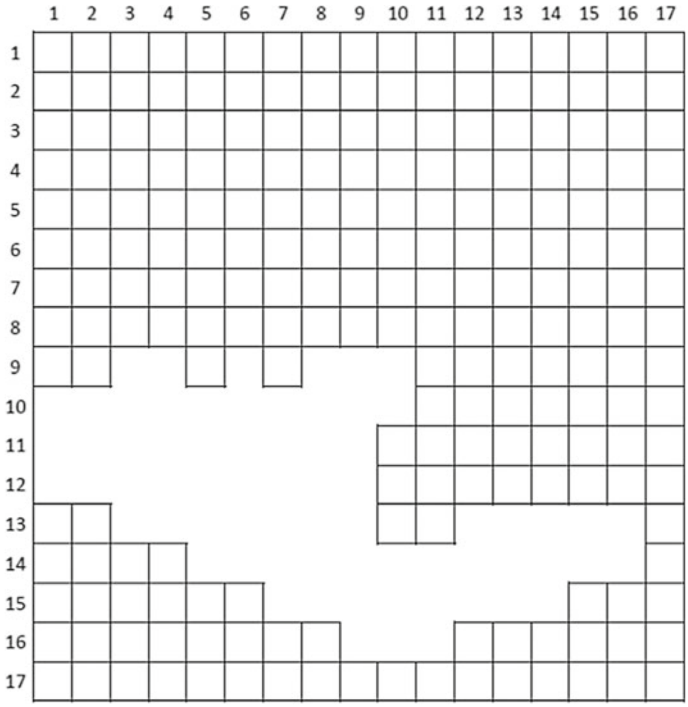
The square cells are widely used to represent the Earth's features. The regular pattern leads to fast algorithms for storage, retrieval and analysis but does not adapt to real spatial phenomena.

There are four main ways to represent irregular tessellations, such as chain codes, run-length codes, block codes and quadtrees codes. These are mainly used for compacting the data in order to reduce the storage space. In the chain codes, the boundary of the region in raster data can be given in terms of its origin and a sequence of unit vectors in the cardinal directions (Fig. 2.9). The directions can be numbered (East = 0, North = 1, West = 2, South = 3); for example, if we start at cell row = 10, column = 1, the boundary of the region is coded clockwise. The run-length code allows the points in each mapping unit to be stored per row in terms, from left to right, of a beginning cell and an end cell (Fig. 2.10).

Chain codes provide a very compact way of storing a regional representation and they allow the estimation of areas and perimeters. On the other hand, overlay operations such as union and intersection are difficult to perform without returning to a full grid representation. The boundaries between regions should be stored twice for data redundancy (Burrough 1986).

In this example, the 69 cells have been completely coded by 22 numbers, thereby effecting a considerable reduction in the space needed to store the data (many-to-one relation). On the other hand, too much data compression may lead to increased processing requirements during cartographic processing and manipulation.

With block code, the idea of run-length codes can be extended to two dimensions by using square blocks to tile the area to be mapped. The data structure consists of just three features: the number, origin (the centre or bottom left) and radius of each square. This is called a medial axis transformation (MAT) (Burrough et al. 2015). The region can be stored in 17 unit squares + 94-squares + 116-squares. Given that two coordinates are needed for each square, the region can



Example of Chain-code

$0, 1, 0^2, 3, 0^2, 1, 0, 3, 0, 1, 0^3, 3^2, 2, 3^3, 0^2, 1, 0^5, 3^2, 2^2, 3, 2^3, 3, 2^3, 1, 2^2, 1, 2^2, 1, 2^2, 1, 2^2, 1^3.$

Fig. 2.9 Irregular tessellation with chain codes

Example of Run-Length

Row 9	2,3	6,6	8,10
Row 10	1,10		
Row 11	1,9		
Row 12	1,9		
Row 13	3,9	12,16	
Row 14	5,16		
Row 15	7,14		
Row 16	9,11		

Fig. 2.10 Irregular tessellation with run-length codes

be stored using 57 numbers (54 for coordinates and 3 for cell sizes) (Fig. 2.11). Run-length and block codes are most efficient for large, simple shapes and least so for small, complicated areas that are only a few times larger than the basic cell. MAT has advantages for performing the union and intersection of regions and/or detecting properties such as elongation.

Quadtrees A more elegant tessellation is the quadtree in which the geographical area is decomposed into four equal quadrants and the decomposition continues until each quad represents a homogeneous unit (Fig. 2.12). The number of times the decomposition process may be applied, known as the resolution of decomposition, may either be fixed a priori or purely

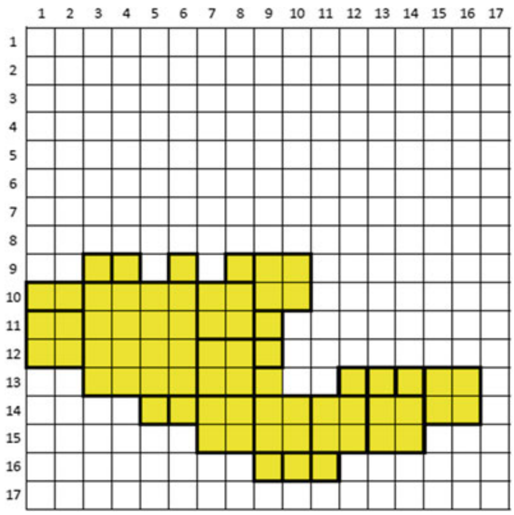


Fig. 2.11 Irregular tessellation with block codes

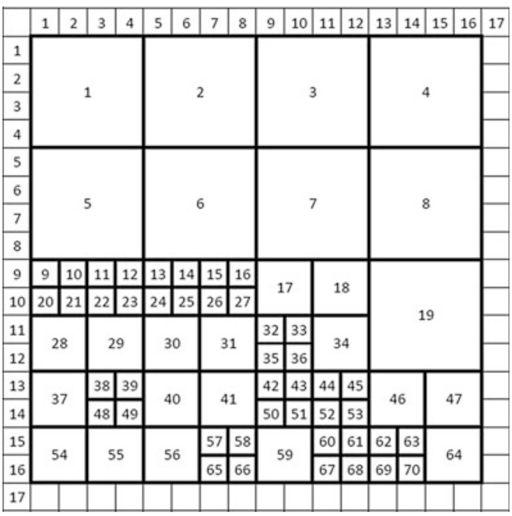


Fig. 2.12 Irregular tessellation with quadtree

determined by the input data. The storage requirements of a quadtree are much lower than those of a raster having the resolution of the smallest quad element. The tessellation into quad results in a tree with each nodes represented by four subnodes, thus the name quadtree. Quadtree variants for representing area, lines and points have been designed to represent polygon, line and point features, respectively.

The square-cell tessellation is mostly used in GIS because of geo-referencing the cells, also known as a raster map. The resolution of the cell is represented by the size of cell or pixel.

2.3.3 Choice between Raster and Vector

Raster and vector data models have different utilities and approaches to represent the geographical data and both are complementary and inter-convertible. The choice of the raster data model provides easy spatial analysis, whereas the vector data model provides manageable size and elegant graphics. Utility mapping such as for roads and railways is feasible in a vector database. The choice is determined by the object and requirement of the application (Table 2.1).

2.3.4 Sources of the Spatial Database

In GIS, accurate and reliable information is always required. The reliability of location is most important. There are many sources available for the spatial database.

Analogue maps The hard copy is known as an analogue map. This map is printed or traditionally drawn on paper or cloth. Examples include printed topographical sheets, census maps, aerial photographs and satellite imagery. Maps should whenever possible be procured from authentic and reliable sources such as the Census of India, Survey of India, National Remote Sensing Centre, Geological Survey of India, National Atlas and Thematic Mapping Organization (NATMO) etc.

Remote-sensing imagery This is provided by the remote-sensing satellite. Initially it provides the digital data directly but it can be supplemented by a hard-copy map, available from the concerned department. It is available at different resolutions from very high to coarse for different applications. In India, remote-sensing data can be procured from the National Remote Sensing Centre in Hyderabad. Digital remote-sensing data are also freely available from various

Table 2.1 Advantages and disadvantages of raster and vector data structures

Raster methods	
Advantages	*Disadvantages*
Simple data structure	Volume of graphical data
The overlay and combination of mapped data with remotely sensed data is easy	The use of large cells to reduce data volumes means that phenomenologically recognisable structures can be lost and there can be a serious loss of information
Various kinds of spatial analysis are easy	Crude raster maps are considerably less elegant than maps drawn with fine lines
Simulation is easy because each spatial unit has the same size and shape	Network linkages are difficult to establish
The technology is cheap and is being energetically developed	Projection transformation is time-consuming unless special algorithms or hardware are used
Vector methods	
Good representation of phenomenological data structure	Complex data structures
Compact data structure	Combination of several vector polygon maps or polygon and raster maps through overlay creates difficulties
Topology can be completely described with network linkage	Simulation is difficult because each unit has a different topological form
Accurate graphical representation	Display and plotting can be expensive, particularly for high quality, colour and cross-hatching
Retrieval, updating and generalisation of graphics and attributes are possible	The technology is expensive, particularly for the more sophisticated software and hardware
	Spatial analysis and filtering within polygons are impossible

sources such as Bhuvan Indian Geo-platform, USGS EarthExplorer, USGS Global Visualization Viewer (GloVis), ESA's Sentinel, Japan Aerospace Exploration Agency (JAXA), Global Land Cover Facility (GLCF) etc. (see Appendix).

Aerial photograph A photograph taken from an aircraft or drone is known as an aerial photograph. It can be digital or analogue. Very detailed information is available in the photograph which is utilised for updating the topographical sheet and providing detailed mapping.

GPS data A global positioning system (GPS) is a constellation of 24 satellites that continuously transmit coded information, which makes it possible to precisely identify locations on Earth by measuring their distance from the satellites. It provides geographical location, altitude and time in text format (ASCII—American Standard Code for Information Interchange) for GIS input.

Field survey This is a collection of positional information and its attributes, acquired in the field. It can be cross-checked by ground validation of spatial information.

2.4 Non-spatial Database

The non-spatial database represents the characteristics, also called attribute data or descriptive information, of the spatial database. It describes regions and defines the characteristics of spatial features within geographic regions. The non-spatial data are usually alpha-numeric and provide information such as the colour, texture, quantity, quality and value of features. For example, a map of Delhi with its 'attributes' data describes Delhi's characteristics such as elevation, land use, populations, boundary information etc.

This information is usually kept in tabular form consisting of rows and columns, managed as a normal database. Each row represents a feature of a map, and a column represents the desired characteristics of a particular row. Changes to any feature on that map, for example an urban boundary, can be generated by the attribute data.

A separate data model is used to store and maintain non-spatial or attribute (additional information) data for GIS. These data models may exist internally within the GIS software, or may be reflected externally through database management systems (DBMS). A variety of different data models exists. The most common non-spatial database structures are hierarchical, network and relational.

2.4.1 Hierarchical Data Structure

When the data have family relations like a parent–child relationship or tree structure, an administrative structure represents the hierarchical structure: i.e. as a state, district, *tehsil* (administrative division), block or village. The data are stored in such a way that a hierarchy is maintained. Each node can be divided into one or more additional nodes. The hierarchical system assumes that each part of the hierarchy can be reached using a key that fully describes the data structure, such as soil family. It is easy to understand, update and expand, like the open system of land-use classification. Data access via keys is easy for key attributes but very difficult for associated attributes. Travel within the database is restricted to only up and down paths. It has a large index file and certain attribute values, repeated many times, leading to data redundancy, which further increases storage and access costs (Fig. 2.13).

2.4.2 Network Data Structure

The network data structure has multiple connectivity with different hierarchies of data—in other words, a node may have more than one parent node. It provides fast linkages between various levels of data. Network structures have a structure, like a ring pointer. They are used in navigating complex topological structures. They avoid data redundancy and make good use of available data (Fig. 2.14).

2.4.3 Relational Data Structure

The relational database stores data in simple records, containing an ordered set of attribute values grouped together in a 2-dimensional table known as a relation. Each row in the table is a record of a feature and each record has a set of attributes stored in columns. Different tables are related through the use of a common identifier called a primary key which should be unique in nature within the whole database. Relational databases have a great advantage because their structure is very flexible and can meet the demands of all queries that can be formulated using the rules. Adding or removing spatial and non-spatial data is very easy because it involves just adding and removing a row and column. The disadvantage of relational databases is that many of the operations involve sequential searches through the file to find the right data to satisfy the specific relation (Fig. 2.15).

2.5 Conclusion

The database is an important part of the GIS and plays a major role in providing inputs in a GIS environment. The features of the real-world system are converted into different themes or layers of the database. These layers are composed of characteristics of those features in the form of spatial and non-spatial types of database. So, in GIS, two

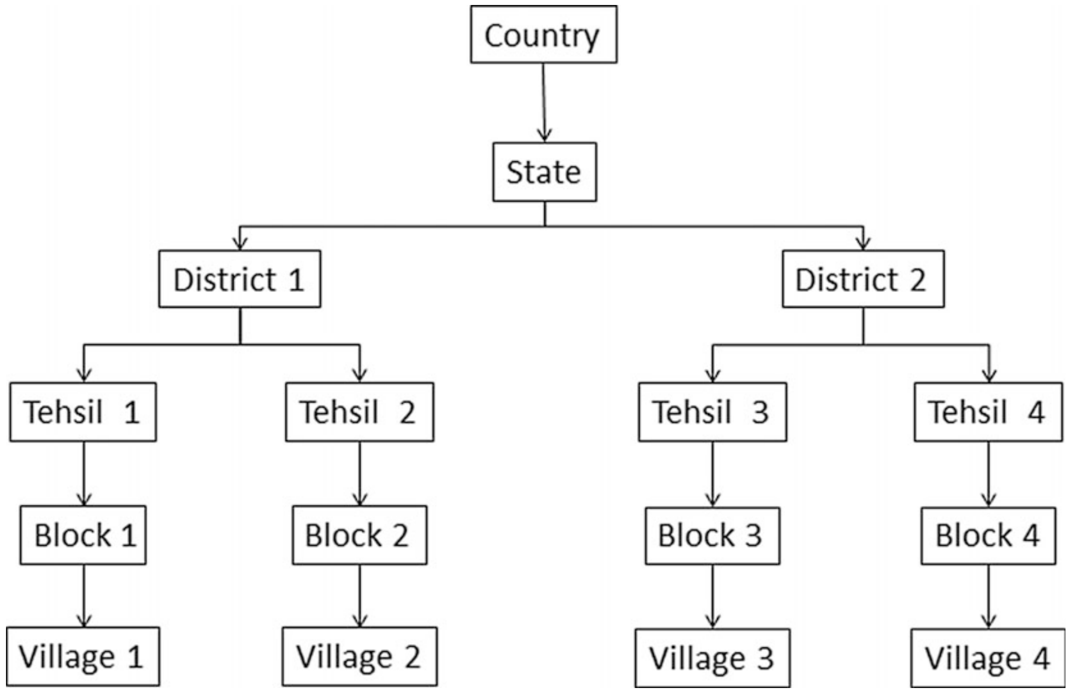


Fig. 2.13 Hierarchical data structure

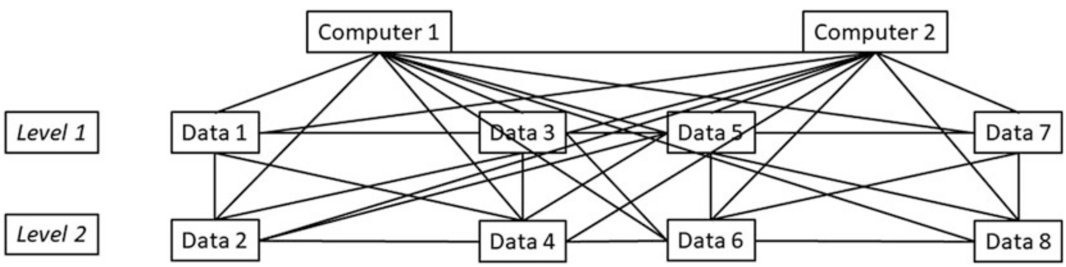


Fig. 2.14 Network data structure

types of database are used: one is spatial and the other non-spatial. All the geographical features of the Earth's surface or spatial features are represented by point, line and polygon features. These features can be stored in vector and raster data structures. The vector data structure is stored in a pair of *x*–*y* coordinates, i.e. it is dimensionless. The spatial features in raster format are a group of pixels or cells arranged in a row and column. Each cell has a dimension of length and width. The raster data are represented in cells and stored in regular and irregular tessellations. Both raster and vector data models have different utilities, represent geographical data, and are complementary to and inter-convertible with each other. There are different sources of spatial databases, in the form of analogue maps, remote-sensing imagery, aerial photographs, GPS data and field surveys.

A non-spatial database includes the characteristics of a spatial database stored alphanumerically and provides information in tabular form. The three most common non-spatial database structures are (1) hierarchical, where a tree structure exists; (2) networked, where multiple

Fig. 2.15 Relational data structure

Total Population				
Block_ID	Block_name	Total Population	Total Male	Total Female
1	Shahpur	171442	90621	80821
2	Arrah	166264	87997	78267
3	Barhara	194439	103113	91326
4	Koilwar	149636	78684	70952
5	Sandesh	90259	47177	43082
6	Udwant Nagar	132258	69201	63057

SC Population			
Block_ID	Total SC	Male SC	Female SC
1	23453	12272	11181
2	28057	15099	12958
3	24541	13109	11432
4	22826	12121	10705
5	12803	6780	6023
6	24364	12762	11602

ST Population			
Block_ID	Total ST	Male ST	Female ST
1	1835	1004	831
2	1492	775	717
3	1764	941	823
4	462	240	222
5	80	53	27
6	43	19	24

connectivity with all the data is there; and most importantly, (3) relational, where the relation is established while joining or appending the various databases.

Questions

1. What do we mean by database in the GIS environment?
2. Discuss the various types of databases and their sources in GIS.
3. What are the differences between spatial and non-spatial databases in GIS?
4. Discuss the spatial data structures that represent the Earth's features.
5. Discuss the storage of spatial features in vector format.
6. Discuss the methods of spatial data storage in raster format.
7. What are the differences between raster and vector data structures to represent the spatial database?
8. Discuss the non-spatial data structure in GIS.
9. Discuss the importance of the unique identification number and its relation with data structure.

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3 Remote-Sensing Technology

Abstract

Spatial information systems provide information about the Earth and its environs. On the Earth's surface, different features are distributed and phenomena are occurring at different places, and these require reliable and quick information. Here remote sensing plays an important role in providing near real-time unbiased spatial information to the user community for mapping the Earth's features. After reading this chapter you should be able to understand the following:

- The meaning and definition of remote sensing
- Remote-sensing processes and platforms
- The electromagnetic spectrum and interaction of electromagnetic radiation
- Elements of photo/image interpretation
- Earth-resource observation remote-sensing satellites, especially those launched by the United States, Europe and India
- Digital image processing—pre-processing, enhancement, image classification and accuracy assessment
- Integration of remotely sensed data and GIS.

Keywords

Platform · Electromagnetic energy · Digital image processing · Satellite system · Image interpretation · Accuracy assessment · Classification

3.1 Introduction

Remote sensing means acquiring knowledge from a distance. Conceptually, remote sensing is not only the sensing but includes the complete processes in which data about the Earth's surface are recorded through monitoring electromagnetic energy; they are processed in the laboratory to make them usable for different applications, and subsequent analysis of rectified data in a multi-disciplinary approach (Kumar and Kaur 2015). Different scholars have defined remote sensing in their own way. Colwell (1966) used the term 'remote sensing' in its broadest sense, which merely means 'reconnaissance at a distance'. He later (1983) defined it as: 'The measurement or acquisition of information of some property of an object or phenomenon, by a recorded device that is not in physical or intimate contact with the object or phenomenon under study.' In 1997 he further refined this as 'The art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems.' Lillesand and Kiefer (2000) suggest that '[r]emote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with

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the object, area, or phenomenon under investigation.' Further, Campbell (2002) defines 'Remote Sensing [as] the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface.' According to Jensen (2007), '[r]emote sensing is the process of collecting data about objects or landscape features without coming into direct physical contact with them. Finally, remote sensing is a multidisciplinary activity which deals with the inventory, monitoring and assessment of natural resources through the analysis of data obtained by observations from a remote platform'. So remote sensing can be defined as an art, science and technique of collecting real information, without being in physical contact with an object or phenomenon through the sensor or camera from the various platforms over the wide range of electromagnetic energy by the means of a tripod, aircraft, spacecraft or satellite for multidisciplinary analysis.

3.2 Elements of Remote Sensing

In the remote-sensing process, various mechanisms/activities are involved while supplying the final data to the user community. They are as follows (see Fig. 3.1).

(a) **Source of energy** The Sun and the Earth are two natural sources of energy. The Sun is a major source of electromagnetic energy that illuminates the object. The other sources of energy are flash gun, radar, geo-thermal energy etc., which interact with an object.

(b) **Interaction of electromagnetic radiation with an atmosphere** Electromagnetic energy travels through the different thicknesses of the

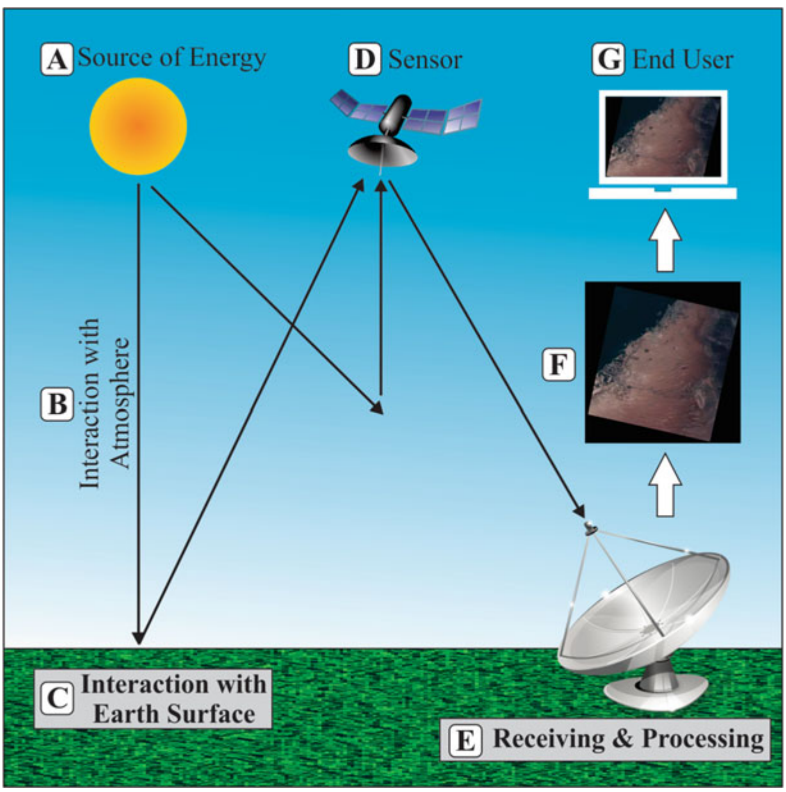


Fig. 3.1 Stages of remote sensing

atmospheric layer to reach the target, at which point it is reflected back to the sensor, thus travelling through the atmosphere twice.

(c) **Interaction of electromagnetic radiation with Earth's surface** The energy interacts with surface features such as land, water and vegetation. The interaction varies according to their properties.

(d) **Electromagnetic energy received by the sensor** After interacting with the object on the Earth's surface, the electromagnetic energy is reflected back to the atmosphere. This reflected energy is acquired by the sensor and the amount received by the sensor depends upon the object's behaviour and the atmospheric conditions.

(e) **Transmission to the ground station** The electromagnetic energy received by the sensor is converted into signals and transmitted to the ground-receiving stations in various global locations. In India, Delhi, Lucknow, Hyderabad and many more cities are receiving these data.

(f) **Rectification of data** The received signals are converted into the picture elements in order to create image data. These image data, in raw form supplied by the sensor, are not useful to the common user. In their original form they contain discrepancies. These data are rectified according to the needs of the user.

(g) **Supply to the user** The rectified image data are called imagery, and supplied in either analogue or digital form to users, according to their requirements. The data are finally digitally or visually analysed and conclusions are drawn that can be applied to various fields or applications.

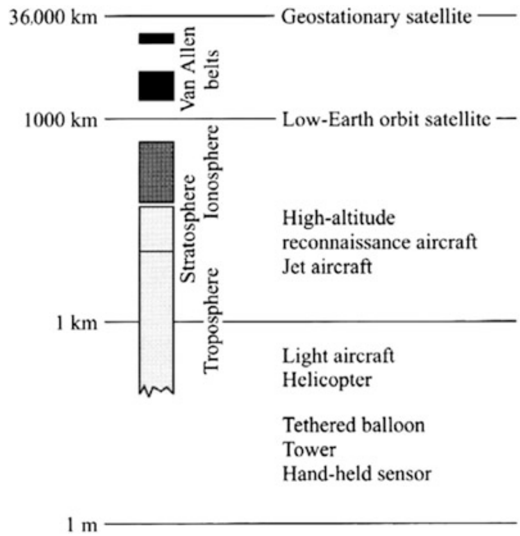


Fig. 3.3 Remote-sensing platforms above the Earth's surface (after Rees 2001)

3.3 Remote-Sensing Platforms

In remote sensing, platforms play an important role to provide bases for sensor mounting in moving or static form. Moving platforms include balloons, kites, pigeons, aircraft and spacecraft/satellites. Static platforms include high-rise buildings, tripods etc. used for collecting ground information (ground truth) or laboratory simulation for experimental purposes. In general, the platform is a means of holding the sensor aloft (Rees 2001). It is a stage on which to mount the camera or sensor to acquire the information about the target under investigation. On the basis of altitude above the Earth's surface, a platform may be classified as groundborne, airborne or spaceborne (Figs. 3.2 and 3.3).

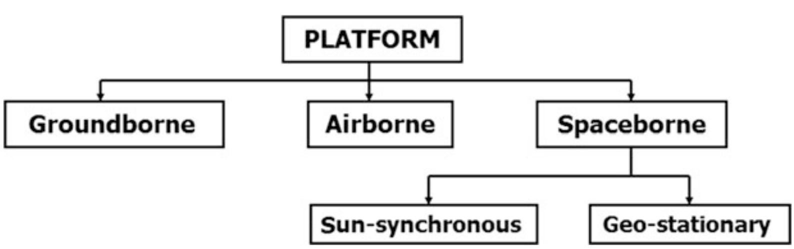


Fig. 3.2 Types of remote-sensing platforms

Fig. 3.4 Groundborne platform on a moving vehicle

3.3.1 Groundborne

As the term suggests, groundborne sensors are positioned near to the ground; they can be hand-held, mounted on a tripod, positioned on the roof of a building or operated from a moving vehicle, in order to collect information. A ground-based remote-sensing system for Earth-resource studies is mainly used for collecting soil samples obtained during fieldwork or for laboratory simulation studies before sensor mounting on the airborne or spaceborne platform. This can, for example, be a camera or radiometer mounted to a pole or tripod or moving vehicle (Fig. 3.4) to assess the reflectance behaviour of an object or phenomenon or a specific crop during a day or season.

3.3.2 Airborne

Airborne observation is carried out by using aircraft with specific modifications to carry remote sensors. In the past, pigeons, balloons or kites were used for airborne remote sensing. The airborne platform provides flexibility in the choice of altitude (platform) and convenience for acquiring the data in terms of time and requirements. Airborne observations are possible from 100 m up to 30–40 km above the ground. The speed of the aircraft can vary between 140 and 600 kmph. The main disadvantage of aircraft, as a platform for remote sensing, is short duration as compared to the spaceborne platform, which means the absence of continuous data as well as influence from atmospheric dynamics producing geometric distortion in the photograph. An airborne observation is acquired from much lower altitudes than spaceborne observations, so the spatial coverage of data is smaller, and it is obviously unsuitable for very large area mapping. On the other hand, it is much more suitable for detailed investigations of smaller areas. Recently drones have been used as airborne platforms.

3.3.3 Spaceborne

A spaceborne sensor is mounted on a satellite and deployed with the help of a satellite launching vehicle. The placing of a satellite-carrying sensor in orbit is more expensive than an airborne platform but benefits include the high speed of the satellite, large field of view (potential swath) and increased spatial coverage due to continuity of observations of the Earth's surface. Spaceborne platforms are not, like airborne platforms, affected by the Earth's atmosphere. Depending upon the altitude, there are two types of orbit: polar (Fig. 3.5) and geostationary (Fig. 3.6). These are used to place the satellites, depending on the objectives of the mission. The orbit height is calculated by subtracting the radius of the Earth from the orbit of the satellite. For example, where the orbit of the satellite is 7200 km and the Earth's radius is 6400 km, then the orbital height of the satellite is 800 km (7200 − 6400 = 800 km).

3.4 Electromagnetic Spectrum

Electromagnetic energy categories on the scale of wavelengths are called the electromagnetic spectrum (Fig. 3.7). This extends from gamma rays (shortest wavelength) to radio waves

Fig. 3.5 Polar orbits

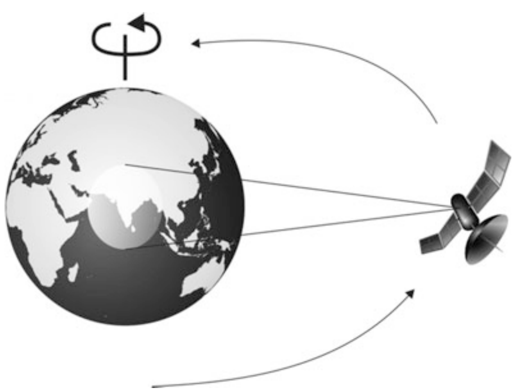


Fig. 3.6 Geostationary orbits

(longest wavelength). Further subdivisions of spectral regions are known as spectral bands. The electromagnetic spectrum plays a vital role by providing atmospheric windows (Table 3.1) for remote-sensing processes for various applications (Table 3.2). Broadly, for remote-sensing purposes, the electromagnetic spectrum is divided into two major parts: the optical region and the microwave region. The optical region of the electromagnetic spectrum refers to that part of the spectrum in which optical laws apply. It ranges from X-rays (0.02 μm) through the visible part of the electromagnetic spectrum to the far infrared (1000 μm) region.

Gamma rays (shorter than 0.3 Å) and X-rays (0.3–300 Å) (ångström = 10^{-10} m) This region has been used to a lesser extent because of atmospheric opacity. Its use has been limited to low-flying aircraft platforms or to the study of planetary surfaces with no atmosphere (e.g., the Moon). It is used mainly to sense the presence of radioactive materials.

Ultraviolet region (300 Å–0.4 μm) This is used mainly to study planetary atmospheres or surfaces with no atmospheres because of the opacity of gases at these short wavelengths. An ultraviolet spectrometer was mounted on the *Voyager* spacecraft to determine the composition and structure of the upper atmosphere of Jupiter, Saturn and Uranus.

Visible region (0.4–0.7 μm) This electromagnetic region plays an important role in remote sensing. This spectral band receives maximum illumination from the Sun and its energy is readily detectable by sensors. This is also known as 'visible light'. It occupies a relatively small portion of the electromagnetic spectrum. This is the only portion of the spectrum that is associated with the concept of colour, i.e. blue, green and red, which are known as primary colours.

Infrared region (0.4–10^3 μm) This region is subdivided into three subregions, i.e. reflected infrared, thermal infrared and far infrared. Reflected infrared divides into near infrared (NIR), the wavelength of which is 0.7–1.4 μm, and short-wave infrared (SWIR), which is 1.4–3.0 μm. Thermal infrared is divided into mid-wave infrared (MWIR), which is 3.0–8.0 μm, and long-wave infrared (LWIR), 8.0–15.0 μm. The far infrared subregion wavelength

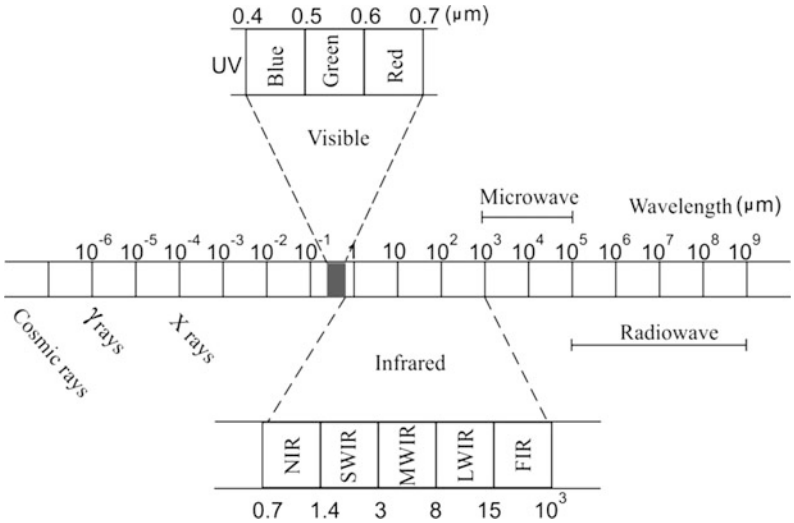


Fig. 3.7 Electromagnetic spectrum

Table 3.1 Atmospheric windows for remote sensing

	Spectral regions	Spectral bands
1	VIS (visible)	0.4–0.70 μm
2	NIR (near infrared)	0.7–1.4 μm
3	SWIR (short-wave infrared)	1.4–1.80 μm 2.0–2.50 μm
4	MWIR (mid-wave infrared)	3.0–5.00 μm
5	LWIR (long-wave infrared)	8.0–9.50 μm 10.0–14.0 μm
6	Far infrared	15 μm–1 mm
7	Microwave	1 mm–1 m

Table 3.2 Application of spectral region

Spectral region	Main interaction mechanisms	Examples of remote-sensing applications
Gamma rays, x-rays	Atomic processes	Mapping of radioactive materials
Ultraviolet	Electronic processes	Presence of H and He in atmosphere
Visible and near infrared	Electronic and vibration molecular processes	Surface chemical composition, vegetation cover, and biological properties
Mid-infrared	Vibrational, vibrational–rotational molecular processes	Surface chemical composition, atmospheric chemical composition
Thermal infrared	Thermal emission, vibrational and rotational processes	Surface heat capacity, surface temperature, atmospheric temperature, atmospheric and surface constituents
Microwave	Rotational processes, thermal emission, scattering, conduction	Atmospheric constituents, surface temperature, surface physical properties, atmospheric precipitation
Radio frequency	Scattering, conduction, ionospheric effect	Surface physical properties, subsurface sounding, ionospheric sounding

is 15.0–1000 μm or 1 mm. In this region, molecular rotation and vibration play important roles. Imagers, spectrometers, radiometers, polarimeters and lasers are used in this region for remote sensing. Thermal infrared gives information about surface temperature.

Microwave region (1 mm–1 m) This covers the neighbouring region, down to a wavelength of 1 mm (300 GHz frequency). In this region, most of the interactions are governed by molecular rotation, particularly at the shorter wavelengths. This region is mostly used by microwave radiometers/spectrometers and radar systems.

Radio wave region (more than 10 cm) This covers the region of wavelengths longer than 10 cm (frequency less than 3 GHz). This region is used by active radio sensors such as imaging radars, altimeters and sounders, and, to a lesser extent, passive radiometers.

3.5 Interaction of Electromagnetic Radiation with Earth Features

When electromagnetic energy is incident on any given Earth-surface feature, three fundamental energy interactions occur, i.e. reflected, absorbed and transmitted. The proportions of energy reflected, absorbed and transmitted will vary for different Earth features in different wavelengths, depending on their material type and condition. These differences permit us to distinguish different features on an image. Many remote-sensing systems operate in the wavelength regions in which reflected energy predominates, so the reflectance properties of Earth features are most important to identify features in an image. A graph of the spectral reflectance of an object as a function of wavelength is termed as a spectral reflectance curve (Fig. 3.8).

3.5.1 Interaction of Electromagnetic Radiation with Soil

Various characteristics of the soil interact differently with electromagnetic energy, such as

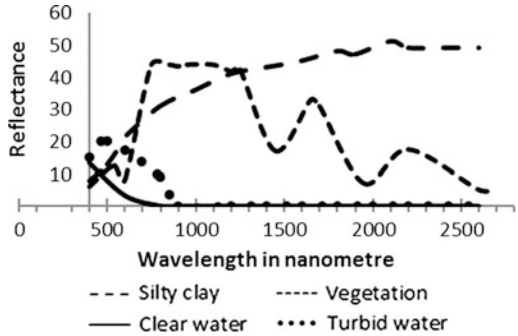


Fig. 3.8 Spectral reflectance curve

moisture, texture, surface roughness and the presence of minerals and organic matter content. Coarse, sandy soils are usually well drained, resulting in low moisture content and relatively high reflectance of electromagnetic energy. Poorly drained, fine-textured soil will generally have lower reflectance of electromagnetic energy. The absence of water in the soil itself will show the reverse tendency, with coarse-textured soils will appearing darker in the imagery than fine-textured soils. Surface roughness and organic matter content decrease soil reflectance. The presence of iron oxide in a soil will also decrease reflectance in the visible region.

3.5.2 Interaction of Electromagnetic Radiation with Vegetation

The characteristics of vegetation relevant to reflectance include leaf structure, moisture content and levels of chlorophyll. Our eyes perceive healthy vegetation as green in colour because of the very high absorption of blue and red energy by plant leaves and the very high reflection of green energy. The blue and red bands constitute the chlorophyll-absorption region. Stress on plants decreases chlorophyll production, resulting in less chlorophyll absorption by these bands. In the near infrared region, the reflectance behaviour is determined by the structure of the leaf. As the structure of the leaf is highly variable between different plant species such as banyan, banana etc., the near infrared region can be useful to discriminate tree species, even if they look the same in the visible region. Near infrared is also used to detect stress on vegetation. The reflectance of healthy vegetation increases dramatically and reflects 40–50% of the energy incident upon it, and very little, less than 5% of energy, is absorbed in this region. The reflectance also increases with the number of layers of leaves in a canopy and maximum reflection is achieved at about eight leaf layers. Beyond 1.3 μm vegetation is essentially absorbed or reflected, with little or no transmittance of energy. There is water absorption at 1.4–1.9 and 2.7 μm. These are referred to as water absorption bands and 1.6 and 2.2 μm wavelengths have a peak reflectance between absorption bands.

3.5.3 Interaction of Electromagnetic Radiation with Water

Basically, water surface acts as specular reflection. But the suspended material in the water and the bottom of a shallow water body interact differently with electromagnetic energy. Clear deep water acts as a blackbody for the near infrared and beyond energy that it absorbs. Suspended material in water changes the reflectance of the energy. The reflectance increases in tandem with the increase in suspended matter. Any increases in chlorophyll concentration in the water tend to decrease reflectance in the blue region and increase reflectance in the green region. Due to this characteristic, electromagnetic energy is used to monitor and estimate the concentration of algae through remote-sensing data. Snow has very high reflectance in the visible region, but it drops in the near infrared region. The mid-infrared region is used to identify snow and cloud due to low reflectance from snow and comparatively high reflectance from cloud.

3.6 Earth Resource Observation Remote-Sensing Satellites

The imagery produced by the satellite is mainly utilised for the monitoring and assessment of natural and man-made resources through mapping processes. In this regard, the characteristics of the sensor are the most important feature of the satellite, especially its level of resolution. Satellite-based remote sensing has been widely accepted since the launch of the first Earth-resource remote-sensing satellite, Landsat, in 1972, followed by the SPOT series, IRS series etc. These satellites also use different orbits for various objectives.

3.6.1 Landsat Series

Landsat is a series of satellites launched by the USA, the first to provide digital imagery for image processing. The Earth Resources Technology Satellite (ERTS) was launched on 23 July 1972; it was renamed Landsat in 1975. Landsat 1 was the first unmanned satellite specifically designed to acquire data about Earth resources on a repetitive, low-resolution and multispectral basis. It was a sun-synchronous, near-polar orbiting satellite. This was very useful for natural and cultural resources-monitoring and assessment of the Earth's surface. Landsat has subsequently successfully launched seven satellites, with the exception of Landsat 6, which failed to achieve orbit in 1993. There are six different sensors incorporated in the Landsat series with different combinations—i.e. Return Beam Vidicon (RBV), Multispectral Scanner System (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Landsat 1, 2 and 3 incorporated RBV and MSS, providing images of the same area by framing and scanning systems, respectively. Landsat 4 and 5 incorporated MSS with enhanced radiometric resolution of 8 bits and TM sensor with 7 bands. Landsat 7, still in operation, has ETM+ and Landsat 8 has OLI and TIRS sensors (Tables 3.3 and 3.4).

3.6.2 Commercial Satellites

IKONOS This is the world's first commercial satellite launched on 24 September 1999 at a 680 km-high orbit, to collect data on

Table 3.3 Landsat satellite characteristics

Satellite (launching year)	Sensor (Revisit)	Spectral range	Spatial resolution (Radiometric resolution)	Swath
(ERTS-1, before 1975) Landsat 1 (23 July 1972) Landsat 2 (22 January 1975)	RBV (18 days)	B1: 475–575 nm VR B2: 580–680 nm VR B3: 690–830 nm VR	80 m	185 km
	MSS (18 days)	B4: 0.5 to 0.6 μm VR B5: 0.6 to 0.7 μm VR B6: 0.7 to 0.8 μm VR B7: 0.8 to 1.1 μm NIR	80 m (6 bits)	185 km
Landsat 3 (5 March 1978) 18 days Landsat 3 (5 March 1978) 18 days	RBV (2 cameras) (18 days)	Panchromatic 0.5 to 1.1 μm	40 m	90 km each (180 km)
	MSS (18 days)	B4: 0.5 to 0.6 μm VR B5: 0.6 to 0.7 μm VR B6: 0.7 to 0.8 μm NIR B7: 0.8 to 1.1 μm NIR B8: 10.4 to 12.6 μm TIR	80 m (6 bits)	185 km
Landsat 4 (16 July 1982) 16 days Landsat 5 (1 March 1984)	MSS (16 days)	B4: 0.5 to 0.6 μm VR B5: 0.6 to 0.7 μm VR B6: 0.7 to 0.8 μm VR B7: 0.8 to 1.1 μm NIR	80 m (6 bits)	185 km
	TM (16 days)	B1: 0.45–0.52 μm VR B2: 0.52–0.60 μm VR B3: 0.63–0.69 μm VR B4: 0.76–0.90 μm NIR B5: 1.55–1.75 μm NIR B6: 10.40–12.50 μm TIR B7: 2.08–2.35 μm MIR	30 m 120 m (B 6) (8 bits)	185 km
Landsat 6 (5 October 1993) *Did not achieve orbit*	ETM	B1: 0.45–0.52 μm VR B2: 0.52–0.60 μm VR B3: 0.63–0.69 μm VR B4: 0.76–0.90 μm NIR B5: 1.55–1.75 μm NIR B6: 10.40–12.50 μm TIR B7: 2.08–2.35 μm MIR B8: 0.52–0.90 μm PAN	30 m (B1–5, 7) 120 m (B6) 15 m (B8) (9 bits)	185 km
Landsat 7 (15 April 1999)	ETM+ (16 days)	B1: 0.45–0.52 μm VR B2: 0.52–0.60 μm VR B3: 0.63–0.69 μm VR B4: 0.76–0.90 μm NIR B5: 1.55–1.75 μm NIR B6: 10.40–12.50 μm TIR B7: 2.08–2.35 μm MIR B8: 0.52–0.90 μm PAN	30 m (B1–5, 7) 120 m (B6) 15 m (B8) (9 bits)	185 km
Landsat 8 (11 February 2013)	OLI Operational Land Imager (16 days)	B1: 0.43–0.45 μm VR B2: 0.450–0.51 μm VR B3: 0.53–0.59 μm VR B4: 0.64–0.67 μm VR B5: 0.85–0.88 μm NIR B6: 1.57–1.65 μm SWIR B7: 2.11–2.29 μm SWIR 2 B8: 0.50–0.68 μm PAN B9: 1.36–1.38 μm Cirrus	30 m (B1–7, 9) 15 m (B8) (12 bits)	185 km
	TIRS Thermal Infrared Sensor (16 days)	B10: 10.6–11.19 μm (TIRS 1) B11: 11.5–12.51 μm (TIRS 2)	100 m (12 bits)	185 km

Table 3.4 Use of Landsat series satellites

Band	Wavelength	Application
1	0.45–0.52 μm (Blue)	This is useful for mapping water near coasts, differentiating between soil and plants, and identifying man-made objects such as roads and buildings
2	0.52–0.60 μm (Green)	Spanning the region between the blue and red chlorophyll absorption bands, this band shows the green reflectance of healthy vegetation. It is useful for differentiating between types of plants, determining the health of plants and identifying man-made objects
3	0.63–0.69 μm (Red)	The visible red band is one of the most important bands for discriminating among different kinds of vegetation. It is also useful for mapping soil-type boundaries and geological formation boundaries
4	0.76–0.90 μm (Near infrared)	This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification, for distinguishing between crops and soil, and for seeing the boundaries of water bodies
5	1.55–1.75 μm (Mid-infrared)	This reflective-IR band is sensitive to turgidity—the amount of water in plants. Turgidity is useful in drought studies and plant vigour studies. In addition, this band can be used to discriminate between clouds, snow and ice
6	10.4–12.5 μm (Thermal infrared)	This band measures the amount of infrared radiant flux (heat) emitted from surfaces, and helps us to locate geothermal activity, classify vegetation, analyse vegetation stress and measure soil moisture
7	2.08–2.35 μm (Mid-infrared)	This band is particularly helpful for discriminating among types of rock formations

panchromatic and multispectral imagery with 0.80 and 3.2 m resolution, respectively. The name IKONOS is derived from the Greek word for ‘image’. The sensor has 11-bit radiometric resolution. The revisit time of this satellite is three days and provides data in the spectral range of 0.45–0.90 μm in panchromatic and four multispectral bands: Band 1 Blue (0.445–0.516 μm), Band 2 Green (0.506–0.595 μm), Band 3 Red (0.632–0.698 μm) and Band 4 Near Infrared (0.757–0.853 μm). The imagery from both sensors (panchromatic and multispectral) can be resolution merged to create 0.80 m pan-sharpened colour imagery. The product of the IKONOS imagery is being used to provide large-scale mapping for national security and infrastructure development.

QuickBird This satellite was launched on 18 October 2001 at an orbital altitude of 450 km. In orbit for more than 13 years, the QuickBird mission ended on 27 January 2015. The spatial resolution was 0.61 m in panchromatic mode and 2.4 m in multispectral mode, providing 11-bit data. The revisit time was approximately 3.5 days. The spectral range of panchromatic imagery was 0.445–0.900 μm and multispectral imagery in four bands: Band 1 Blue (0.450–0.520 μm), Band 2 Green (0.520–0.6 μm), Band 3 Red (0.630–0.690 μm) and Band 4 Near Infrared (0.760–0.900 μm).

GeoEye-1 This satellite was launched on 6 September 2008 at an orbital altitude of 681 km. The satellite collects images at 0.41 m panchromatic and 1.65 m multispectral resolution. It can collect up to 350,000 km^2 of pan-sharpened multispectral imagery per day with three days’ revisit period. The spectral range of panchromatic imagery is 0.440–0.800 μm and multispectral imagery in four bands: Band 1 Blue (0.450–0.510 μm), Band 2 Green (0.510–0.580 μm), Band 3 Red (0.655–0.690 μm) and Band 4 Near Infrared (0.780–0.920 μm).

WorldView-1 This satellite was launched in September 2007 at an orbital altitude of 496 km

Table 3.5 WorldView-3 sensor band

Panchromatic: 450–800 nm	
8 multispectral:	
Coastal: 400–450 nm Blue: 450–510 nm Green: 510–580 nm Yellow: 585–625 nm	Red: 630–690 nm Red edge: 705–745 nm Near-IR1: 770–895 nm Near-IR2: 860–1040 nm
8 SWIR bands:	
SWIR-1: 1195–1225 nm SWIR-2: 1550–1590 nm SWIR-3: 1640–1680 nm SWIR-4: 1710–1750 nm	SWIR-5: 2145–2185 nm SWIR-6: 2185–2225 nm SWIR-7: 2235–2285 nm SWIR-8: 2295–2365 nm
12 CAVIS bands:	
Desert clouds: 405–420 nm Aerosol-1: 459–509 nm Green: 525–585 nm Aerosol-2: 635–685 nm Water-1: 845–885 nm Water-2: 897–927 nm	Water-3: 930–965 nm NDVI-SWIR: 1220–1252 nm Cirrus: 1365–1405 nm Snow: 1620–1680 nm Aerosol-3: 2105–2245 nm Aerosol-3: 2105–2245 nm

with an average revisit time of 1.7 days. This satellite has only a panchromatic imaging system with very high spatial resolution of 0.5 m at 0.4–0.9 μm with 11-bit data. The satellite is also equipped with state-of-the-art geo-location accuracy capabilities and exhibits stunning agility with rapid targeting and efficient in-track stereo collection.

WorldView-2 This satellite, launched on 8 October 2009, is the first high-resolution 8-band multispectral commercial satellite with an orbital altitude of 770 km, and has an average revisit time of 1.1 days. WorldView-2 provides 46 cm panchromatic resolution and 1.85 m multispectral resolution with 11-bit data. The spectral range of panchromatic imagery is 0.450–0.800 μm and multispectral imagery in eight bands: Band 1 Coastal (0.4–0.45 μm), Band 2 Blue (0.450–0.510 μm), Band 3 Green (0.510–0.580 μm), Band 4 Yellow (0.585–0.625 μm), Band 5 Red (0.630–0.690 μm), Band 6 Red Edge (0.705–0.745 μm), Band 7 Near Infrared 1 (0.770–0.895 μm) and Band 8 Near Infrared 2 (0.860–1.040 μm).

WorldView-3 This is the first multi-payload, super-spectral, high-resolution commercial satellite, launched on 13 August 2014 at an orbital altitude of 617 km. WorldView-3 provides 31 cm panchromatic resolution, 1.24 m multispectral resolution, 3.7 m short-wave infrared resolution, and 30 m CAVIS (clouds, aerosols, vapors, ice, and snow) resolution. The radiometric resolution of panchromatic and multispectral region is 11 bit and 14-bit data of SWIR. WorldView-3 has an average revisit time of less than one day (Table 3.5).

WorldView-4 This satellite, launched on 11 November 2016, has panchromatic and multispectral (visible and NIR) bands, two sensor bands with the same orbit altitude and spatial resolution as WorldView-3. Both sensors provide 11-bit pixel information. The swath width of the sensors at nadir is 13.1 km with daily revisits. It also contains 3200 Gb solid state onboard storage capacity.

3.6.3 SPOT Series

Satellite Pour l'Observation de la Terre (SPOT) is a programme which is run by the French government in collaboration with Sweden and Belgium. Since 1986, SPOT satellites have been acquiring images of the Earth. There are seven satellites in this series. Among these SPOT 1, 2 and 3 ceased operation in 2003, 2009 and 1996, respectively (http://www.cnes.fr/web/CNES-en/1415-spot.php). SPOTs 1-3 carried a high resolution visible (HRV) sensor, while SPOT 4 carried a high resolution visible infraRed (HRVIR) sensor. SPOT 5 has a high-resolution stereoscopic (HRS) imaging instrument (HRS), dedicated to taking simultaneous stereo pairs of a swath strip 120 km across and 600 km long. The stereopairs are also acquired in panchromatic mode with a spatial resolution of 10 m. *Vegetation* instruments were also deployed on SPOT 4 (*vegetation 1*) and SPOT 5 (*vegetation 2*) with a very wide angle Earth observation instrument and 1 km of spatial resolution. These use the same spectral bands as the HRVIR instruments (B2, B3 and Mid-IR) plus an additional band known as B0 (0.43–0.47 µm) for oceanographic applications and for atmospheric corrections.

SPOT 6 and 7 are currently operational (Table 3.6). The objectives of the programmes are to explore Earth's resources; detect and forecast phenomena involving climatology and oceanography; and monitor human activities and natural phenomena. The SPOT 6/7 constellation is composed of two twin satellites operating as a

Table 3.6 Characteristics of SPOT satellites

Satellite (launching year)	Sensor (repeativity)	Spectral range (microns)	Spatial resolution (radiometric resolution)	Swath (km)
SPOT 1 SPOT 2 SPOT 3	Multispectral (26 days)	B1: 0.50–0.59 µm B2: 0.61–0.68 µm B3: 0.78–0.89 µm	20 m	60
	PAN (26 days)	0.50–0.73 µm	10 m	60
SPOT 4 (24 March 1998)	Multispectral (26 days)	B1: 0.50–0.59 µm B2: 0.61–0.68 µm B3: 0.78–0.89 µm B4: 1.58–1.75 µm	20 m	60
	PAN (26 days)	0.61–0.68 µm	10 m	60
SPOT 5 (3 May 2002)	Multispectral (2–3 days)	B1: 0.50–0.59 µm B2: 0.61–0.68 µm B3: 0.78–0.89 µm B4: 1.58–1.75 µm	10 m 20 m (B4) (8 bits)	60
	PAN (2–3 days)	0.48–0.71 µm	5 m (8 bits)	60
SPOT 6 (9 September 2012) SPOT 7 (30 June 2014)	Multispectral (1 day)	B1: 0.455–0.525 µm B2: 0.530–0.590 µm B3: 0.625–0.695 µm B4: 0.760–0.890 µm	6 m (12 bits)	60
	PAN (1 day)	0.450–0.745 µm	1.5 m (12 bits)	60
Pleiades 1A	PAN (1 day)	0.480–0.830 µm	0.5 m (12 bits)	20
Pleiades 1B (2 December 2012)	Multispectral (1 day)	B1: 0.430–0.550 µm B2: 0.490–0.610 µm B3: 0.600–0.720 µm B4: 0.750–0.950 µm	0.5 m (12 bits)	20

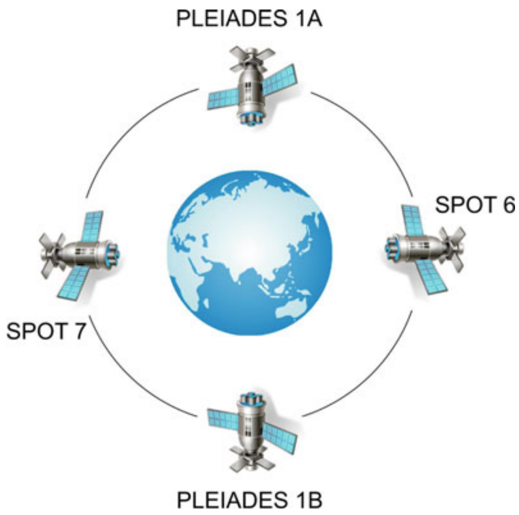


Fig. 3.9 SPOT 6/7 and PLEIADER 1A/1B constellation (http://www.cnes.fr/web/CNES-en/1415-spot.php)

true constellation on the same orbit and phased 180° from each other (Fig. 3.9). Added to their oblique viewing capability (up to 45° angle) and exceptional agility, this orbit phasing allows the satellites to revisit any point on the globe daily. The Pleiades twins are very high-resolution sensor (0.5 m) satellites on the same orbit. The phased orbit of the satellite constellation offers 1-day revisit above 40° latitude within a ±30° angle corridor; 2-days revisit between equator and 40° latitude; and 1-day revisit with two satellites and an increased angle of 45°. The Pleiades constellation also offers high-resolution stereoscopic cover capability. This is achieved within the same pass of the area, which enables a homogeneous product to be created quickly and also provides an additional quasi-vertical image (tristereoscopy), thus allowing the user to obtain an image together with its stereoscopic environment.

3.6.4 Indian Remote-Sensing Satellites

IRS series The Indian Remote Sensing (IRS) satellite system is one of the largest constellations of remote-sensing satellites operating in the world today (Table 3.7). The IRS programme began with the launch of IRS-1A in 1988 and presently includes more than ten satellites that continue to provide imagery in a variety of spatial resolutions from better than a metre ranging up to 500 m.

IRS 1A This was the first-generation Indian Remote Sensing Satellite (IRS), mounted on a Vostok rocket and launched on 17 March 1988 from the Baikanur Cosmodrome, Kazakhstan, Russia. The satellite carried three pushbroom scanners, one LISS-I and two LISS-II. The initial mission life of this satellite was three years but IRS-1A completed 8 years and 4 months in July 1996.

IRS-1B This satellite was launched on 29 August 1991 using the same vehicle as IRS-1A. It completed 12 years and 4 months on 20 December 2003. It also carried the same sensor specification as IRS-1A.

IRS-1C This was India's second-generation operational remote-sensing satellite, launched on 28 December 1995 from Baikanur, mounted on a Molniya rocket. It carried payloads with enhanced capabilities that included better spatial resolution, an additional spectral band, modified revisit period and augmented remote-sensing capabilities. It had three payloads, viz., PAN, LISS-III and WiFS. The mission was completed on 21 September 2007 after serving for 11 years and 8 months.

IRS-1D This satellite was launched on 27 September 1997 by the PSLV-C1 (Polar Satellite Launching Vehicle-C1) from the Satish Dhawan Space Centre (SDSC, also known as the Sriharikota Range or SHAR), India. It was a follow-on satellite to IRS-1C and belonged to the second generation of IRS series of satellites. It had similar capabilities to IRC-1C in terms of spatial resolution, spectral bands, stereoscopic imaging, wide field coverage and revisit capability. The mission was completed during January 2010 after serving for 12 years and 3 months.

ResourceSat-1 This satellite was launched on 17 October 2003 to continue the remote-sensing data services provided by IRS-1C and IRS-1D. It was mounted on the PSLV-C5 launch vehicle

Table 3.7 Characteristics of Indian remote-sensing satellites

Satellite (launching year)	Sensor (repeativity)	Spectral range	Spatial resolution (radiometric resolution)	Swath (km)
IRS-1A (17 March 1988) IRS-1B (29 August 1991)	LISS I (22 days)	B1: 0.45–0.52 μm B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm	72.5 m (7 bits)	148 km
	LISS II (22 days)	B1: 0.45–0.52 μm B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm	36.25 m (7 bits)	74 km
IRS-1C (28 December 1995)	LISS III (24 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm	23.5 m (7 bits)	142 km
	PAN (5 days)	0.50–0.75 μm	5.8 m (6 bits)	70 km
	WiFS (24 days)	B3: 0.62–0.68 μm B4: 0.77–0.86 μm	189 m (7 bits)	774 km
IRS-1D (27 September 1997)	LISS III (24 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm	23.5 m (7 bits)	142 km
		B5: 1.55–1.70 μm (SWIR)	70 m (7 bits)	148 km
	PAN (5 days)	0.50–0.75 μm	5.8 m (6 bits)	70 km
	WiFS (24 days)	0.62–0.68 μm 0.77–0.86 μm (NIR)	189 m (7 bits)	774 km
IRS-P6 ResourceSat-1 (17 October 2003)	LISS III (24 days)	0.52–0.59 μm 0.62–0.68 μm 0.77–0.86 μm 1.55–1.70 μm	23.5 m (7 bits)	140 km
	LISS IV MS (5 days)	0.52–0.59 μm 0.62–0.68 μm 0.77–0.86 μm	5.8 m (7 bits)	23.9 km
	LISS IV PAN (5 days)	0.62–0.68 μm	5.8 m (7 bits)	70 km
	AWiFS (5 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm B5: 1.55–1.70 μm	56 m (10 bits)	740 km
ResourceSat-2 (20 April 2011) ResourceSat-2A (7 December 2016)	LISS III (24 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm B5: 1.55–1.70 μm	23.5 m (10 bits)	140 km
	LISS IV MX (5 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm	5.8 m (10 bits)	70 km
	LISS IV PAN (5 days)	0.62–0.68 μm	5.8 m (10 bits)	70 km
	AWiFS (5 days)	B2: 0.52–0.59 μm B3: 0.62–0.68 μm B4: 0.77–0.86 μm B5: 1.55–1.70 μm	56 m (12 bits)	740 km

(continued)

Table 3.7 (continued)

Satellite (launching year)	Sensor (repeativity)	Spectral range	Spatial resolution (radiometric resolution)	Swath (km)
IRS-P5 CartoSat-1 (5 May 2005)	PAN (2 Cameras) (5 days)	0.5–0.85 μm	2.5 m (10 bits)	30 km (stereo)
CartoSat-2 (10 January 2007)	PAN (5 days)	0.45–0.85 μm	0.8–1 m (10 bits)	9.6 km
CartoSat-2A (28 April 2008)	PAN (4 days)	0.5–0.85 μm	<1 m (10 bits)	9.6 km
CartoSat-2B (12 July 2010)	PAN (4 days)	0.5–0.85 μm	<1 m (10 bits)	9.6 km

from the SHAR Centre. This is the most advanced remote-sensing satellite built by ISRO, carrying payloads of LISS-IV, LISS-III, AWifS-A and AWiFS-B cameras, with a mission life of five years.

ResourceSat-2 This is a follow-on mission to ResourceSat-1, launched on 20 April 2011 by the PSLV-C16 from the SHAR Centre to provide enhanced multispectral and spatial coverage. It has 70 km of swath in an LISS-IV sensor with 10-bit radiometric resolution. It also carries an addition payload known as an automatic identification system (AIS) for ship surveillance to plot position, speed and other information about ships. ResourceSat-2A was launched by the PSLV-C36 on 7 December 2016 from the SHAR Centre. It is intended to continue the remote-sensing services to global users provided by ResourceSat-1 and ResourceSat-2.

IRS-P3 This experimental Earth observation satellite was launched by the PSLV-D3 on 21 March 1996 from the SHAR Centre. IRS-P3 carried two remote-sensing payloads—a Wide Field Sensor (WiFS) similar to that of IRS-1C for vegetation dynamic studies, with an additional short wave infrared (SWIR) band and a Modular Opto-electronic Scanner (MOS) designed for oceanic applications. It also carried an X-ray astronomy payload and a C-band transponder for radar calibration. The mission was completed during January 2006 after serving 9 years and 10 months.

IRS-P4 (Oceansat-1) This was the first satellite primarily built for ocean applications, launched by the PSLV-C2 from the SHAR Centre on 26 May 1999. This satellite carried an ocean colour monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR) for oceanographic studies. Thus, IRS-P4 expanded the capabilities of earlier launched remote-sensing Indian satellite applications to newer areas. It completed its mission on 8 August 2010.

Oceansat-2 This satellite extends the services of earlier Oceansat satellites, and was launched by the PSLV-C14 from the SHAR Centre on 23 September 2009. It carries three payloads: an Ocean Colour Monitor, Ku-band Pencil Beam scatterometer and radio occultation sounder for atmosphere (ROSA). The OCM has an 8-band multi-spectral camera operating in the visible and near-infrared region. The scatterometer will be used to determine ocean surface-level wind vectors through estimation of radar backscatter. The ROSA is used to characterise the lower atmosphere and the ionosphere for the development of several scientific studies. The mission life of this satellite was five years but it is still operational.

TES The Technology Experiment Satellite (TES) was launched by the PSLV-C3 on 22 October 2001. TES is an experimental satellite to demonstrate and validate new technologies in the field of satellites. It carries a panchromatic camera for remote-sensing experiments.

CartoSat-1 This is the first Indian Remote Sensing Satellite capable of providing in-orbit stereo images and was launched on 5 May 2005 by the PSLV-C6 from the SHAR Centre. It has two payloads that carry PAN-Fore and PAN-Aft sensors for cartographic applications to meet global requirements. The spatial resolution of the camera is 2.5 m. This satellite also provides stereo pairs during 5-day revisit periods, required for generating digital elevation models and orthoimage and value-added products for various GIS applications. The mission life was five years and it is still operational.

CartoSat-2 This is an advanced remote-sensing satellite capable of providing scene- specific spot imagery and was launched on 10 January 2007 at 630.6 km orbital altitude by the PSLV-C7 from the SHAR Centre. The panchromatic camera (PAN) on-board the satellite can provide imagery with a spatial resolution better than 1 m and a swath of 9.6 km. This is the nation's second mapping satellite since May 2005. The satellite can be steered up to ±45° along- and ±26° across-track providing a 5-day revisit period. The data from the satellite can be used for detailed mapping and other cartographic applications at the cadastral level, urban and rural infrastructure development and management, as well as applications in land information system (LIS) and GIS. The mission life is five years.

CartoSat-2A This is the third satellite of the CartoSat series launched on 28 April 2008 at 630 km orbital altitude by the PSLV-C9 rocket, from the SHAR Centre. It is a sophisticated and rugged remote-sensing satellite that can provide scene-specific spot imagery. This satellite carries a panchromatic camera (PAN) operating at 0.5–0.85 μm and can be steered up to ±45° along- and across-track to facilitate imaging of any area more frequently. The spatial resolution of this camera is better than 1 m and provides a swath of 9.6 km. Imagery from this satellite is used for cartographic application, as for CartoSat-2.

CartoSat-2B This satellite was launched on 12 July 2010 by the PSLV-C15 from the SHAR Centre at an orbital altitude of 637 km. It is an advanced remote-sensing satellite mainly intended to provide remote-sensing data services for the users of multiple spot-scene imagery. This satellite provides better than 1 m spatial resolution and 10 km swath in the panchromatic band. It can be steerable up to ±26° along- and across-track to achieve stereoscopic imagery and provide a 4/5 day revisit capability. The satellite imagery can be useful for village-level/cadastral-level resource assessment and mapping, detailed urban and infrastructure planning and development, transportation system planning, preparation of large-scale cartographic maps, preparation of micro-watershed development plans and monitoring at the village/cadastral level.

CartoSat-2C This was launched by the PLSV-C34 on 22 June 2016 from the SHAR Centre into a 505 km polar sun-synchronous orbit. It carries a multispectral imaging system in addition to the panchromatic imager which is a first for the CartoSat series. The spectral range is of 450–900 nm and reaches a ground resolution of 65 cm when employing apparent velocity reduction for along-track imagery. Four MX detectors with bandpass filters between 450 and 860 μm deliver imagery at a 2 m ground resolution along a 10 km swath.

CartoSat-2D This was launched on 15 February 2017 by the PSLV-C37.

CartoSat-2E This was launched on 23 June 2017 by the PLSV-C38.

CartoSat-2F This was launched on 12 January 2018 from the SHAR Centre by the PSLV-C40 launch.

The imagery sent by the CartoSat series will be useful for utility management, coastal land use and regulation, urban and rural applications and cartographic applications.

RISAT-1/RISAT-2 Radar Imaging Satellite-1 (RISAT-1) is an Indian state-of-the-art satellite for microwave remote sensing carrying a synthetic aperture radar (SAR) payload operating in the C-band (5.35 GHz), which enables imaging of the surface features during both day and night under all weather conditions. The purpose of active microwave remote sensing is to provide cloud penetration and day–night imaging. This unique characteristic has various applications in agriculture, particularly paddy monitoring in *kharif* (monsoon) season and management of natural disasters like floods and cyclones. RISAT-2 is a radar imaging satellite that enhances the ISRO's capability for disaster management applications.

3.7 Digital Image Processing

The satellite image which is received by the sensor in the ground station is in raw image format, which is not useful to the user community, and requires a significant amount of processing. There are geometric and radiometric errors in the raw image, which are generated during the image acquisition processes. The clarity of the raw image is very poor and the noise present can also decrease image quality. This problem should be addressed for better visualisation and positional accuracy, which rectifies the inherent distortion in the raw image. Digital image processing in general involves the use of computers for manipulating digital images in order to improve their quality and/or modify their appearance (Wolf and Dewitt 2000). It is a task of processing and analysing the digital data using an image-processing algorithm. This is a process applied by the operator, instructing the computer to perform an interpretation according to certain conditions. These conditions are defined by the operator through various algorithms. The main processes are pre-processing, enhancement and image classification.

3.7.1 Pre-processing

Pre-processing is the process of image rectification and restoration to correct distortion to create a more faithful representation of the original image. Typically, geometric and radiometric correction (as well as noise correction) are applied.

Geometric Correction This involves relating the spatial coordinates in the image to the corresponding spatial coordinates on the Earth's surface. Geometric correction means the repositioning of the pixels from their original locations in the data array into a specified reference grid. It involves three processes: the selection of a suitable *mathematical distortion model, coordinate transformation and resampling* (interpolation) (Schowengerdt 2006).

Table 3.8 Number of GCPs per order of polynomial

Polynomial order	Minimum GCPs
1	3
2	6
3	10
4	15
5	21
6	28
7	36
8	45
9	55
10	66

Mathematical Distortion Model Two approaches, the satellite model and polynomial model, are used to correct the raw image by mathematical distortion. In the satellite model, information on satellite position, altitude, orbit, scan geometry and Earth model is used to produce system-corrected products. The residual of the system-corrected products can be corrected by the polynomial functions and ground control points (GCPs) (Table 3.8).

Transformation Model The characteristics of the Earth (geoid) cannot be represented on a flat surface without shrinking, breaking or stretching it somewhere. It is also not possible to achieve all five properties (true shape, equal area, true distance, true direction and simplicity) required to make a perfect map. It is, however, possible to develop projections which have one or more of these properties, though not all of them (Mishra and Ramesh 2002). There are various projections available for transformation of the coordinate from 3-dimension to 2-dimension modelling.

Resampling Methods These methods transform the raw image into a referenced image (transformation), resulting in empty pixels in the array of the image. These empty pixels are filled in by the interpolation process known as resampling. There are three methods of resampling: nearest-neighbour, bilinear and cubic convolution (Fig. 3.10). In nearest-neighbour resampling, the

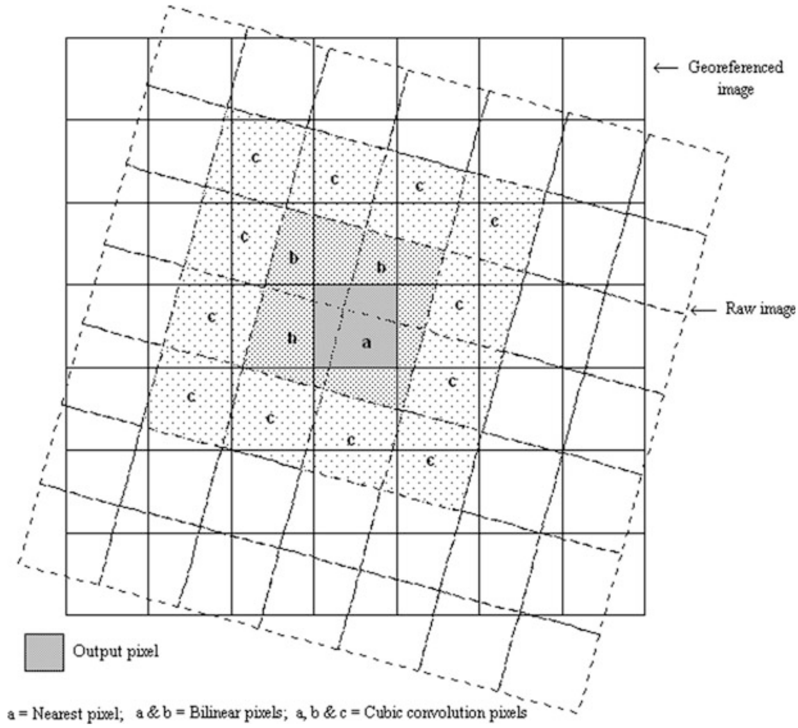
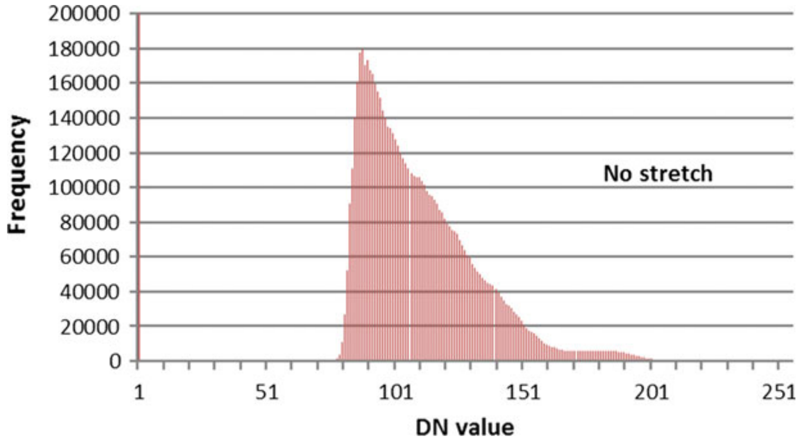


Fig. 3.10 Type of resampling

pixel value in the original image that is spatially nearest to the calculated position is copied to the location in the new image. It means that the value of each new pixel in the reference image is the nearest pixel value of the calculated raw image. This approach has the merit that there is no calculation required to derive the output pixel value, so it does not alter the pixel value. Bilinear interpolation uses *2×2 neighbourhood pixels* and smooths the results and imagery produced by interpolation, in which the pixel values copied into the reference image are an average of the four neighbourhood pixel values of the raw image. It can introduce the new pixel value by averaging the four nearest pixels of the raw image. Bicubic interpolation uses *4×4 neighbourhood pixels.* The smoothing incurred with bilinear interpolation may be avoided by the cubic interpolation method, which provides a slightly sharper image, involving more computation processes and introducing new pixel values by averaging the nearest 16 pixels.

Radiometric Correction Radiometric correction is categorised into two groups: *cosmetic* and *atmospheric*. *Cosmetic correction* involves all those operations that are aimed at correcting visible errors and noise in the image data. Defects in the data may be in the form of line dropouts (periodic or random missing lines), line striping and random or spike noise. Line dropouts occur due to recording problems when one of the detectors of the sensor gives wrong data or stops functioning. The Landsat Thematic Mapper has 16 detectors in all its bands except the thermal band. A loss of one of the detectors would result in every sixteenth scan line being a string of zeros that would plot as a black line on the image. In Landsat MSS, this defect would occur in every sixth line. Line striping is far more common than line dropout. It often occurs due to the non-identical detector response. Although the detectors for all satellite sensors are carefully calibrated and matched before the launch of the satellite, over time the response of some

Fig. 3.11 Histogram without enhancement



detectors may drift to higher or lower levels. As a result, every scan line recorded by that detector is brighter or darker than the other lines. Histogram matching is the most popular method to correct this effect. Random or spike noise occurs during data transmission. The individual pixel acquires values much higher or lower than the surrounding pixels, which produce much brighter or darker spots. All reflected and emitted radiations leaving the Earth's surface are attenuated mainly due to absorption and scattering by the constituents in the atmosphere. These distortions are wavelength dependent and corrected by atmospheric correction techniques for haze, sun angle and skylight. Thus, radiometric corrections constitute an important step in the pre-processing of remotely sensed data. They are comprised of cosmetic corrections to reduce the influence of atmospheric and illumination parameters. Atmospheric corrections are particularly important for generating image mosaics and for computing multi-temporal remote-sensing data.

3.7.2 Image Enhancement

Image enhancement involves techniques for increasing the visual distinctions between features in a scene. It can be divided into two parts, one operating on individual pixels and enhancing their values without reference to their spatial context, also known as radiometric enhancement, e.g. contrast enhancement, histogram equalisation; the other, using spatial information, deals with the average value of neighbouring pixels, known as spatial enhancement, e.g. spatial filtering. An image histogram is simply a graph or table showing the number of pixels (*y-axis*) in an image having pixel value (*x-axis*). An image histogram is a graph (Fig. 3.11) that shows the distribution of pixel values in a digital image, displaying the frequency of the digital number values. The number of pixels is shown on the *y*-axis, the DN values on the *x*-axis. Histogram matching is very important for producing a mosaic of two images.

Contrast Enhancement is a conversion of an original digital range into a full range of display. It is only intended to improve the visual quality of a displayed image because of low visibility in the raw image. There are various reasons for low contrast in the original digital image. Sometimes objects and background have made similar or uniform responses at the same wavelength. So a scene itself may have a low contrast ratio. Scattering of electromagnetic radiation also reduces the contrast in short wavelengths. The contrast refers to the range (or ratio) between maximum and minimum intensity over the image. The larger the ratio, the easier it is to interpret.

The sensor is designed to acquire the full range of radiance from 0 to 255 DN value (0 means black and 255 means white in grey scale) in 8-bit quantification data. But the scene generally receives a radiance range much less than the full range, resulting in low contrast in the displayed image. Radiance values from the ocean, with low solar elevation angle and high latitude, are low, while those from snow and sand, with high solar elevation angle and low latitude are high. The contrast enhancement is categorised into linear and non-linear contrast stretches.

Linear Stretch A linear stretch is used when equal weight is given to all DN values (Fig. 3.12). It is used to increase or decrease the contrast of an image. If the DN range is less than the display range then linear stretch increases the contrast of the image. If the DN range is more than the display range the linear stretch decreases the contrast of the image. The human eye cannot usually distinguish more than about 50 DN (grey level) at any one time (Schowengerdt 2006).

Whereas X is the DN value of a raw image, Xmin is the minimum DN value of a raw image (79) and Xmax is the maximum DN value of a raw image (158). For example, if we linear enhance the DN value of 100, then (100 − 79/79 − 158) * 255 = 68. So the value in the Look Up Table (LUT) is 68 by linear stretch. LUT is used to generate the display of an image, and not the image data themselves. The original image data are unchanged.

Non-linear Stretch or Histogram Equalisation This is used when it is felt necessary to weight the DN by their frequency of occurrence. The number of grey levels in the enhanced image is less than that in the original image due to grouping of certain adjacent grey values. In histogram equalisation, more contrast is applied to the high frequency of the DN value of the original image. In this process dark and bright portions of the original image/histogram are compressed, resulting in loss of information at both ends (Fig. 3.13).

Gaussian Stretch This enhances the contrast at the tails of the histogram, at the expense of contrast in the middle part of the histogram (grey scale).

Spatial Filtering The digital image is made up of spatial components known as pixels having digital numbers at different places. The digital image consists of high frequencies and low frequencies. Contrast enhancement does not alter the image data, merely the way they are displayed. Spatial filtering, on the other hand, does change the image data according to the pixel values in its neighbourhood. Spatial averaging is one of the functions of spatial filtering, which is used to reduce noise or speckle in the data. Diagrammatically, a spatial filter is a grid of boxes, with each box representing a pixel, having their brightness value termed a kernel or convolution matrix or mask (Fig. 3.14). The centre of the kernel is the average value of the surrounding box pixel value (3 × 3, 5 × 5, 7 × 7). Spatial filtering is a means of improving the image by

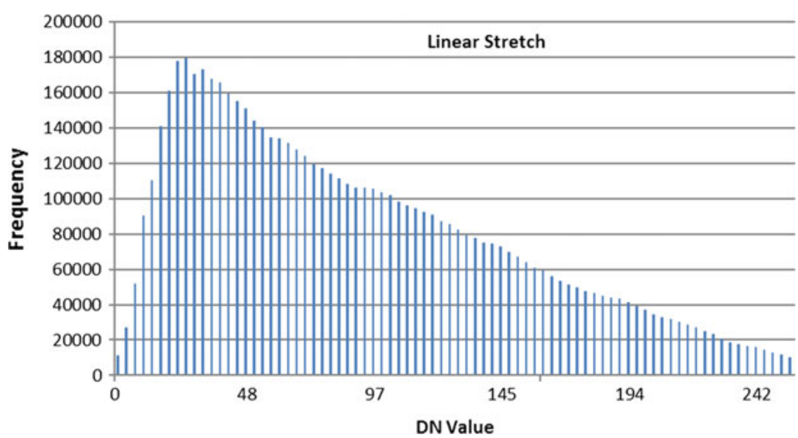


Fig. 3.12 Histogram of linear enhancement

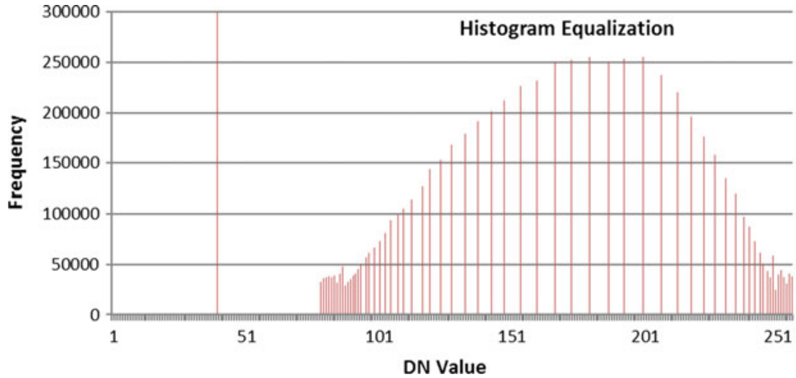


Fig. 3.13 Histogram equalisation

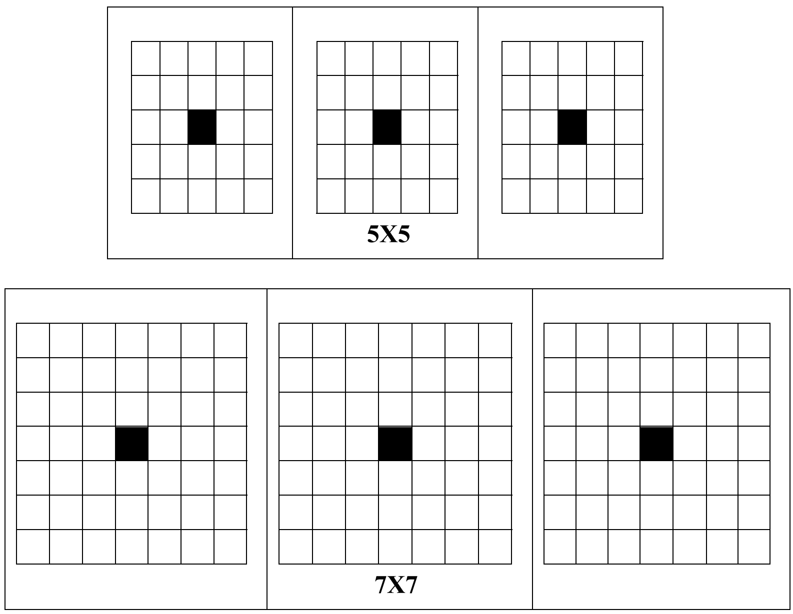


Fig. 3.14 Kernels 5 × 5 and 7 × 7

suppressing (low-pass filtering) or enhancing (high-pass filtering) certain spatial frequencies, directions and textures (Rosenfeld and Kak 1976). Spatial frequency is a 'roughness' of the tonal variations occurring in an image (Fig. 3.15).

$$\text{Image} = \text{low pass} + \text{high pass}$$

The low-pass filter passes low frequencies and blocks high frequencies. It preserves the local mean (the sum of their weight is one) and smooths the output layer. Low-pass filters smooth the image resulting in a blurring effect in the output image. The larger the window (kernel) the smoother the image. This filter is very useful in periodic 'salt and pepper' noise removal.

$$\text{Low pass} = \text{image} - \text{high pass}$$

The high-pass filter removes the local mean (the sum of their weight is zero) and produces an output which is a measure of the deviation of the input signal from the local mean.

$$\text{High pass} = \text{image} - \text{low pass}$$

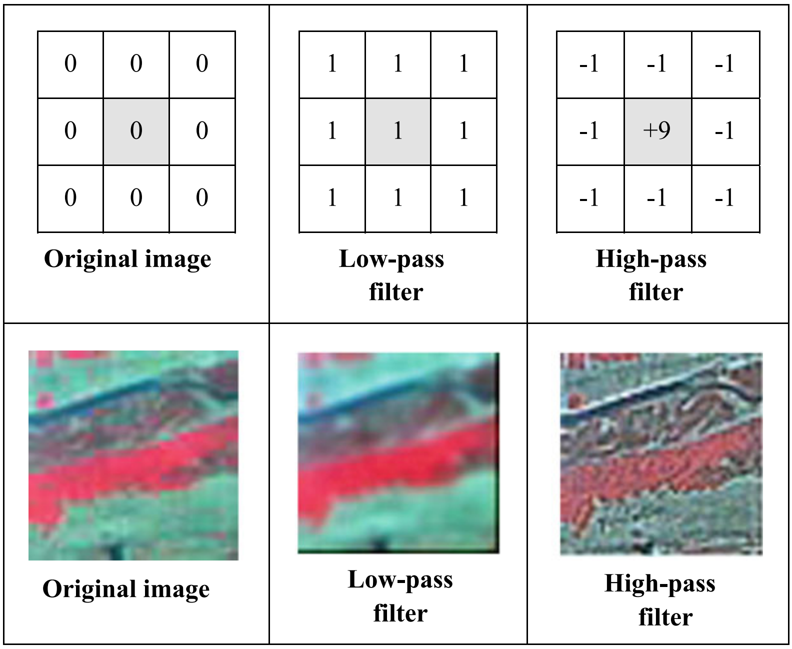


Fig. 3.15 Low- and high-pass filtering

3.7.3 Image Classification

The rectified image can be used for extracting the information. This information can be extracted by two methods. The first, visual image interpretation, involves making a printout of the rectified image; the second is digital image classification. Digital image classification is a process of generating thematic categorisation of similar pixels. Image classification (pattern recognition) is the process used to produce thematic maps from imagery (Schowengerdt 2006). It involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land-use/cover identity of each pixel in an image. Basically, multispectral data with 8 bits (256 colours) is used to categorise single-band thematic information into several classes. The level of classes depends on the resolution of the sensor used to capture the image. There are various classification systems with different levels available as given by Anderson (Table 3.9) and the National Remote Sensing Centre, Government of India (Table 3.10) etc. It is generally accepted that the Anderson level I categories can be reliably mapped using Landsat MSS imagery, and level II categories with TM and SPOT multispectral imagery (Lillesand and Kiefer 1987). Level III and further requires SPOT, IRS LISS-IV or higher-resolution imagery for classification.

3.7.4 Elements of Aerial Photo/Image Interpretation

Tone This refers to the relative brightness or tonal variation in photographic film and represents the radiance value received by the sensor from the object on the Earth's surface. Some objects appear darker and crisper than others. Light tones represent areas with high radiance and dark tones represent areas with low radiance. The nature of the materials on the Earth's surface affects the amount of light reflected. The terms light, medium and dark are used to describe the tonal variation. For example, the area of laterite soil is dark grey in tone and the areas of salt-affected soil are light grey in tone; dry soil has light tones and wet soil has dark tones in photographs.

Colour In multispectral imagery, colour is the most important element to discriminate two

Table 3.9 Land-use and land-cover classification system for use with remote-sensor data (Anderson et al. 1976)

Level I	Level II
1 Urban or built-up land	11 Residential 12 Commercial and services 13 Industrial 14 Transportation, communications and utilities 15 Industrial and commercial complexes 16 Mixed urban or built-up land 17 Other urban or built-up land
2 Agricultural land	21 Cropland and pasture 22 Orchards, groves, vineyards, nurseries and ornamental horticultural areas 23 Confined feeding operations 24 Other agricultural land
3 Rangeland	31 Herbaceous rangeland 32 Shrub and brush rangeland 33 Mixed rangeland
4 Forest land	41 Deciduous forest land 42 Evergreen forest land 43 Mixed forest land
5 Water	51 Streams and canals 52 Lakes 53 Reservoirs 54 Bays and estuaries
6 Wetland	61 Forested wetland 62 Non-forested wetland
7 Barren land	71 Dry salt flats 72 Beaches 73 Sandy areas other than beaches 74 Bare exposed rock 75 Strip mines, quarries and gravel pits 76 Transitional areas 77 Mixed barren land
8 Tundra	81 Shrub and brush tundra 82 Herbaceous tundra 83 Bare ground tundra 84 Wet tundra 85 Mixed tundra
9 Perennial snow or ice	91 Perennial snowfields 92 Glaciers

features which cannot be easily identified by tonal variation in panchromatic imagery. For example, in a true-colour image healthy vegetation is represented by green but in a panchromatic one, it is represented in greyscale; even in standard false-colour composites, it will be represented by red.

Tone and colour are the basic and primary elements of interpretation.

Size Some features are easily identified by their size, with reference to their length, width, perimeter and area in the context of the scale of the photograph. Size is a relative term which may be small, medium or big, according to the scale of the photograph/imagery. The size of a water body, for example, will help to determine whether it is a small pond or a big lake. National highways can be easily distinguished from

Table 3.10 Land-use/cover scheme used by the National Remote Sensing Centre (2007)

Sl. No	Description-1	Description-2	Classes from NRC LULC50K mapping project
1	Built-up	Urban	Residential, mixed built-up, public/semi-public, communication, public utilities/facility, commercial, transportation, reclaimed land, vegetated area, recreational, industrial, industrial/mine dump, ash/cooling pond
		Rural	Rural
		Mining	Mine/quarry, abandoned mine, land-fill area
2	Agriculture	Cropland	*Kharif*, *rabi*, *zaid*, two-cropped, more than two-cropped
		Plantation	Plantation: agricultural, horticultural, agro-horticultural
		Fallow	Current and long fallow
		Current shifting cultivation	Current shifting cultivation
3	Forest	Evergreen/semi-evergreen	Dense/closed and open category of evergreen/semi-evergreen
		Deciduous	Dense/closed and open category of deciduous and tree-clad area
		Forest plantation	Forest plantation
		Scrub forest	Scrub forest, forest blank, current and abandoned shifting cultivation
		Swamp/mangroves	Dense/closed and open mangrove
4	Grass/grazing	Grass/grazing	Grassland: alpine/sub-alpine, temperate/subtropical, tropical/desertic
5	Barren/unculturable/wastelands	Salt-affected land	Gullied, shallow ravine and deep ravine area
		Gullied/ravined land	Gullied, shallow ravine and deep ravine area
		Scrubland	Dense/closed and open category of scrubland
		Sandy area	Desertic, coastal, riverine sandy area
		Barren, rocky	Barren, rocky
		Rann (salt marsh)	*Rann* (salt marsh)
6	Wetlands/water bodies	Inland wetland	Natural and man-made inland wetland
		Coastal wetland	Natural and man-made coastal wetland
		Rivers/streams/canals	Perennial and dry river/stream and lined and unlined canal/drain
		Water bodies	Perennial, dry, *kharif*, *rabi* and *zaid*, extent of lake/pond and reservoir and tanks
7	Snow and glacier		Seasonal and permanent

smaller roads. Long rivers can be distinguished from smaller tributaries. Residential areas are easily distinguished from industrial areas in the urban environment.

Shape This refers to geometric shapes, e.g. linear, curvilinear, circular, elliptical, radial, square, rectangular, triangular, hexagonal, star, elongated etc. Consolidated agricultural areas tend to have geometric shapes like rectangles and squares. Streams are linear (line) features that can have many bends and curves. Canals, roads, and railway lines tend to have fewer curves than streams. Stadiums may be circular or elliptical shapes. Some objects can be identified almost solely on the basis of their shapes, such as the pyramids in Egypt or the Pentagon building in the USA.

Texture This refers to the roughness and smoothness of the features in aerial photograph/satellite imagery, as well as the arrangement of tonal variation or repetitions of tone and colour. The textural classes may be smooth (uniform, homogeneous), intermediate and rough (coarse, heterogeneous). Grassland appears smoother than forest. Paddy fields appear smoother than sugar-cane fields. Water in a lake or a cemented area appears smoother than ploughed agricultural land.

Size, shape and texture are secondary elements for interpretation.

Pattern Features of the Earth's surface produce regular, linear, systematic, irregular or random spatial arrangements. These may be natural or man-made features. The difference between planned (systematic) and unplanned cities can be observed. Chandigarh city has a checkerboard pattern while Connaught Place in New Delhi has a radial pattern. The pattern of the drainage may be radial, trellis, dendritic etc. The differences between forests, forest plantations and orchards can also be observed. The patterns formed by the features in photographs/imagery can be used to identify the objects.

Shadow Shadows are clues to identify an object. These are cast by the object on the vertical aerial photograph. They may provide more information than the objects themselves, particularly when determining height. For example, the shadows cast by a hill or mountain may help to identify physiographic information. Objects ranging in size and type from the Qutab Minar and the Eiffel Tower to a bridge or signboard are often very informative. Shadows also help to determine the height of features such as high-rise buildings in the aerial photograph.

Patterns and shadows are tertiary elements of interpretation.

Site or Location This refers to geographical location. This characteristic of photographs/imagery is important in identifying the feature located in a particular area or region such as various vegetation types and landforms. For example, some tree species are found more commonly in one geographic location than in others such as evergreen forests, mangroves etc.; some landforms are found in particular locations such as sand dunes, alluvial fans, river deltas; large circular depressions in the ground are identified as sinkholes in central Florida; some cultural features such as brick-kilns, thermal power plants and nuclear power plants can be determined.

Association Some objects on the Earth's surface are always found in association with others. These associated features provide clues as to the identity of the object such as a sugar mill associated with a surrounding field of sugar-cane, molasses tank, storage godown (warehouse) etc. A vegetated area within an urban setting may be a park. Commercial centres will likely be located next to major roads, railways or waterways. Industrial areas are associated with several clusters. Some structures may also help us determine the precise nature of enterprises such as the combination of one or two tall chimneys, a large central building, siting along a waterway, cooling towers and solid fuel piles which point to the presence of a thermal power station.

Resolution Resolution of a sensor system may be defined as its capability to discriminate two closely spaced objects from each other. It may be high, medium or low. Small features can be identified from high-resolution imagery. For example cadastral-level or infrastructure mapping needs high-resolution imagery where individual plots or houses can be identified.

Regional-level mapping requires comparatively low-resolution imagery.

3.7.5 Visual Image Interpretation

This is defined as an act of examining the image to identify the object or phenomenon and judge its significance by interpretation. It is based on an interpreter's ability to extract the information visually with the help of various characteristics present in the image known as elements of image interpretation (cf. Chap. 4). With the help of this element or set of elements, the interpreter prepares the interpretation key, a reference that provides the logical rules to identify the features or objects in the image. The quality of the interpretation depends on the quality of the image—its clarity, tonal or colour contrast and sharpness that enable one to distinguish one object from another. Campbell (1978) has defined five categories of image interpretation strategies; i.e. field observation, direct recognition, interpretation by inference, probabilistic interpretations and deterministic interpretation. The visual interpretation methods involve a sequence of activities including detection, recognition and identification, analysis, deduction, classification, idealisation and accuracy determination. Detection involves selectively picking out objects that are directly visible. Recognition and identification involve naming objects. Analysis involves trying to detect their spatial order. Deduction is rather more complex and involves the principles of convergence of evidence to predict the occurrence of certain relationships in the aerial photographs. Classification involves arranging the objects and elements that have been identified into an orderly system. Idealisation uses lines which are drawn to summarise the spatial distribution of objects. The final stage is accuracy assessment to validate the classification (Curran 1985). Visual interpretation has certain disadvantages; for example it requires intensive labour for delineation and evaluation of each and every theme. Our eyes cannot discriminate certain features due to poor tonal characteristics, resulting in entire spectral characteristics not being utilised by the interpreter. It is also difficult to incorporate into the GIS environment for further analysis in comparison to digital classification.

3.7.6 Digital Image Classification

There are basically two methods for digital image classification: supervised and unsupervised, although hybrid classification is done by a combination of both methods. The ultimate aim of digital image classification is to increase the accuracy of the classified image. Thus it is important to select appropriate satellite images and their spectral bands for the classification process because it will help in collecting the training sample as well as increase the time of processing in the computer. The highly correlated spectral band will increase computing time rather than classification accuracy (Moik 1980). It is preferable to determine the degree of inter-band correlation and to use only wavelength bands that are poorly correlated to each other (Curran 1985).
Supervised Classification This method is performed when the interpreter has a priori knowledge about an image area. To obtain meaningful and accurate image classifications there is a need for the environmental scientist to take the computer operator's seat and interact with the image data by supervising the classification sequence (Schmidt 1975). There are a few steps that should be followed while applying supervised classification methods, such as selection of the sample or training samples, evaluation of selected samples and appropriate classification algorithms.

Training samples These are sets of pixels selected to represent the individual land-use/cover class (feature class). The samples must be pure and representative of the particular class. The aim of training is to obtain sets of spectral data that can be used to determine decision rules for the classification of each pixel in the whole image data set (Merchant 1982). To a large extent, our ability to perform accurate classification of a given multispectral image is determined by the extent of overlap between class signatures.

Sample evaluation Accurate classification of an image totally depends on the training samples, and must be evaluated by signature separability analysis and a contingency matrix. Separability analysis can be performed on the training samples to estimate the expected error in classification for various feature combinations as well as band combinations (Table 3.11). Separability is a statistical measure of distance between two signatures. It can be calculated for any combination of bands that is used in the classification, enabling the ruling out of any bands that are not useful in the results of the classification (ERDAS Field Guide 2005). The contingency matrix determines the purity of the sample pixel of each class; if the pixels of the sample are pure, then it provides accurate classification results (Table 3.12).

Classification algorithms There are various algorithms to assign an unknown pixel to known classes. The most important and frequently used algorithms are minimum distance to mean, parallelepiped and maximum likelihood classifier. These algorithms are used to classify the unknown pixels in the image.

The minimum distance to mean algorithm is a very simple and fast method to classify the image where the mean value of the digital number (DN) from the training sample is calculated and unknown pixels are allotted the class nearest to the mean value of the DN. The most important feature of this algorithm is that there are no unclassified pixels because every pixel is spectrally closer to either one or another sample mean. This problem is eliminated by deciding the upper limit of the pixels that are farthest from the means of their classes. Another problem is that this classifier does not consider the variability of the sample data resulting in misclassification due to the fact that pixels that belong to the class are usually spectrally closer to their mean than those of other classes to their means.

Table 3.11 Report of signature separability

File: e:/subset_filter/class.sig	Separability listing
Distance measure: Euclidean distance	Bands AVE MIN Class pairs:
Using bands: 1 2 3 4 (Taken 3 at a time)	1:2 1:3 1:4 2:3 2:4 3:4
	1 3 4 54 4 71 4 42 70 93 45
Class	
1 water	Separability listing
2 veg1	Bands AVE MIN Class pairs:
3 water1	1:2 1:3 1:4 2:3 2:4 3:4
4 deep water	2 3 4 54 5 69 5 44 70 92 48
Separability listing	Best minimum separability
Bands AVE MIN Class pairs:	Bands AVE MIN Class pairs:
1:2 1:3 1:4 2:3 2:4 3:4	1:2 1:3 1:4 2:3 2:4 3:4
1 2 3 55 3 80 3 36 81 90 38	2 3 4 54 5 69 5 44 70 92 48
Separability listing	Best average separability
Bands AVE MIN Class pairs:	Bands AVE MIN Class pairs:
1:2 1:3 1:4 2:3 2:4 3:4	1:2 1:3 1:4 2:3 2:4 3:4
1 2 4 41 4 57 4 38 58 46 42	1 2 3 55 3 80 3 36 81 90 38

Table 3.12 Contingency matrix (error matrix)

Matrix (pixel in number)					Matrix (pixel in percentage)				
Data	Water	Water1	Veg1	Deep water	Data	Water	Water1	Veg1	Deep water
Water	118	37	0	0	Water	88.06	36.27	0.00	0.00
Water1	16	65	0	5	Water1	11.94	63.73	0.00	0.56
Veg1	0	0	105	0	Veg1	0.00	0.00	100.0	0.00
Deep water	0	0	0	891	Deep water	0.00	0.00	0.00	99.44
Total	134	102	105	896	Total	100	100	100	100

The parallelepiped algorithm or box classifier creates a box around each class in the training sample, and the pixels in the total data set can then be classified by the box into which they fall. It is also known as a parallelepiped algorithm because opposite sides are parallel. The box is created by considering the range of the value in the training samples or of the mean and standard deviation per class. The range is defined by the lowest and highest DN values in each band and appears as a rectangular shape. If the DN value of the pixel does not fall in the range then it is classified as an unknown pixel. The disadvantage of this algorithm is that the overlap between the classes or a pixel may fall into two or more boxes or parallelepipeds. In such a case, there are two methods: one in which the overlapped pixel is classified by the order of sample taken and the other in which the pixel is classified by the parametric rule. If the pixel cannot satisfy the parametric rule then it can be classified as unknown.

Maximum Likelihood Classifier considers not only the cluster centre but also its shape, size and orientation (Janssen and Huurneman 2001). This classifier calculates the mean, variance and correlation for each class of training samples, on the usually valid assumption that the data for each class are normally distributed (Castleman 1979). With this information the spread of pixels around each mean value can be described using a probability function, resulting in bell-shaped surfaces that are called probability density functions. There is one such function for each spectral category. This classifier delineates ellipsoidal equiprobability contours in the scatter diagram (Lillesand and Kiefer 2000). After evaluating probability in each category, the pixel is assigned to the most likely class or high-probability value. This function is used to classify the unclassified pixel to a particular class. This algorithm is the most accurate classifier and the results are totally reliant on the statistical computation, meaning it takes a long time to compute.

Post-classification smoothing The low-pass filtering is applied to remove the random noise in the classified image. The central pixel value in the window is replaced by the mostly frequently occurring value.

Unsupervised Classification Unlike supervised classification, unsupervised classification does not use the training sample to classify the image. An algorithm determines the internal structure of the data, not the training sample. The classification of classes is based on clusters or natural groupings of data value known as spectral classes. A cluster is a distinct group of pixels in a localised region of the multidimensional data space. These classes or clusters are initially unidentified, and need to be identified with the help of the interpreter. The main feature of this classification is that it can identify the distinct spectral classes presented in the image which may not be identified by supervised training samples. The K-mean is one of the most important algorithms and can be used for clustering. In this algorithm, a system arbitrarily locates the number of cluster centres (number of required classes as defined by a user) in the 2-dimensional image data known as a mean vector. Then each pixel of an image is assigned to the class whose mean vector is closest, thus forming the first set of decision boundaries of the classes. Again the new set of the mean vector is calculated on the basis of a previous set of classes and the pixels are reassigned accordingly. In each iteration, the K-mean will tend to gravitate towards concentrations of data. The iterations are continued until there are no significant changes in pixel assignments.

Hybrid The main objective of image classification is to produce an accurate thematic map from the image. In this regard, sometimes supervised and unsupervised classification techniques individually do not produce the desired level of accuracy. For example, in supervised classification, the user may not be able to delineate the particular signature, or in results, the class signature is not statistically separable in a feature space. In the case of unsupervised classification, this algorithm only considers the internal structure of the data and sometimes produces classes that are insignificant to the user. The combined approach can eliminate both classification drawbacks and produce satisfactory results. In this approach, initially unsupervised classification is applied with approximately 5–10 times more desired clustering. Then these clusters must be evaluated by various field data, resulting in some clusters being combined or subdivided. Finally the evaluated classes can be utilised for supervised classification.

3.7.7 Accuracy Assessment

Once the image is classified, there is a need to assess the accuracy of the classification that can represent true information about an area. It is not possible to check each pixel of an image to verify. Stratified random sampling is one of the best methods to collect samples in the land-use/cover classified map for accuracy assessment. These collected samples can be verified with fieldwork or other ancillary data known as reference data. The overall verification of the sample data is known as ground truthing. It is an acquisition of knowledge about the study area by various sources which may be primary or secondary, such as fieldwork, analysis of previous images or photographs, personal experiences etc. Ground-truth data are considered to be the most accurate data available about the area of study. They should be collected at the same time as the remotely sensed data, so that they correspond as much as possible (Star and Estes 1990). Both data, i.e. field-verified referenced data and sample data from the classified image, can be put into the error matrix (Table 3.13). The error matrix is also known as a contingency table or confusion matrix. It is a 2-dimensional matrix where a column represents the reference data and a row represents classified data. The accurate classification of each class which is verified from the field is mentioned diagonally in the matrix

Table 3.13 Accuracy assessment by error matrix

	Field verification data (reference data)					Total classified
	Agriculture	Forest	Fallow land	Water body	Wasteland	
Classified data						
Agriculture	*480*	20	0	0	5	505
Forest	50	*480*	20	0	0	550
Fallow land	10	0	*530*	0	0	540
Water body	0	0	0	*490*	0	490
Wasteland	0	0	50	15	*350*	415
Total verified	540	500	600	505	355	2500

Table 3.14 Assessment of omission and commission errors

Class	Omission			Commission		
	Sample omitted	Total verified	% of error	Sample committed	Total classified	% of error
Agriculture	30	540	5.6	25	505	5.0
Forest	20	500	4.0	35	550	6.4
Fallow land	20	600	3.3	10	540	1.9
Water body	15	505	3.0	0	490	0.0
Wasteland	5	355	1.4	30	415	7.2

and all the non-diagonal samples are errors. A sample which is verified in the field but not classified in the same (verified) class is an error and it may be by omission or commission. If a verified sample is not found in the classified class it is known as an error of omission. For example, a sample verified as agriculture is not classified in the agriculture class and is classified into others. A classified sample not verified in the field verification but that is found in other classes is known as an error of commission. For example, a classified sample of agriculture is verified as another class or classes.

In the classified image, 505 samples are collected. Among these, 480 samples are found to be correct by the field verification in this class. It means that 25 samples (505 − 480 = 25) are found to be incorrect. That difference of 25 samples (20 in forest and 5 in wasteland) is an *error of commission*, which occurs in the wrong classes (Table 3.14). The next aspect of the error matrix is *error of omission*, where 540 samples of agriculture are found in the field verification. Among these only 480 are correctly classified in agriculture and another 60 samples (50 in forest and 10 in fallow land) are classified in other classes as errors of omission.

The accuracy of individual categories can be calculated by dividing the number of correctly classified pixels in each category by either the total number of pixels in corresponding rows or in columns to obtain producers' or users' accuracy, respectively (Table 3.15). The producers' accuracy is calculated by dividing the number of correctly classified pixels in each category by the number of total verified pixels in a particular category. The users' accuracy is calculated by dividing the number of correctly classified by the number of total classified pixels in each category. The overall accuracy is calculated by dividing the total number of correctly classified pixels by the total number of verified pixels.

3.8 Remotely Sensed Data and GIS

All the remotely sensed data in the geo-corrected form and classified image may be used as a base map and thematic map, respectively. The geo-corrected or geo-referenced map is also used as a base map for the digitisation of different layers from the imagery or aerial photographs. The multi-temporal satellite imagery can be used for overlay analysis and updation. Sometimes, a classified raster image can be converted into vector format for further geographical database creation and analysis.

3.9 Conclusion

Remote sensing is a technique to acquire data remotely. It requires a multidisciplinary approach. There are several mechanisms involved, from *source of energy* to *supply of end product to the end user*. Remote sensing can be conducted from three platforms: groundborne, airborne and spaceborne. The product of remote sensing may

Table 3.15 Assessment of producers, users and overall accuracy

Class	Verified samples	Total verified	Total classified	Producer accuracy (verified samples/total verified)	User accuracy (verified samples/classified samples)
Agriculture	480	540	505	480/540 = 89%	480/505 = 95%
Forest	480	500	550	480/500 = 96%	480/550 = 87%
Fallow land	530	600	540	530/600 = 88%	530/540 = 98%
Water body	490	505	490	490/505 = 97%	490/490 = 100%
Wasteland	350	355	415	350/355 = 99%	350/415 = 84%
Total	2330	2500	2500	Overall accuracy = 2330/2500 = 93.2%	

be in the form of a photograph or imagery. Electromagnetic energy is the medium by which different sensors acquire information about the Earth's surface. The limited portion of the electromagnetic energy used is known as an atmospheric window, where the energy interacts with the Earth's features and is reflected back to the upper atmosphere where a deployed sensor is utilising that energy to form an image. The basic material of the Earth is soil, vegetation and water. These materials are interacting differently with electromagnetic energy, which is reflected in the reflectance curve. There are various Earth-resource observation remote-sensing satellites in orbit. Landsat is one of the pioneers in satellite observation systems, followed by European and Indian satellites launched to obtain information about the Earth's surface. The imagery received from the satellite is not usable directly by the user community, so that digital image processing is applied to geometric and radiometric correction as well as enhancement techniques to increase the interpretability of the imagery in digital classification and visual interpretation with the help of elements of photo or image interpretation keys. This classified or interpreted satellite imagery needs accuracy assessment for correctness, and finally these images are used as thematic maps. Satellite imagery with classification can also be used in a GIS environment to create a database as a base layer. Thus, remote sensing provides the base information as well as thematic information to integrate with a GIS environment.

Questions

1. What is meant by remote sensing? Discuss its process.
2. Discuss the different types of platform in remote sensing.
3. What is the difference between electromagnetic radiation and the electromagnetic spectrum?
4. Discuss the electromagnetic spectrum and atmospheric window.
5. Describe the different Earth-resource satellites orbiting the planet.
6. What is meant by digital image processing? Discuss the various processes to achieve the end-user product.

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4 Global Positioning System

Abstract

In the previous chapters, you have learnt about remote-sensing technology which is one of the reliable sources of the spatial database. In this chapter, you will learn about the Global Positioning System (GPS). As the name denotes, it provides an exact position on the Earth. This is one of the most reliable sources for providing positional information for the GIS environment. After reading this chapter you should be able to understand the following:

- The background to the US, Russian and Indian Global Positioning Systems
- Segments of GPS—space, ground and user
- How GPS receives location information
- Sources of error in GPS
- differential global positioning system (DGPS)
- Applications of GPS

Keywords

GPS satellites · DGPS · WAAS · Navigation · Tracking · Waypoint

4.1 Introduction

Reliable and accurate information about the spatial database is a prerequisite for any geographical or spatial analysis, especially the position of the features or phenomena on the Earth. The position means the exact location represented in terms of longitude and latitude (Kumar and Kaur 2015). Information about the location can easily be determined by the topographical sheets available in every country, but the current position of a particular feature is determined by GPS. Using the GPS receiver, one can easily determine the locational (*x*–*y* location) as well as altitudinal information for integration in the GIS environment that produces 2-dimensional or 3-dimensional information about the features and phenomena for the science of 'where'. GPS is a network of satellites that continuously transmit information in the form of code that makes it possible to identify precise positions on the Earth's surface by measuring distances from the satellites. Usually, GPS refers to a group of US Department of Defense satellites, NAVSTAR (Navigation Satellite Timing and Ranging), which is constantly circling the Earth to fulfil defence-positioning needs as well as to serve the public.

The satellites transmit very low-power radio signals allowing GPS receivers, which may be in the form of mobile phones or any navigation system installed on any vehicle, to determine their location on the Earth by their latitude and longitude. GLONASS, that is, Global Navigation Satellite System, is a Russian satellite-based GPS system brought into operational testing in 1993, and by 1995 the whole orbit group of 24 satellites were launched (Table 4.1). The system

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Table 4.1 GPS satellites

GPS satellite	Launched	Operational
NAVSTAR	70	30
GLONASS	132	24
IRNSS	07	07

provides continuous global navigation for all types of users with different levels of quality requirements, mainly for navigational purposes. The horizontal accuracy of GLONASS is 4–7 m whereas the vertical error is 10–15 m. Being a Russian satellite, it is more useful in northern latitudes. It was the first GPS commercially used in car navigation.

IRNSS (the Indian Regional Navigation Satellite System) is an autonomous and regional satellite system developed by ISRO (the Indian Space Research Organisation), India to provide accurate positional information to users in India and their surrounding countries up to 1500 km from an Indian boundary. The extent of the coverage area ranges from 30° South to 50° North latitude and 30° East to 130° East longitude. IRNSS has two types of signals in the L5 (1176.45 MHz) and S (2492.028 MHz) bands. It offers public service as well as restricted service pertaining to defence use. It provides 10 m accuracy over landmass and 20 m over the Indian Oceans region. This system is a constellation of seven satellites consisting of IRNSS-1A, IRNSS-1B, IRNSS-1C, IRNSS-1D, IRNSS-1E, IRNSS-1F and IRNSS-1G. The IRNSS-1A was the first satellite launched on board by the PSLV-C22 on 1 July 2013 and IRNSS-1G was the seventh navigation satellite launched on board by the PSLV-C33 into a sub-geosynchronous transfer orbit on 26 April 2016 from the Satish Dhawan Space Centre, SHAR, Sriharikota (www.isro.gov.in).

4.2 Segments of GPS

There are three segments in the GPS system: space, controlling and user (Fig. 4.1).

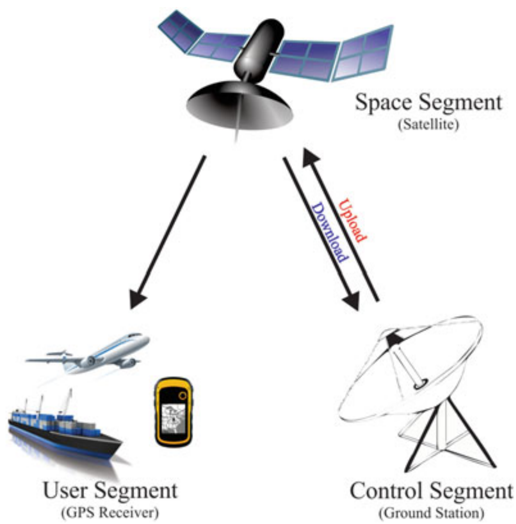

Fig. 4.1 GPS segments

4.2.1 Space Segment

The first GPS satellite was launched on 22 February 1978 by the United States Air Force. A complete constellation of 24 satellites, in which 21 satellites were operational and 3 satellites active spares, was achieved in 1994. These satellites are positioned at 20,000 km above the Earth, which is about 3 times the Earth's radius. These satellites travel at a speed of 13,000 kmph to complete a circle of the Earth every 12 h. The lifetime of each satellite is 10 years and replacements are constantly being built and launched into orbit.

Each satellite transmits low-power radio signals on several frequencies designated as L1, L2, L3, L4 and L5 (Table 4.2). A civilian GPS receiver works on the L1 frequency of 1575.42 MHz (19 cm wavelength) in the ultra high frequency (UHF) band and L2 frequency 1227.60 MHz

Table 4.2 GPS frequency overview

Band	Frequency MHz	Description
L1	1575.42	Coarse-acquisition (C/A) and encrypted precision (P(Y)) codes, plus the L1 civilian (L1C) and military (M) codes on future Block III satellites
L2	1227.60	P(Y) code, plus the L2C and military codes on the Block IIR-M and newer satellites
L3	1381.05	Used for nuclear detonation (NUDET) detection in the Earth's atmosphere and near space
L4	1379.913	Being studied for additional ionospheric correction
L5	1176.45	Proposed for use as a civilian safety-of-life (SoL) signal for aviation. This frequency falls into an internationally protected range for aeronautical navigation

(24 cm wavelength). The satellites are distributed in a manner that ensures that at least four satellites are visible almost anywhere in the world at any time. The GPS signal travels 'line of sight', which means it will pass through clouds, glass and plastic, but will not go through most solid objects such as buildings and mountains.

4.2.2 Ground Segment

The ground segment is also known as the control or operational segment. The ground segment is the controlling unit of GPS satellites that determines the position in space, clock offset and uploading of the navigation data to satellites as well as ensuring proper operation. NAVSTAR consists of five tracking stations, including four unmanned, distributed around the Earth. These are Hawaii, Ascension Island, Diego Garcia, Kwajalein and Colorado Springs (Fig. 4.2). The control segment tracks all satellites, ensures they are operating properly and computes their position in space.

The GLONASS ground segment consists of one System Control Centre (SCC) located at Krasnoznamensk; five Telemetry, Tracking and Command centres (TT&C) located at Schelkovo, Komsomoisk, St-Petersburg, Ussuriysk and Yenisseisk; one Central Clock (CCM) situated in Schelkovo; three upload stations at Yenisseisk, Komsomoisk and Schelkovo; two Laser Ranging Stations (SLR) at Schelkovo and Komsomoisk; four Monitoring and Measuring Stations located at Schelkovo, Krasnoznamensk, Yenisseisk and Komsomolsk; six additional Monitoring and Measuring Stations (MS) are to start operating on the territory of the Russian Federation and the Commonwealth of Independent States in the near future located at Yakutsk, Ulan-Ude, Nurek, Vorkuta, Murmansk and Zelenchuk (Fig. 4.3).

The IRNSS ground segment consists of 15 stations located in different parts of India. The ISRO Navigation Centre (INC) is located at

Fig. 4.2 Master control and monitor station of NAVSTAR

Fig. 4.3 Controlling segment of GLONASS (www.navipedia.net)

Byalalu near Bengaluru. The IRNSS Range and Integrity Monitoring Stations (IRIMS) used for integral determination of the IRNSS constellation are located at Gaggal, Dehradun, Lucknow, Jodhpur, Udaipur, Bhopal, Shillong, Kolkata, Pune, Goa, Byalalu, Hassan, Kavaratti, Mahendragiri and Port Blair. The IRNSS CDMA ranging stations (IRCDR) are located at Jodhpur, Bhopal, Shillong and Hassan. The IRNSS Network Timing Centre (IRNWT) is located only at Byalalu. The Spacecraft Control Facility (SCF) is located at Bhopal and Hassan to control the space segment through TT&C networks (Fig. 4.4).

4.2.3 User Segment

The user segment consists of a person and GPS receiver (Fig. 4.5). The user segment may include boaters, pilots, hunters, the military or anyone who wants to know where they are, where they have been or where they are going.

4.3 GPS Functioning

GPS works by determining the location of satellites and distances between satellites via the GPS receiver. Information about the GPS location is determined by the GPS receiver by obtaining it in two types: almanac information and ephemeris information. Almanac information contains the approximate location (position) of the satellites. This data is continuously transmitted and stored in the memory of the GPS receiver so it knows the orbits of the satellites, where each satellite is supposed to be as well as determines which satellites it expects in the local sky. It is periodically updated with new information as the satellites move around the Earth. Ephemeris information shows the GPS receiver where each GPS satellite could be at any time throughout the day. In reality, satellites can travel slightly out of orbit, so the ground monitor stations keep track of the satellites' orbit, altitude, location and speed. The ephemeris data is very precise orbital and clock correction data necessary for precise positioning of the satellite. The ground stations send the orbital data to the master control station, which in turn sends corrected data to the satellites. This corrected and exact position data are called the 'ephemeris' information, which is valid for a period of about 2–6 h and is transmitted in coded information to the GPS. With the help of these two forms of information, almanac and ephemeris, the GPS receiver knows the exact location of the satellites at all times (Fig. 4.6).

It is also necessary to know how far away the satellites are so that their positions can be determined on Earth. The receiver distance from a given satellite object equals the velocity of the transmitted signal multiplied by the time it takes the signal to reach the receiver. Velocity or speed of the radio wave is 186,000 miles/300,000 km per second (speed of light). The GPS receiver needs to determine the distance by 'pseudo-random code', that is

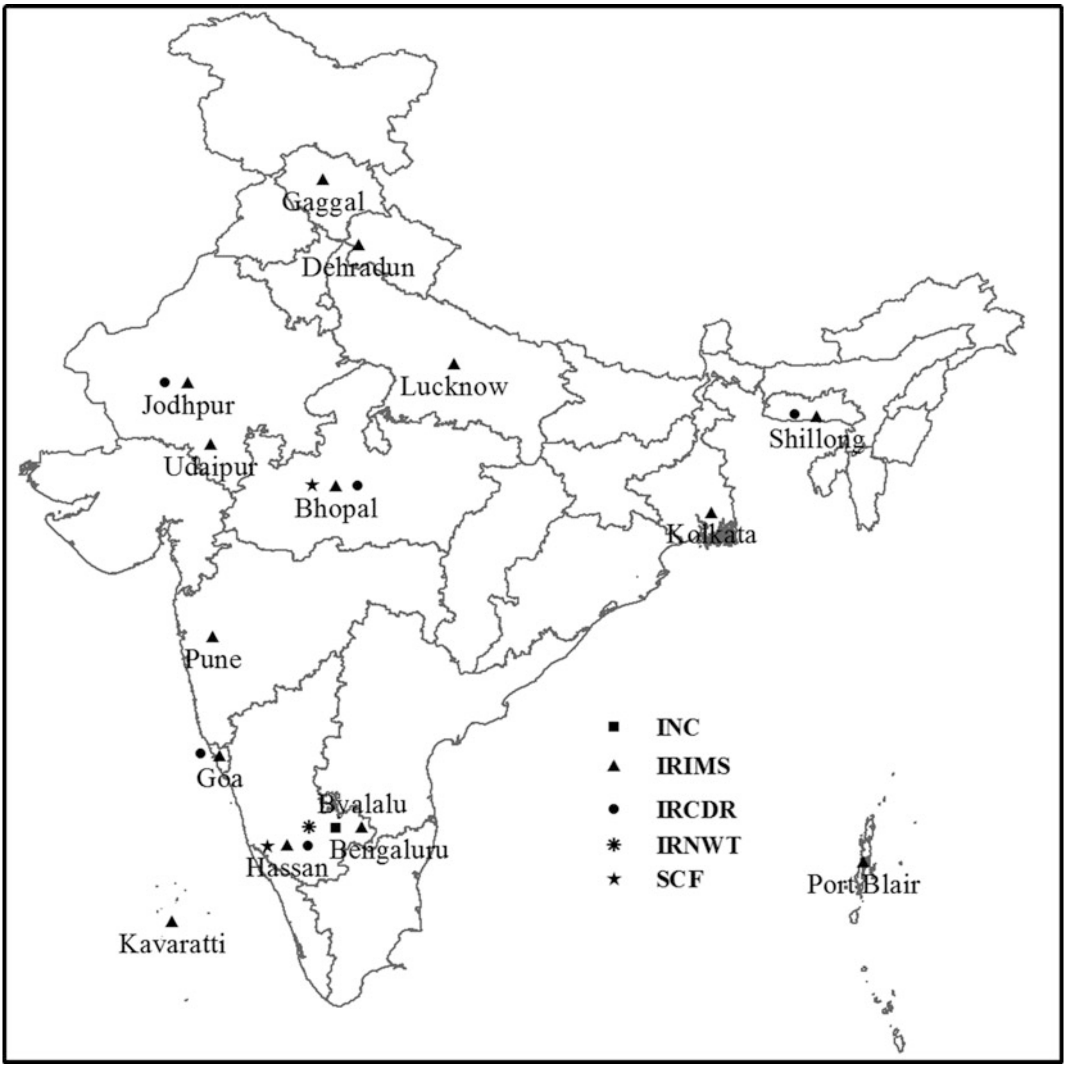

Fig. 4.4 The IRNSS ground segment (www.isro.gov.in)

the identification number of the satellite which is transmitted by the satellite itself. In the GPS receiver, this is visible by the number attached to each signal bar that identifies from which satellite (s) it is receiving the signal. When a satellite generates the pseudo-random code, the GPS receiver generates the same code and tries to match it up to the satellite's code. The receiver then compares the two codes to determine how much it needs to delay its code to match with the satellite code. This delay time is multiplied by the speed of light to get the distance of the satellite from the receiver.

4.4 GPS Receivers and Their Positions

Most modern GPS receivers are paralleled multi-channel design. Parallel receivers typically have 5–12 receiver circuits, each devoted to one particular satellite signal, so strong locks can be

Fig. 4.5 GPS receivers (www.garmin.co.in)

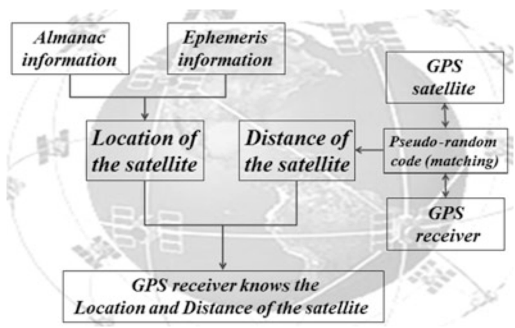

Fig. 4.6 GPS mechanism

maintained on all satellites at all times. Paralleled channel receivers are quick to lock onto a satellite when first turned on and they are unequalled in their ability to receive satellite signals even in difficult conditions such as dense foliage or urban settings with tall buildings.

It is also necessary to know how the GPS receiver determines the positions of *x*, *y* and *z*. Let's assume that our GPS receiver is 18,000 km from one satellite. Our location would be somewhere on an imaginary sphere that has the satellite in the centre with a radius of 18,000 km. Then we assume the second satellite is 19,000 km from another satellite. The second sphere would intersect with the first sphere to create a common circle. The third satellite, at a distance of 20,000 km, will have two common points where the three spheres intersect. Even though there are two possible positions, these differ greatly in latitude/longitude position and altitude. To determine which of the two common points in-between the actual position is correct, we need to enter the approximate altitude into the GPS receiver. This will allow the receiver to calculate a 2-dimensional position (latitude and longitude). However, by adding a fourth satellite, the receiver can determine a 3-dimensional position, i.e., altitude. So, the forth satellite at a distance of 16,000 km intersecting with the first three spheres at one common point is the actual location of the GPS receiver (Fig. 4.7).

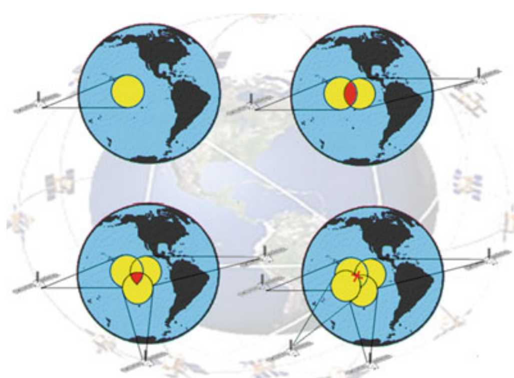

Fig. 4.7 GPS positioning

4.5 Sources of Error

GPS receivers also have potential positional errors due to accumulated errors arising out of the following sources:

Ionosphere and Troposphere Delays The satellite signals slow as they pass through the atmosphere. The system uses a built-in 'model' that calculates an average, but not an exact amount, of delay.

Orbital Errors These are also known as 'ephemeris errors'. These may be due to inaccuracies in location provided by the ground-control units to the satellite.

Receiver Clock Errors Since it is not practical to have an atomic clock in a GPS receiver, the built-in clock can have very slight timing errors.

Multi-path Signal This occurs when the GPS signal is reflected off objects such as tall buildings or large, rocky surfaces before it reaches the receiver, thereby increasing the travel time of the signal causing errors in the GPS location.

Number of Satellites Visible The accuracy is dependent on the number of satellites a GPS receiver can locate. The larger the number of satellites identified by the GPS receiver the better will be the accuracy. Buildings, indoors, underground, terrain, underwater, electronic interference or sometimes even dense foliage in the forest can also block signal reception, causing positional errors. The clearer the view, the better will be the reception in the GPS receiver.

Satellite Geometry This means the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in tight grouping.

Intentional Degradation of the Satellite Signal The US military's intentional degradation of the signal for civilian use is intended to prevent military adversaries from using the highly accurate GPS signals.

4.6 Differential Global Positioning System (DGPS)

DGPS works by placing a GPS receiver at a known location. Since the reference station knows its exact location, it can determine the errors in satellite signals. It does this by measuring the ranges to each satellite using the signals received and comparing these measured ranges to the actual ranges calculated from its known position (Fig. 4.8). The differences between the measured and calculated ranges for each satellite in view become a 'differential correction'. The differential corrections for each tracked satellite are formatted into a correction message and transmitted to DGPS receivers. Typical DGPS accuracy is 1–5 m.

WAAS (Wide Area Augmentation System) This refers to a network of 25 ground-reference stations that cover the entire USA and some areas of Canada and Mexico. These reference stations are located at precisely surveyed spots and compare GPS distance measurements to known values. Each reference station is linked to a master station, which puts together a correction message and broadcasts it via satellite.

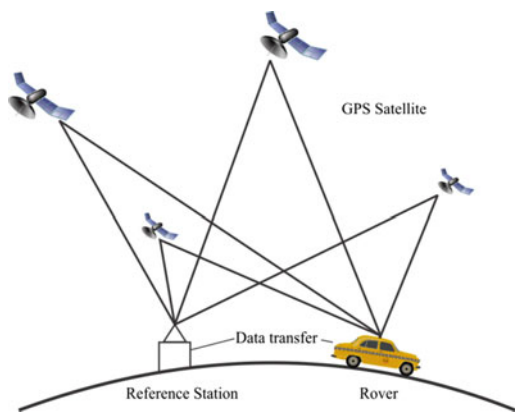

Fig. 4.8 DGPS model

4.7 Applications of GPS

Determination of position is the basic application of the GPS system. It determines the *x*, *y* and *z* values of the given place to the receiver. Navigation is the most important application of GPS in vehicles, ships and aircrafts. In the car a compatible navigation device is installed to find the route and directions. Tracking and monitoring are also used for the movement of vehicles and people such as GPS-enabled police vehicles, milk vans, taxis etc. GPS is also used for mapping purposes with the help of coordinates that are provided by the GPS receiver. It may be in static or mobile form and can store the *x* and *y* position which can further be used in mapping the features.

With the help of satellites, the GPS receiver also provides precise timing on a global scale. GIS can be used to help visually impaired people to find their way in new settings and navigate places (Harvey 2008).

4.8 GPS and Mapping Technology

GPS receivers enable us to provide accurate and precise coordinates of the geometry of features such as point, line and polygon during fieldwork or surveying in map-making processes. The coordinate of Earth features such as rivers, ponds, mountains, roads, trekking routes, buildings, utilities etc. can be mapped through GIS. The GPS system efficiently collects the *x* (longitude), *y* (latitude) and *z* (altitude) values of the site along with the identification number for the 2-dimensional or 3-dimensional visualisation of the feature (Fig. 4.9). *x*, *y* and *z* values can be imported into GIS software to generate the geographical features of any geometry. Initially, GIS software generates point features from *x*, *y* and *z* coordinates, then that point feature can be connected with lines to generate polyline or polygon features by the GIS tool, which increases the efficiency and productivity provided in the map-making process with the help of GPS coordinates.

Proper planning is required while going into fieldwork with a GPS receiver. Initially, GPS receivers should be prepared with project names and setting the coordinate system which should be similar to your digital map for the proper location of the feature. For verification of the particular location, the list of sample coordinates (*x*, *y*) and their name (feature) is required to verify the location. For example, if you are interested in verifying your remote-sensing satellite-based

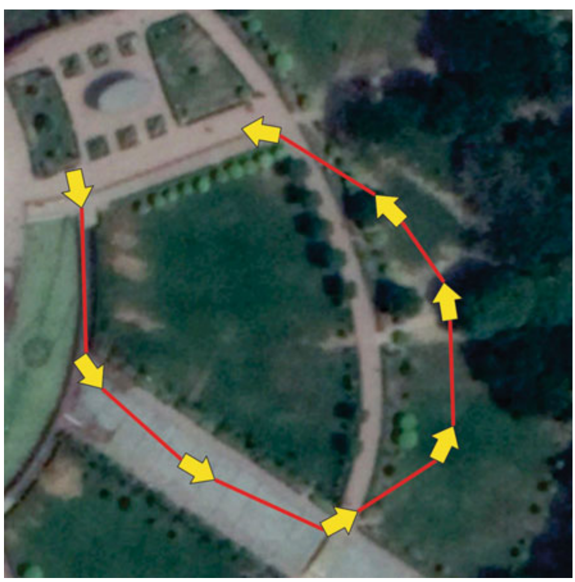

Fig. 4.9 GPS data in tabular form and map created by a database in the GIS environment

land-use/cover map, then you need the type of land-use/cover such as kharif crop area, pond, park etc. along with their *x–y* coordinates for the verification of a particular location with its land-use/cover. In the field, the user must go to the particular *x–y* coordinate with a GPS receiver to verify the specific land-use/cover. Suppose you want to update your road network with its attributes of road-crossing, red-light locations or other attributes. So, you have to navigate along the road network and wherever you find any of the features stop there to collect the waypoint number and its coordinates by GPS receiver and note the copy along with its name and type. Suppose you want to create a parcel boundary of the agriculture field, you then go to that parcel and start your GPS receiver at any point and move around that parcel of land to collect the waypoint of each corner of the parcel. After field verification or the creation of a new database or updated data, you can download GPS receiver data into GIS software and overlay it with your existing database or create or update your database.

4.9 Conclusion

GPS is an instrument that provides the precise location of a particular point. Generally, GPS refers to the US NAVSTAR satellite but GLONASS and IRNSS are also providing positional information from Russian and Indian satellite constellations, respectively. There are space, ground and user segments in GPS. In the space segment, each satellite transmits low-power radio signals on five frequencies designated as L1, L2, L3, L4 and L5. The ground segment is a controlling segment that controls the space-segment satellites to determine proper operations. The GPS receiver acts as a user segment which is installed in road–rail–air–water navigation systems. With the help of four satellite signals, the receiver determines the 3-dimensional position. To enhance the positional accuracy, the differential global positioning system (DGPS) can be used, where a minimum of two GPSs are required, one acting as base station and the other as rover. The most important application of GPS is for navigation but it can also be used for tracking and monitoring the movement of vehicles as well as time correction.

Questions

1. What is Global Positioning System? Discuss the significance of GPS in the GIS environment.
2. Discuss the NAVSTAR, GLONASS and IRNSS GPSs.
3. What do you understand by segments of GPS? Discuss the types of GPS segment.
4. Discuss the mechanism to collect positional information by the GPS receiver.
5. What is DGPS and how is it different from GPS?
6. Discuss the applications of GPS and DGPS.

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www.isro.giv.in

www.navipedia.net

www.garmin.co.in

5 Geo-Referencing System

Abstract

At this point, you have learnt about the basic concept of the database in the GIS environment. The aim of this chapter is to understand our Earth's reference system and how we can manage our database in the real coordinate system to locate Earth's features. After reading this chapter you should be able to understand the following:

- Needs of the geo-reference system
- The Earth's reference system and its characteristics
- Coordinate systems and their types
- Map projection, mostly used in India—polyconic, Lambert Conformal Conic (LCC) and Universal Transverse Mercator (UTM)

Keywords

Coordinate system · Datum · Flattening · Map projection · UTM · Non-perspective projection

5.1 Introduction

In spatial data, information about location is most important and should be geo-referenced to know the location of any feature on a map, which means the map should be referenced with the Earth's coordinate system. Various spatial databases are created with different geo-reference systems by different organisations, and this requires us to bring the same geo-reference platform for the integration of databases for further geographical analysis. The literal meaning of geo-reference is to associate anything with the Earth. In other words, it is defined as positioning objects in either 2- or 3-dimensional space. So geo-referencing is a process of providing coordinate systems of the Earth to the database which may be raster or vector. The coordinate system is composed of a spheroid (a mathematical description of the Earth's shape) and map projection (a mathematical conversion from spherical to planar coordinates). Coordinate systems may be geographic or projected. This geo-referencing of databases provides the ability to measure the length, size and shape of the Earth's features.

Before understanding the coordinate system, we must know the characteristics of the globe that correspond to the Earth as offered by Mishra and Ramesh (2002):

1. The equator divides the globe into two halves, the northern and southern hemisphere.
2. The equator is perpendicular to the polar axis.
3. All parallels are parallel to the equator.

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4. Spacing between any two parallels is the same along all meridians.
5. The equator is the only great circle line of latitude. All other lines of latitudes (parallels) are shorter than the equator and are not a great circle.
6. Each meridian is one half of a great circle in length. It is the shortest line between the two poles.
7. All meridians converge at the North and South polar points.
8. Spacing between meridians is equal along a given parallel, but the space between meridians decreases pole-wards.
9. Parallels and the meridians intersect at right angles.
10. All areas are in correct scale ratio to Earth's measurements.

Properties of a map such as shape, area, distance and direction are affected by the projection system. Different projection systems preserve different properties of a map and it is not possible to include all properties of a map in a single projection.

1. **Conformality or orthomorphism** This represents the features of the Earth's surface in their true shape.
2. **Equal area or equivalence** All the features represented on it maintain their proportional sizes.
3. **True distance** Geodetic lines on the Earth which give the shortest distance between any two points appear as the shortest lines on the globe. The distance is correctly maintained.
4. **True direction** The directions of points on the globe from a given point are the same as the directions on the surface of the Earth. It represents true direction on a globe.
5. **Simplicity** The longitudes and latitudes are so precisely arranged that it becomes convenient to locate a point or network of graticules which have the property of simplicity.

5.2 Coordinate System

A coordinate system is a measurement framework or reference framework consisting of a set of points, lines and surfaces with a set of rules that are used to define the positions of points in space in either two or three dimensions. There are two types of coordinate systems: *real and geographic*, where spherical coordinates are measured from the centre of the Earth and use ellipsoid and datum; and *planar coordinate or projected coordinate system*, where the Earth's coordinates are projected into a 2-dimensional plane (Fig. 5.1). Both coordinate systems are used to present the Earth's surface with different specifications.

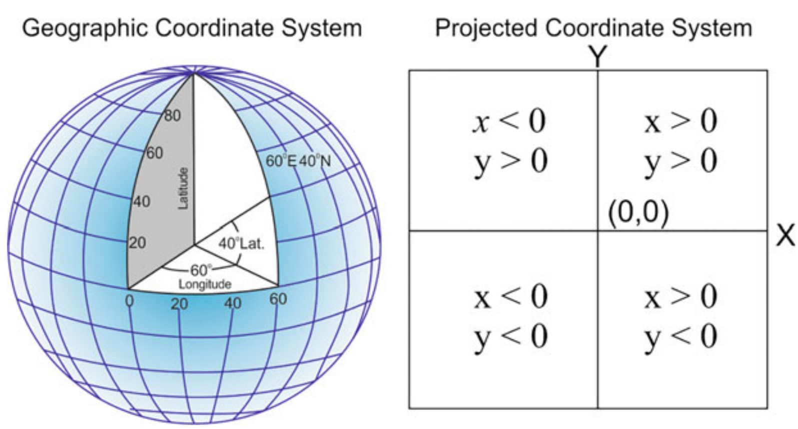

Fig. 5.1 Geographic and projected coordinate system

5.2.1 Real or Geographic Coordinate System

A reference system that uses latitude and longitude to define the locations of points on the surface of a sphere or spheroid is represented by decimal degree (0.00) and degree (Degree, Minute and Second). Longitudes and latitudes are angular measurements from the Earth's centre to a point on the Earth's surface. The longitude is measured in degrees East or West of the prime meridian (Greenwich) and latitude is measured in degrees North or South of the equatorial plane. For longitude 0°, the prime meridian, starting at the North Pole, passes through Greenwich, England and ends at the South Pole. Longitude is measured form Greenwich (0°) eastwards up to 180° and West up to −180°. For latitude 0° is the equator, 90° is at the North Pole and −90° at the South Pole. A geographic coordinate system definition includes a datum, prime meridian and angular unit. It is also known as a Universal Coordinate System and is used for locating positions on the surface of a globe. Latitude and longitude are not uniform units of measurement; one degree of longitude at the equator represents 111.321 km (Clarke 1866 spheroid) and one degree of longitude at 60° latitude represents 55.802 km (Clarke 1866 spheroid). This reference system assumes that the Earth is not a perfect sphere. The geographic coordinate system (latitude and longitude) is not efficient for measuring distances and areas.

5.2.2 Planar or Projected Coordinate System

This can be referred to as a map projection because the Earth is a spheroid and a mathematical model must be used to convert a spherical surface to a flat map sheet. There are two dimensions, *x* and *y*, which measure the distance in horizontal and vertical directions, resulting in the positions of vector and raster formats of data divided into two dimensions. This is also known as a planar or Cartesian coordinate system. Typically, the measurement unit of this system is linear, such as a metre (metric system) or foot (British system). A projected coordinate system is defined by a geographic coordinate system, a map projection, any parameter needed by the map projection and a linear unit of measurement. A map projection is the systematic transformation of locations on the Earth (latitude/longitude) to planar coordinates. The measurements of length, angle and area remain constant by this projection system. The representation of the Earth's features into two dimensions always involves distortion of some parameter such as shape, area, distance or direction. Different projections produce different types of distortions. Therefore, different types of applications require different projections.

5.3 Shape of the Earth and Datum

A datum is a set of reference points used to locate places on the Earth's surface and also determine the precise position on the Earth's surface by defining the origin and orientation of latitude and longitude lines. Satellite technology has revealed that the shape of the Earth is neither a perfect sphere nor a perfect spheroid (Fig. 5.2) due to

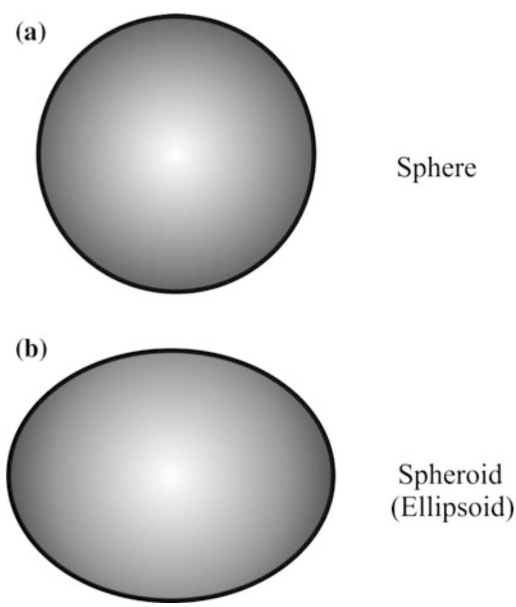

Fig. 5.2 Shape of the earth: **a** sphere, **b** spheroid

flattening at the poles as well as gravitational and surface feature variations. Ellipsoid is a mathematical figure generated by the revolution of an ellipse about one of its axes. The ellipsoid that approximates the geoid is an ellipse rotated about its minor axis, or an oblate spheroid. Ideally, a spheroid is a 3-dimensional shape or rotating figure of the Earth obtained by rotating an ellipse on its minor axis, resulting in an oblate spheroid, or about its major axis, resulting in a prolate spheroid. In other words, a spheroid is created from the 2-dimensional ellipse and the ellipse is an oval shape of the Earth with major and minor axes. It is also defined by the flattening of the Earth which is calculated by the given formula:

$$\text{Flattening} = \frac{\text{Semi-major axis} - \text{Semi-minor axis}}{\text{Semi-major axis}}$$

The flattening result lies between 0 and 1. Flattening value 0 means both axes are equal. The flattening of the Earth is approximately 0.0033. The reference specifications of a measurement system are the system of coordinate positions on a surface (a horizontal datum) or heights above or below a surface (a vertical datum). Therefore, an ellipsoid is the best-fitted shape of the Earth and assumes that the Earth has a homogenous surface with no mountains and trenches. But the Earth has irregular surfaces (mountains and trenches) causing variation in local heights. A geoid is also a model of the Earth's surface that shows the mean global sea level. A geoid is the equipotential surface in the gravity field of the Earth which approximates the undisturbed mean sea level extended continuously through the continents. The direction of gravity is perpendicular to the geoid at every point. The geoid is the surface of reference for astronomic observations and for geodetic levelling. The shape of the geoid passes through the Earth's crust (Fig. 5.3). The vertical distance between ellipsoid and geoid is called geoid height, and it ranges from −100 m (negative geoid) to +100 m (positive geoid). It is also important to know that elevations and contour lines on the Earth are reported relative to the geoid, not the ellipsoid. Latitude, longitude and all plane coordinate systems, on the other hand, are determined with respect to the ellipsoid.

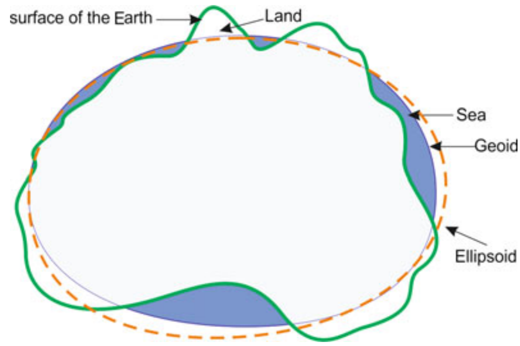

Fig. 5.3 Model of the Earth: ellipsoid, geoid and the Earth's surface

5.3.1 Geocentric Datum

In the last 15 years, satellite data have provided geodesists with new measurements to define the best earth-fitting spheroid, which relates coordinates to the Earth's centre of mass. An earth-centred or geocentric datum uses the Earth's centre of mass as the origin. The most recently developed and widely used datum is WGS 1984. It serves as the framework for locational measurement worldwide (Fig. 5.4).

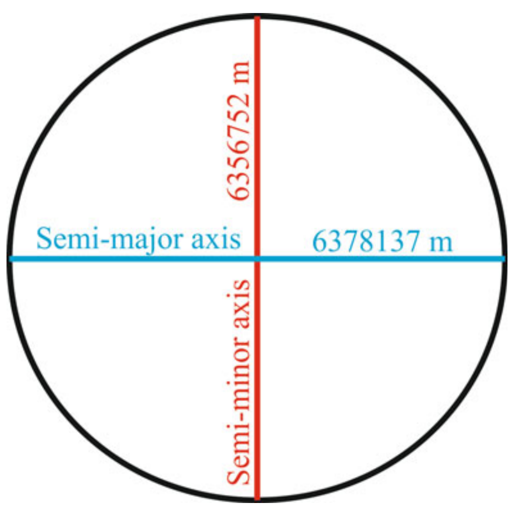

Fig. 5.4 Geocentric datum (WGS84)

Table 5.1 Ellipsoid parameters for India

Sl. No.	Ellipsoid	Semi-major axis	Semi-minor axis
1	Everest 1830	6377299.3600000003	6356098.3516280400
2	Everest adj 1937	6377276.3449999997	6356075.4131402401
3	Everest def 1962	6377301.2429999998	6356100.2301653838
4	Everest def 1967	6377298.5559999999	6356097.5503008962
5	Everest def 1975	6377299.1509999996	6356098.1451201318
6	Everest India Nepal	6377301.2429999998	6356100.2301653838
7	Everest modified (1830)	6377304.0630000001	6356103.0389931547
8	Everest modified (1969)	6377295.6639999999	6356094.6679152036
9	Indian 1954	6377276.3449999997	6356075.4131402401
10	Indian 1960	6377276.3449999997	6356075.4131402401
11	Indian 1975	6377276.3449999997	6356075.4131402401
12	WGS_1984	6378137.0000000000	6356752.3142451793

5.3.2 Local Datum

A local datum aligns its spheroid to closely fit the Earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the Earth. This point is known as the origin point of the datum. The coordinates of the origin point are fixed, and all other points are calculated from it (Shekhar 2015) – e.g. the Everest datum is used to locate the Indian sub-continent (Snyder 1987) (Table 5.1).

5.4 Map Projection

Map projection is a systematic drawing of parallels of latitude and meridians of longitude on a plane surface for the whole Earth or part of it on a certain scale so that any point on the Earth's surface may correspond to that on the drawing (Singh and Singh 2009). According to Snyder (1987), a map projection is a systematic representation of all or part of the surface of a round body, especially the Earth, on a plane. In other words, a map projection is one which represents longitude and latitude in the same way as a globe on a flat surface. There are various projection systems by which the curved surface of the Earth is portrayed on a flat surface (Fig. 5.5).

Basically, various criteria are used for classification of projection. On the basis of source of light, map projection can be perspective and non-perspective. Perspective projections are created by projecting latitude and longitude as true geometric projections by the source of light on the plane surface. It can be visualised as a transparent globe with a light bulb at its centre (though not all projections originate from the globe's centre, it can be three positions such as one of pole, equator and in-between pole and equator) casting lines of latitude and longitude into a sheet of paper. Generally, the paper is either flat or placed tangentially to the globe (a planar or azimuthal projection) or formed into a cone or cylinder and placed over the globe (cylindrical and conical projections). When the source of light is placed at the centre of the globe to project toward the North or South Pole this is known as gnomonic projection. Where the source of light is placed at a pole to project toward the opposite pole this is known as stereographic projection, and when the source of light is infinite to project this is known as orthographic projection (Fig. 5.6). Map projection can be categories on the basis of tangent

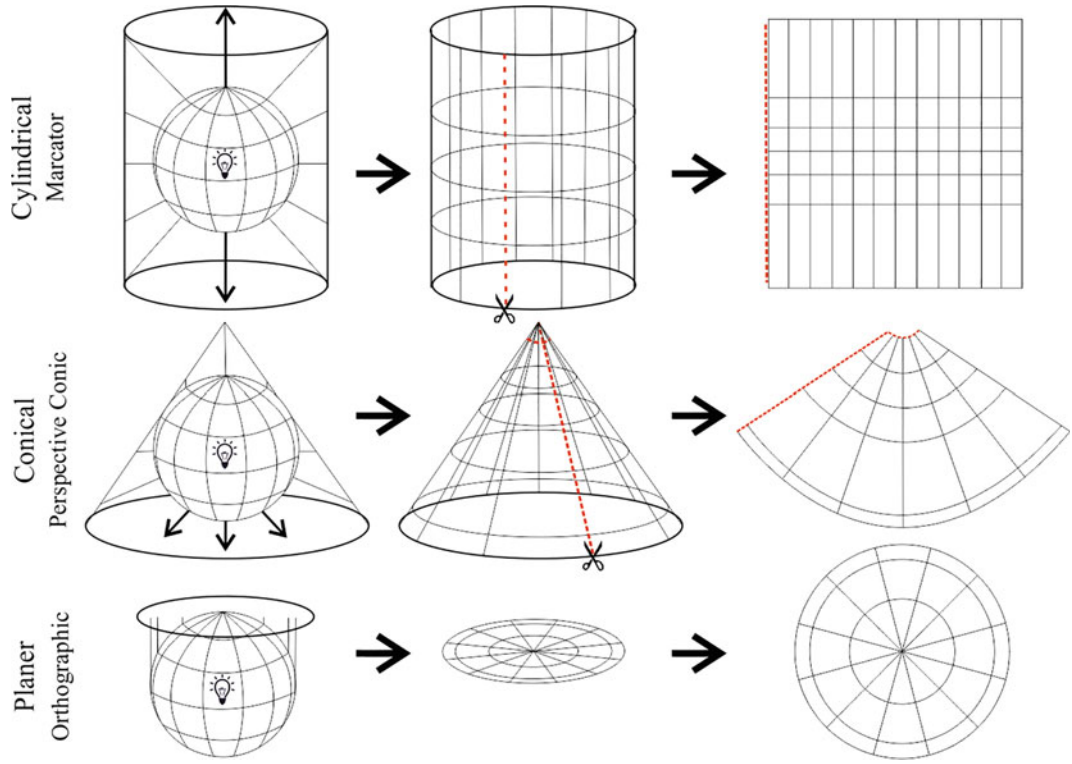

Fig. 5.5 Type of map projection

and secancy. Cylindrical, conical and planar projection are shown in Fig. 5.7. This is basically a different tangent plane where a network of latitude and longitude is projected. If the tangent surface is parallel to the pole this is known as transverse projection. When the tangent surface is perpendicular to the equator this is known as normal projection, and when the tangent plane is in-between normal and transverse it is known as oblique projection.

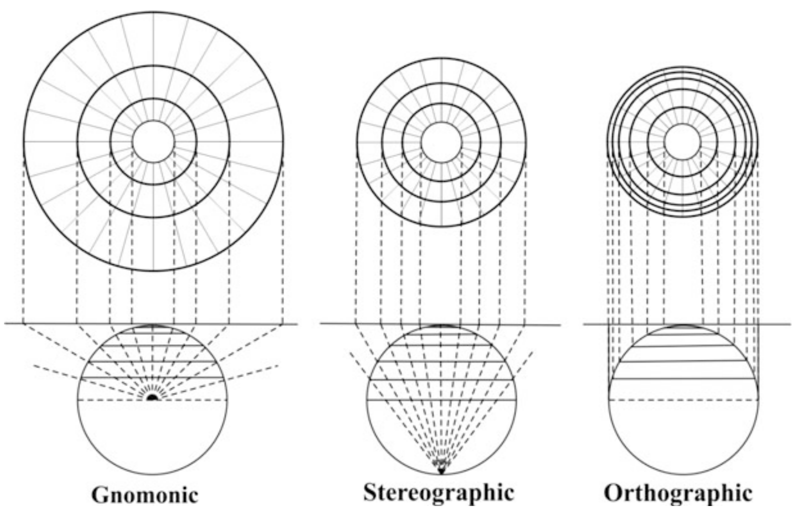

Fig. 5.6 Perspective projection

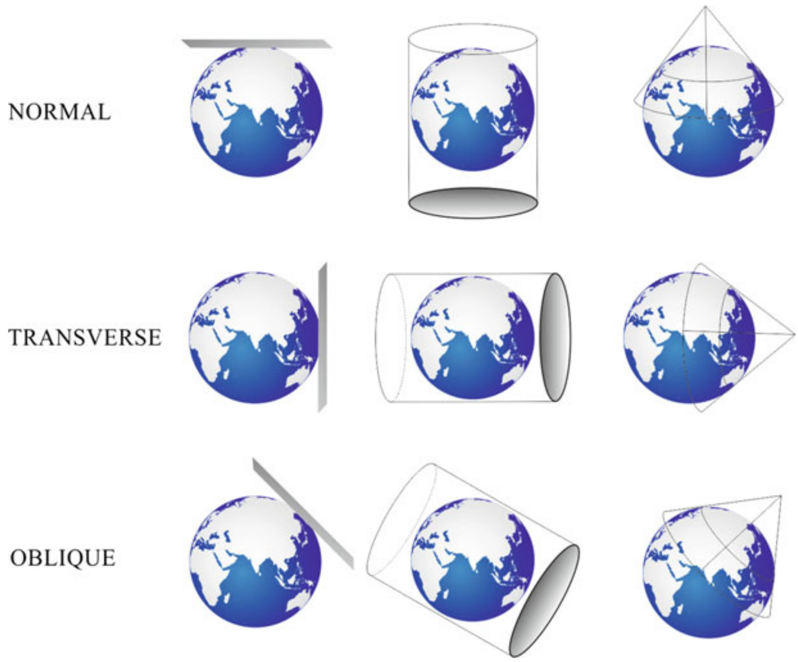

Fig. 5.7 Tangent projection

Non-perspective projections are formed with the longitude and latitude networks of curved or straight lines as well as spacing between longitudes and latitudes reduced or enlarged. On the basis of a developable surface, it can be cylindrical, conical and plane (zenithal or azimuthal). When a cylinder is wrapped around the globe that touches the equator throughout its circumference, the network of latitude and longitude is projected on the cylinder. When a cylinder is cut along longitude and unrolled, then the cylindrical projection is formed with straight latitude and longitude. Mercator's projection is one example of cylindrical projection. When a cone is placed over the globe and its peak along the polar axis of the globe and the surface of the cone touches the globe along latitude, the network of latitude and longitude projected over the cone is basically known as conical projection. Single standard parallel conical projection is an example of conical projection. When a plane tangent to the globe pole and longitude is projected as straight lines radiated from the pole towards the equator as well as latitude formed as complete circles, this is centred on the pole to make planar projection. Gnomonic and stereographic projection form the planar projection. Map projection generally requires a systematic mathematical transformation of the Earth's longitude and latitude into a plane. Every map projection has some distortion to preserve some characteristics of a globe in terms of distance, area, shape or direction. It is a choice of a cartographer to choose certain characteristics of the globe at the expense of others. On the basis of global characteristics, a map projection can be equal-area, conformal and azimuthal. There are three main cartographic criteria that are applied to the evaluation of map projection properties: *equidistance* – correct representation of distance, usually one or more lines on a map along which the scale remains true, but the scale is not correct throughout the map (equidistant projections); *conformality or orthomorphism* – correct representation of shape – orthomorphic is derived from two words, *orthos* meaning 'straight' and *morphe* meaning 'shape', so the relative local angles about every point on the map are shown correctly; and *equal area or equivalence* – correct representation of area but the shapes, angles and scale are distorted on most parts of a map. There are thousands of map projections varying by choosing different points on the Earth as the centre or as a starting point of projection. But there are three basic types of developable surfaces onto which most map projections are based: cylindrical, conical and azimuthal.

There are two methods for map projection in a GIS environment: direct, in which one maps from ellipsoidal to projection surface; and double, which involves a transformation from ellipsoidal to spherical surfaces and from the spherical to the projection surface. Before creating a map on any projection system, one needs to provide a datum or ellipsoid. The proper scale should be specified according to the output material size and the appropriate projection system chosen on which basis the map should be transformed (Fig. 5.8). The Indian grid system was designed during British periods, dividing India into nine zones in the Lambert Conformal Projection. The topographical map of India is on 1:25,000, 1:50,000 and 1:250,000 scales and on polyconic projection, and now it is being converted to the Universal Transverse Mercator (UTM) projection. So, polyconic projection, Lambert Conformal Conic projection (LCC), Transverse Mercator and Universal Transverse Mercator (UTM) projections are widely used for India.

5.4.1 Polyconic Projection

Polyconic projection was developed by Ferdinand Hassler, First Superintendent of the US Coast Survey, in 1820 for mapping of the eastern

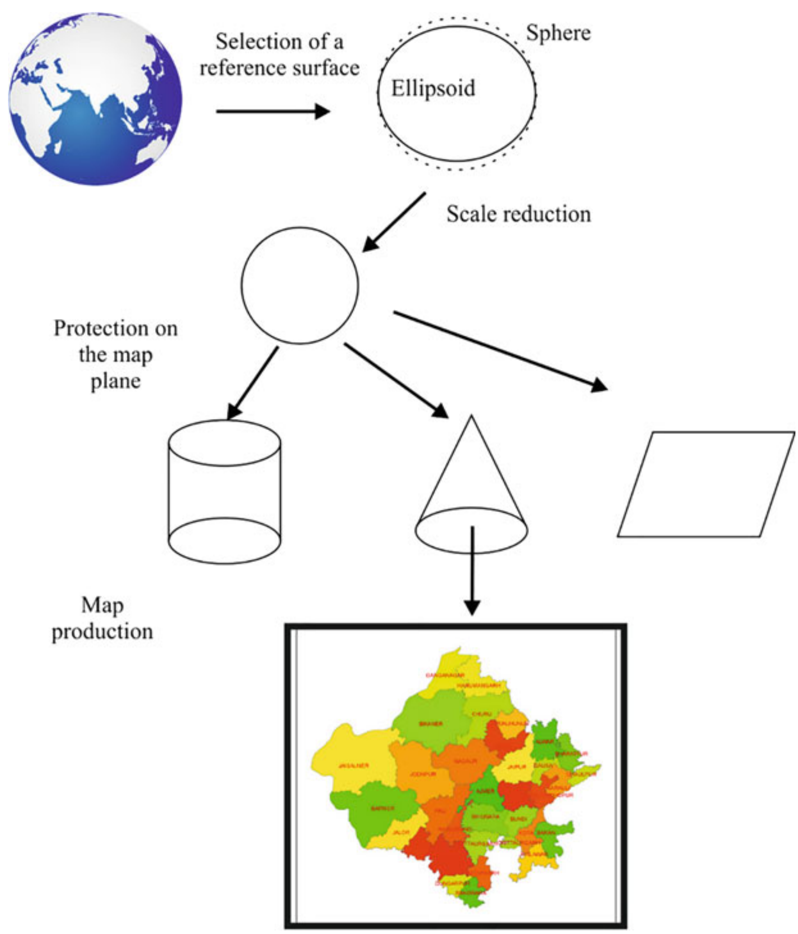

Fig. 5.8 Flow diagram of map-projection system

coast of the USA. This refers to the projection methodology. This affects the shape of the meridians. Unlike in other conic projections, the meridians are curved rather than linear. The Polyconic Projection, usually called the American Polyconic in Europe, achieved its name because the curvature of the circular arc for each parallel on the map is the same as it would be following the unrolling of a cone which had been wrapped around the globe tangent to the particular parallel of latitude, with the parallel traced onto the cone. Thus, there are many ('poly') cones involved, rather than the single cone of each regular conic projection. The Polyconic Projection is neither equal-area nor conformal. Along the central meridian, however, it is both distortion-free and true to scale. Each parallel is true to scale, but the meridians are lengthened by various amounts to cross each parallel at the correct position along the parallel, so that no parallel is standard in the sense of having conformality (or correct angles), except at the central meridian. Near the central meridian distortion is extremely small. Parallels of latitude (except for the equator) are arcs of circles, but are not concentric. The central meridian and equator are straight lines; all other meridians are complex curves. The scale of this projection is true along each parallel and along the central meridian, but no parallel is 'standard'. There is no distortion in local shape along the central meridian. Distortion increases with distance from the central meridian; thus, East–West distortion is greater than North–South distortion. The area, distance and local angle are accurate along the central meridian but are distorted with increases in the distance from the central meridian (Figs. 5.9 and 5.10). This projection was used for 7½- and 15-min

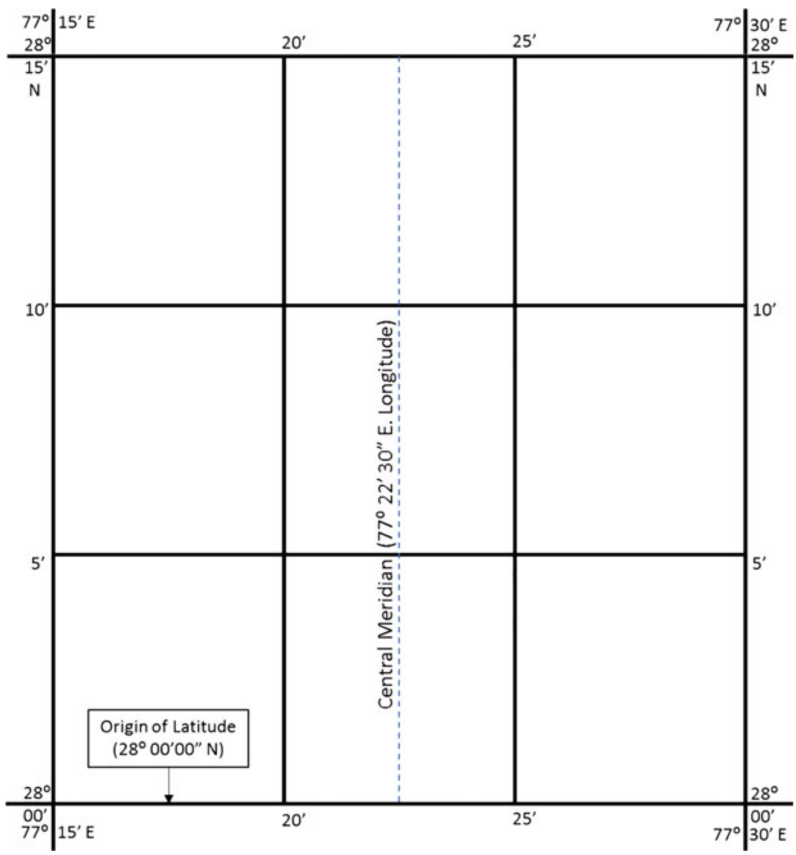

Fig. 5.9 Projection parameter for polyconic projection

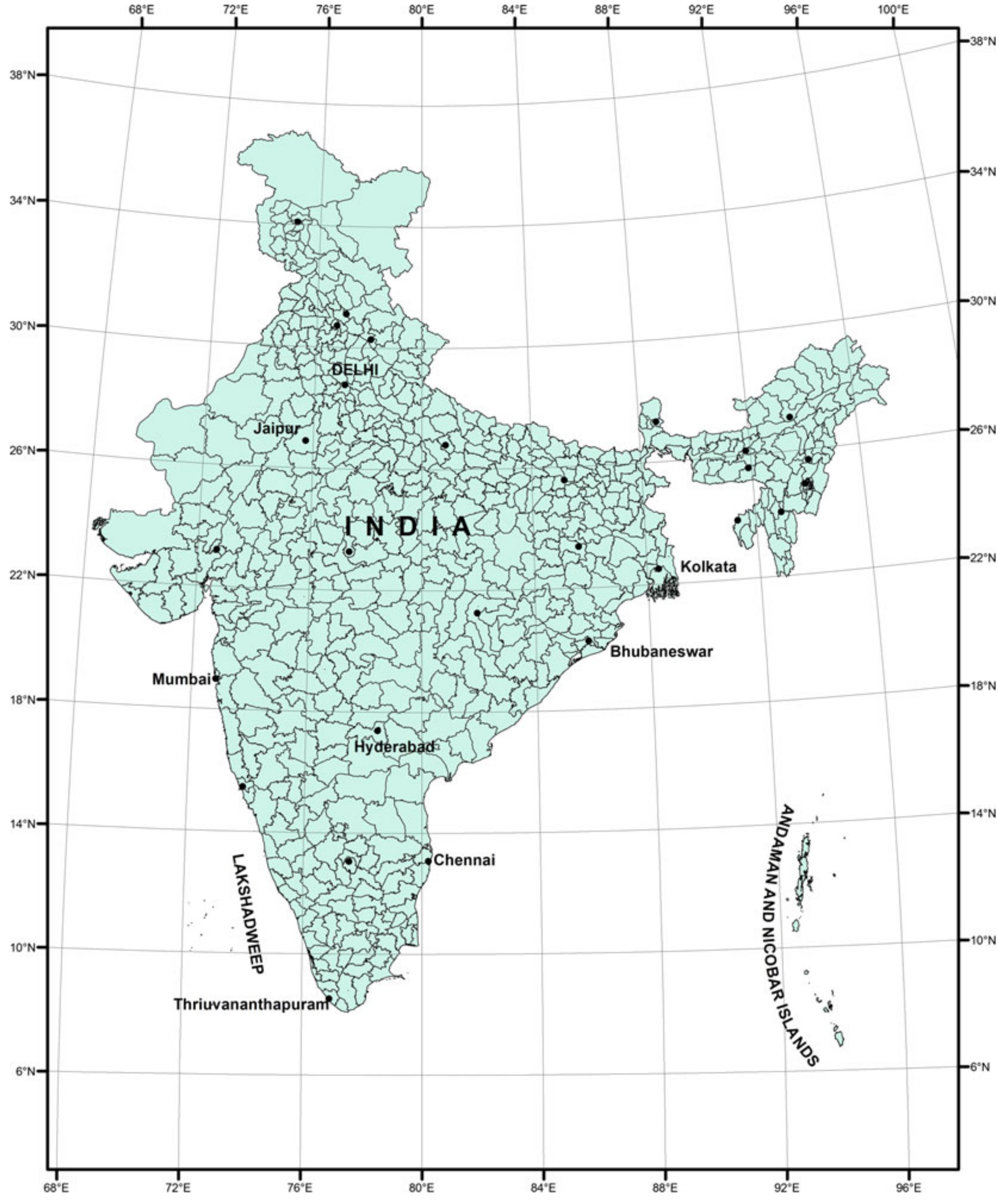

Fig. 5.10 India on a polyconic projection

topographic USGS quad sheets from 1886 until approximately 1957. It was also used in the Survey of India Topographical sheet on 1:50,000 and 1:25,000 in India.

Suppose you have a map sheet which extended between 77° 15′ East to 77° 30′ East longitude and 28° 00′ North to 28° 15′ North latitude, the parameters would be as follows:

Name of projection	Polyconic
Longitude of central meridian	77° 22′ 30′
Latitude of origin of projection	28° 00′ 00′
False easting at central meridian	00
False northing at origin	00
Unit	Metre

The central meridian of the toposheet will be mid-value of the extent of the toposheet, and sometimes the region of study is extended over the large area, and in that case the central meridian will be mid-value of longitudinal extent. The origin of the projection is the lowest extent of latitude of the study area or toposheet. The false easting or northing is a value assigned to the origin of eastings or northings in a grid coordinate system, to avoid the inconvenience of using negative coordinates. Easting is the eastward reading or left-to-right reading of grid values on a map, similarly northing is the northward or bottom-to-top reading of grid values.

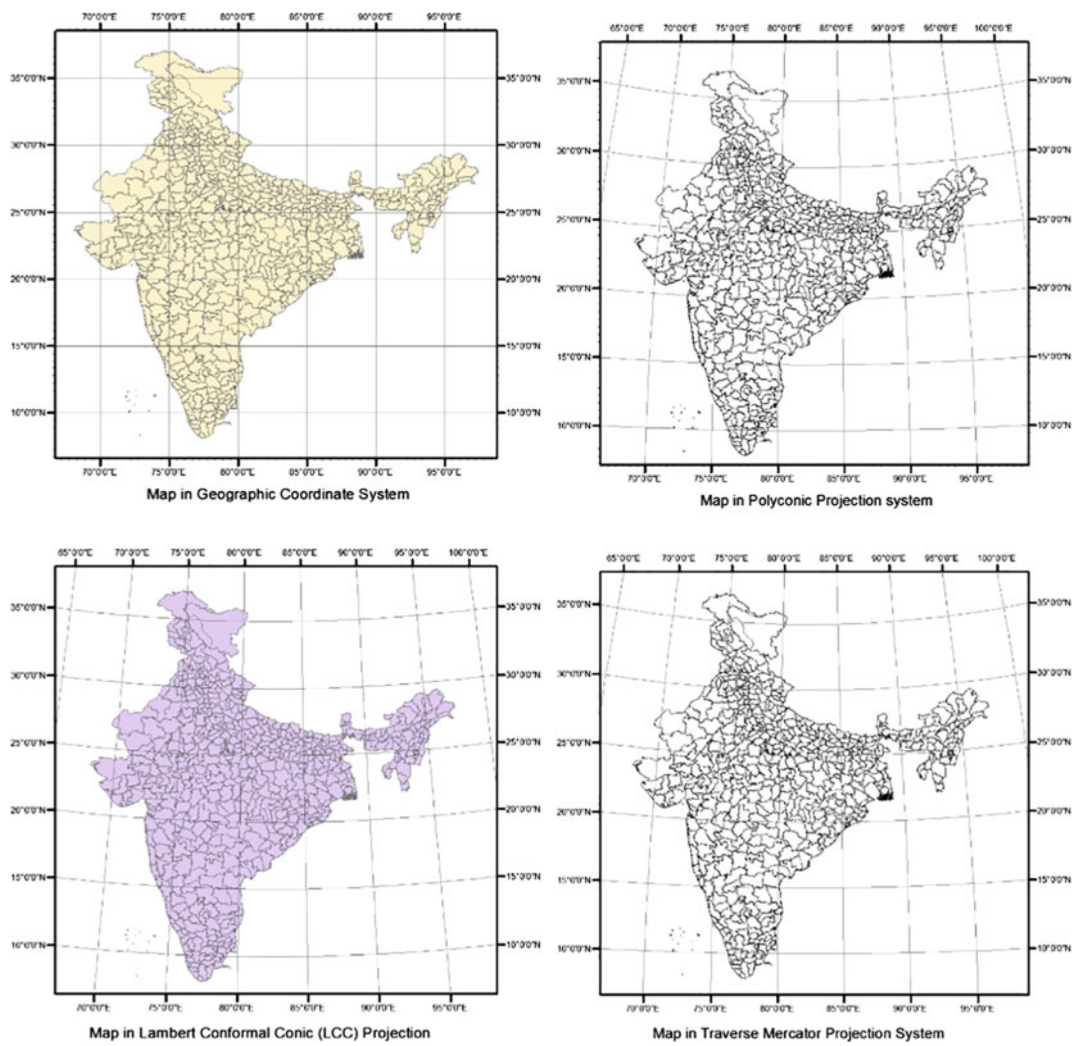

Fig. 5.11 Comparison of maps in different projections

5.4.2 Lambert Conformal Conic (LCC) Projection

The Lambert Conformal Conic projection is a modified conical projection for mid-latitude countries developed by Johann Heinrich Lambert. This projection consists of one and two standard parallels. The spacing between latitude increases beyond the standard parallels. The scale along the standard parallels is correct. It is reduced between the parallels and increases beyond standard parallels. Direction and shape are maintained in this projection. There is minimum distortion in area near standard parallels (Fig. 5.11). This projection is best suited for countries where East–West extent is more and total latitude range should not exceed 35°.

The following parameters are important while using this projection:

Name of projection	Lambert Conformal Conic
Central meridian	82° 30′ 00′ E
Latitude of origin	08° 00′ 00′ N
Standard parallel	1 23° 30′ 00′ N
Standard parallel	223° 30′ 00′ N (*if one standard parallel projection is used then value of standard parallel 1 should be put in the standard parallel 2*)
False easting	00
False northing	00

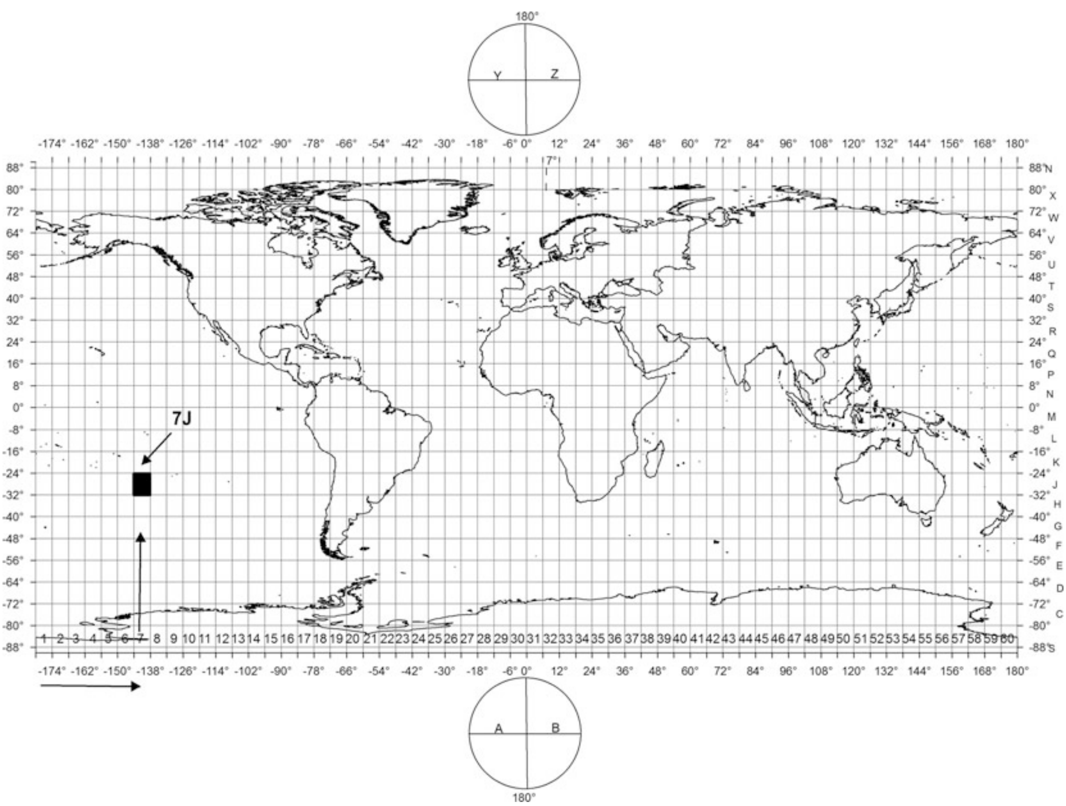

Fig. 5.12 Universal Transverse Mercator (UTM) grid for the world

5.4.3 Universal Transverse Mercator (UTM) Projection

The Universal Transverse Mercator (UTM) projection and grid were adopted by the US Army in 1947 for designating rectangular coordinates on large-scale military maps of the entire world. The UTM is the ellipsoidal Transverse Mercator to which specific parameters, such as central meridians, have been applied. The Earth, between latitude 84° North and 80° South, is divided into 60 zones, each generally 6° wide in longitude. Bounding meridians are evenly divisible by 6°, and zones are numbered from 1 to 60 proceeding East from the 180th meridian from Greenwich with minor exceptions. There are English alphabetical letter designations from South to North. From latitude 84° North and 80° South to the respective poles, the Universal Polar Stereographic (UPS) projection is used instead of UTM. Each geographic location in the UTM projection is given *x* and *y* coordinates in metres (Fig. 5.12).

In the Northern Hemisphere, the equator at the central meridian is considered the origin, with an *x* coordinate of 500,000 m and *y* of 0 m. For the

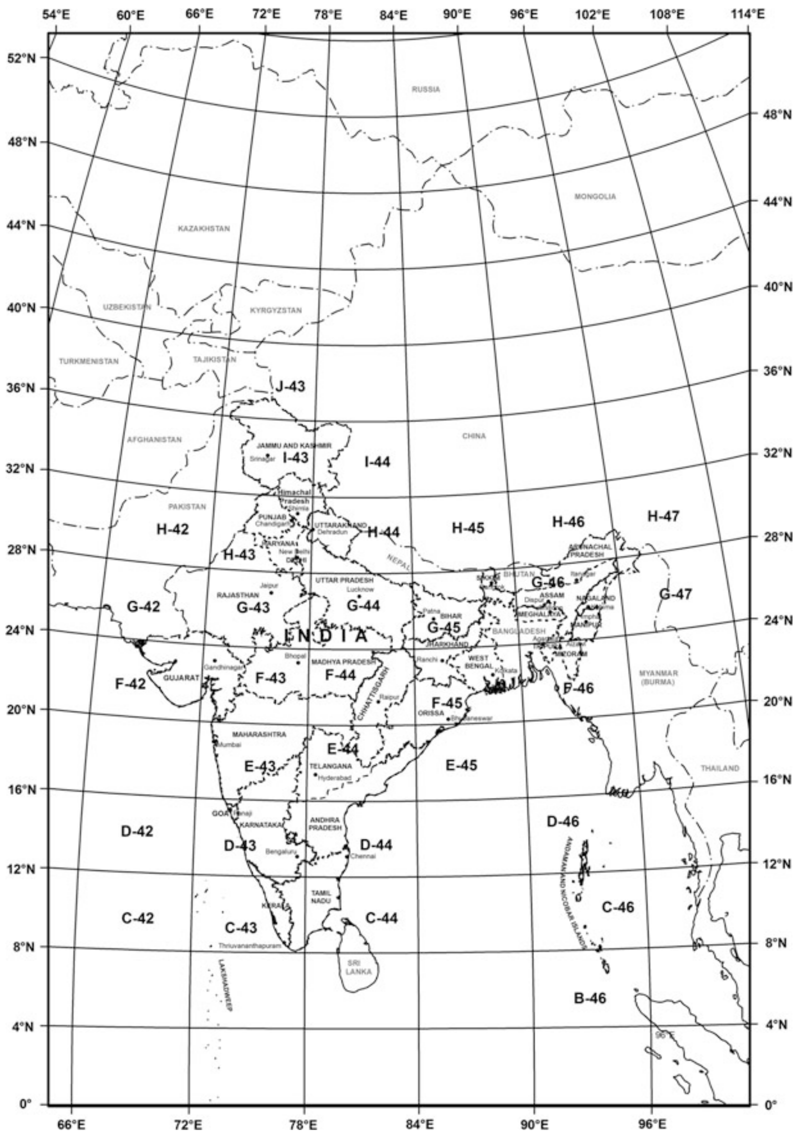

Fig. 5.13 Universal Transverse Mercator (UTM) grid zone designations for India

Southern Hemisphere, the same point is the origin, but, while x remains 500,000 m, y is 10,000,000 m. In each case, numbers increase toward the East and North. Negative coordinates are thus avoided in this projection. The ellipsoidal earth is used throughout the UTM projection system, but the reference ellipsoid changes with the particular region of the Earth. Now in India, Survey of India is using UTM projection with WGS 84 ellipsoid (Fig. 5.13).

5.5 Choice of Projection

The following should be considered while choosing map projection (see Table 5.2):

- Initially, a similar projection should be chosen which is mentioned in the map while transforming.
- To show the distribution map or any thematic map, equal-area projections should be used.
- For presentation maps usually conformal projections and equal-area projections can be used.
- Navigational maps should be made on Mercator, true direction and equidistant projections.
- The projection should be chosen according to the extent of the map, such as world, continent, state or small area. Location of an area is also important while choosing projections, such as equatorial, mid-latitude or polar region.

Table 5.2 Choice of projection

	Properties		Projection
1	***World (Earth should be treated as a sphere)***		
	Conformal *(gross area distortion)*	Constant scale along the equator	Mercator
		Constant scale along meridian	Transverse Mercator
		Constant scale along oblique great circle	Oblique Mercator
	Equal-area	Standard without interruption	Hammer
			Mollweide
			Eckert IV or VI
			Sinusoidal
		Interrupted for land or ocean	Mollweide
			Sinusoidal
		Oblique aspect to group continents	Oblique Mollweide
	Equidistant	Centred on a pole	Polar Azimuthal Equidistant
		Centred on a city	Oblique Azimuthal Equidistant
	Straight rhumb lines		Mercator
	Compromise distortion		Miller Cylindrical
			Robinson

(continued)

Table 5.2 (continued)

	Properties			Projection
2	***Hemisphere (Earth should be treated as a sphere)***			
	Conformal			Stereographic (any aspect)
	Equal-area			Lambert Azimuthal Equal-Area (any aspect)
	Equidistant			Azimuthal Equidistant (any aspect)
	Global look			Orthographic (any aspect)
3	***Continent, ocean, or smaller region (Earth should be treated as a sphere for larger continents and oceans and as an ellipsoid for smaller regions, especially at a larger scale)***			
	Predominant East–West extent	Along the equator	Conformal	Mercator
			Equal-area	Cylindrical Equal-Area
		Away from the equator	Conformal	Lambert Conformal Conic
			Equal-area	Albers Equal-Area Conic
	Predominant North–South extent		Conformal	Transverse Mercator
			Equal-area	Transverse Cylindrical Equal-Area
	Predominant oblique extent *(for example: North America, South America, Atlantic Ocean)*		Conformal	Oblique Mercator
			Equal-area	Oblique Cylindrical Equal-Area
	Equal extent in all directions *(for example: Europe, Africa, Asia, Australia, Antarctica, Pacific Ocean, Indian Ocean, Arctic Ocean, Antarctic Ocean)*	Centre at pole	Conformal	Polar Stereographic
			Equal-area	Polar Lambert Azimuthal Equal-Area
		Centre along Equator	Conformal	Equatorial Stereographic
			Equal-area	Equatorial Lambert Azimuthal Equal-Area
		Centre away from a pole or the equator Azimuthal Equal-Area	Conformal	Oblique Stereographic
			Equal-Area	Oblique Lambert
	Straight rhumb lines (principally for oceans)			Mercator
	Straight great-circle routes			Gnomonic (for less than hemisphere)
	Correct scale along meridians	Centre at a pole		Polar Azimuthal Equidistant
		Centre along the equator		Equidistant Cylindrical
		Centre away from a pole or the equator		Equidistant Conic

Source Modified after Snyder (1987)

5.6 Conclusion

In geo-referencing of the spatial database it is important to understand the location of particular features and phenomena on the Earth's surface. The huge size of the Earth is not represented in same-size but the model of the Earth is represented in a reduced size, i.e. globes with their characteristics of true shape, equal area, true distance, true direction and simplicity. The coordinate system of the Earth is a reference system which is used for mapping a 3-dimensional Earth or any part of the Earth to a 2-dimensional plane. In GIS, two types of coordinate systems are used; geographic and planer. While mapping the Earth's features on any projection system, datum is used to locate the precise position because the shape of the Earth is spheroid due to flattening at the poles. There are two types of datum used while mapping: geocentric and local. There are various families of projection systems available – cylindrical, conical and azimuthal – to represent the various locations of the Earth's surface. In India, Polyconic, Lambert Conformal Conic (LCC) and Universal Transverse Mercator (UTM) projections are widely used to represent small-scale to large-scale maps.

Questions

1. What is a geo-referencing system? Why is it needed in GIS?
2. What are the basic properties of a globe to understand with regard to coordinate systems?
3. What is a coordinate system? Discuss the type of coordinate systems used in a GIS environment.
4. What is a datum in GIS? Discuss the types and uses of datum to represent our maps.
5. What is map projection? Why do we need different map projections for different locations on Earth?
6. Discuss a type of map projection with special reference to India.

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6 Spatial Mapping and Sustainable Resource Management

Abstract

In this chapter, you learn how to operationalise working in a GIS environment. After reading this chapter you should be able to understand the following:

- Data preparation for working in digital and GIS environments
- Choice of database for a GIS environment
- Geo-referencing or transforming scanned maps into real coordinate systems
- Spatial and non-spatial database creation
- Correction of spatial databases by editing features, edge matching, tolerance setting and topology building
- Creating a non-spatial database by adding and joining with a spatial database
- Linkage of GIS databases.

Keywords

Coordinate transformation · Scanning digitization · Sliver polygon · Tolerance edge matching · Topology

6.1 Introduction

The management of resources on the Earth is crucial for its sustainability. It requires complete information about available and potential resources. The United Nations General Assembly on 25 September 2015 adopted 'Transforming Our World: The 2030 Agenda for Sustainable Development', for the prosperity of the people and the planet. They recognised the need of data strengthening and the better use of data in the process of policymaking and monitoring of resources as a fundamental means for the 2030 Agenda of Sustainable Development. The final 2015 report noted that geospatial data can support monitoring in many aspects of development, from health care to natural resource management. Knowing the location of people and things and their relationship with each other is essential for informed decision-making. Comprehensive location-based information is helping governments to develop strategic priorities, make decisions, and measure and monitor outcomes. Poor data quality, lack of timely data availability and unavailability of disaggregated data on important dimensions are among the major challenges. These challenges can be minimised by creating digital data for the preparation of various thematic maps in the GIS environment. It requires various procedures, including data preparation, spatial and non-spatial data entering into a computer, editing of the spatial data, preparation of topology between spatial data, joining the non-spatial (attributes) data with spatial data and final map generation according to the theme (Mohammad et al. 2007). Once the database is created, it can enhance the capabilities for

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governments, NGOs, international organisations and researchers to analyse and monitor spatial databases as well as models for the Sustainable Development Goals (SDGs).

6.2 Data Preparation or Design

This is the most important activity before creating the digital database in a computer. This includes the choice of data, data layer identification such as boundaries, roads, railways, drainage, elevation points, wells, land use, soil type, rainfall etc., with different geographical features such as point, polyline and polygon; defining their attributes and creating the master tic or geo-referencing table (coordinate system), depending upon the objective of your mapping. The following points should be borne in mind while choosing and creating a database in the GIS environment:

- **Quality of Map** The map should be in good condition and readable. The analogue map should not be folded or torn and should have a proper coordinate grid. Poor-quality maps decrease accuracy and usability.
- **Real-time Data** The objective of your research is the most important task while choosing the time period of the data. Basically, reliability of the digital data decreases with the passage of time. But it can be very useful if it requires historical data for comparison or a change in the detection type of analysis.
- **Map Scale** This is the most important parameter because it provides the details of information in the map. Large-scale maps have more detailed information than small-scale maps. Different levels of mapping require different or appropriate scales, but sometimes non-availability of appropriate data leads to utilisation of different scales of maps.
- **Relevance of Data** It is necessary to define the requirement of data while collecting. For example, in very high-resolution satellite imagery or aerial photographs, all the information may not be very useful for the research and then you have to choose the desired data according to the needs of your study. It is obvious that small-scale maps have less information and less reliability than large-scale maps. Sometimes appropriate data are not available; in that case an interpolation technique is required for the generation of data. For example, weather data are not available for all locations, and such cases may require interpolated data.
- **Data Inaccuracy** Sometimes we are using secondary digital data for our mapping purposes. There is the chance of various inaccuracies occurring in the data. It may contain positional, elevation errors and wrongly attached attributes.
- **Data Compatibility** While using digital data from different software sources, they may not be compatible with your software. Therefore, compatibility is required in digital databases. For example, databases developed in MapInfo software directly do not open in ArcGIS software.
- **Data Authority** The authentic sources of data should be utilised and most of these data have proprietorship or copyright issues. The data should be procured through the concerned authority with permission.
- **Procedure** There should be a standard sequence of procedures – for example, if there are many sheets for digitisation. Users need to complete one map sheet fully before moving to another sheet. Within a map sheet, suppose one digitises any feature, such as point, then such features should be completed before moving to another feature like polyline or polygon. If a map has a road network or rail network with different themes, then it is necessary to complete one theme instead of a haphazard creation of databases that road networks and rail networks may produce.
- **Maintaining a Record Book** Maintenance of a record book is important for monitoring the objectives, projection system, types of maps required and types of attributes needed. There is also a need to make one status table for each theme or layer of your work, such as

scanning, geo-referencing, digitising, editing, attribute data joining, final mapping, analysis and so on.

After addressing the above conditions a tic attribute table is required while geo-referencing the data in geographic and projected coordinate systems (see Chap. 5). The coordinates should be systematic, well distributed throughout the map and identical in nature. In our Indian topographical sheet, coordinate (latitude and longitude) values in degree are present in four corners. These pairs of coordinate values should be mentioned in the tic attribute table, in degrees, minutes and seconds (DMS) format; and in decimal degree (DD) (Table 6.1). Some GIS software recognises DMS or DD (see formula) and some recognises both formats. The following formula can be used for converting DMS to DD coordinates:

$$\text{Decimal Degree} = \text{Degree} + \frac{\text{Minutes}}{60} + \frac{\text{Second}}{3600}$$

Organisation of a data layer includes the identification of required features and their attributes (non-spatial database). There are two important points that should be considered while identifying data layers: first, the basis of the feature type, for example point, line and polygon, should be stored in a separate layer (Table 6.2); and second, the basis of thematic information, such as soil type, land use, drainage, rainfall etc., should be stored in separate layers because these layers have different attributes (Table 6.3). The identification number (ID) in the feature attribute table should be unique in nature for each feature and open system. This is in order that it can be easily adopted for the further addition of a particular feature(s).

6.3 Registration and Transformation into Real Coordinate System

Scanned maps in their prime form do not geo-reference with the Earth coordinate system and it is necessary to transform them into a real coordinate system according to the base map. Sometimes the maps from other sources have different reference systems and should be converted into the same reference system of your database. The transformation from unknown coordinate systems to known coordinate systems involves three processes: mathematical model, coordinate transformation and resampling. In a mathematical model, polynomial function and control points or tic are required. At least four control points are needed to determine the relationship between unknown and known locations in 1st polynomial order (see Table 3.8 in Chap. 3). Sometimes, more than one polynomial order is used in the raw image known as rubber sheeting, where the area is too large in satellite imagery generally due to the curvature of the Earth and in aerial photographs due to a central projection.

Coordinate registration requires a very accurate location of longitude–latitude (x–y pairs) and it should be same for all the layers created from the same transformed image by copying the coordinate system (Fig. 6.1). Coordinate transformation needs the numerous geo-reference systems that describe the real world in different ways and with varying precision. In this process, the real coordinates should be assigned to the

Table 6.1 Tic attribute table for map sheet

TIC ID	Coordinates in DMS		Coordinates in DD	
	Longitude	Latitude	*X*	*Y*
83152430	83° 15′ 00′ E	24° 30′ 00′ N	83.25000	24.50000
83152445	83° 15′ 00′ E	24° 45′ 00′ N	83.25000	24.75000
83302430	83° 30′ 00′ E	24° 30′ 00′ N	83.50000	24.50000
83302445	83° 30′ 00′ E	24° 45′ 00′ N	83.50000	24.75000

Table 6.2 Feature attribute table (each for point, line and polygon)

Point ID	Point feature	Line ID	Line feature	Polygon ID	Polygon feature
100	Religious place	501	Road	5001	Built-up
200	Tube-wells	601	Railway line	6001	Parks
300	Tourist place	701	Canal	7001	Rivers
400	Head-quarter	801	Pipelines	8001	Agriculture land

Table 6.3 Identification of layers and their attributes

Layer	Theme	Feature type	Attributes
1	Tourist place	Point	Name, visitors, season to visit
2	Tube-wells	Point	Owner, operation mode (electrified or diesel)
3	Road	Polyline	Name, lanes, category (national, state, others)
4	Drainage	Polyline	Name, rate of flow, tributary
5	Land use	Polygon	Land-use type (forest, waterbody), area
6	Soil	Polygon	Name, colour, suitability class, use

GIS database that may be a geographic or projected coordinate system.

The accuracy of the coordinate transformation is assessed by the root mean square (RMS) error that measures the difference between locations that are known and locations that have been interpolated or digitised. RMS error is derived by squaring the differences between known and unknown points, adding those together, dividing that by the number of test points, and then taking the square root of that result as follows:

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N} (x_i - \bar{x}_i)^2}.$$

Sometimes maps need to be generated from different sources; e.g. a soil map, administrative map and topographical map each needs different coordinate registration separately while registering all these maps due to minor errors in coordinate locations creates an issue of boundary mismatch or offset in boundaries which further produces the sliver polygon (Fig. 6.2). In that case, boundary of the authentic source should be retained as a base map in the thematic map.

6.4 Spatial Data Input

There are direct and indirect methods to get the spatial data into the computer. Earlier, the indirect method was used to input the map through a digitiser table or board. Recently with the development of different sensors and scanning devices most of the data are directly input through the digital copy of remote-sensing satellite imagery or digital aerial photographs and through scanning hard-copy maps to raster format. Another method is data collected from the fieldwork through GPS (global positioning system), which is the most reliable and provides the coordinates of the feature.

Scanning This is a process of converting a hard-copy map to soft-copy map through an instrument called a scanner (Fig. 6.3). It can

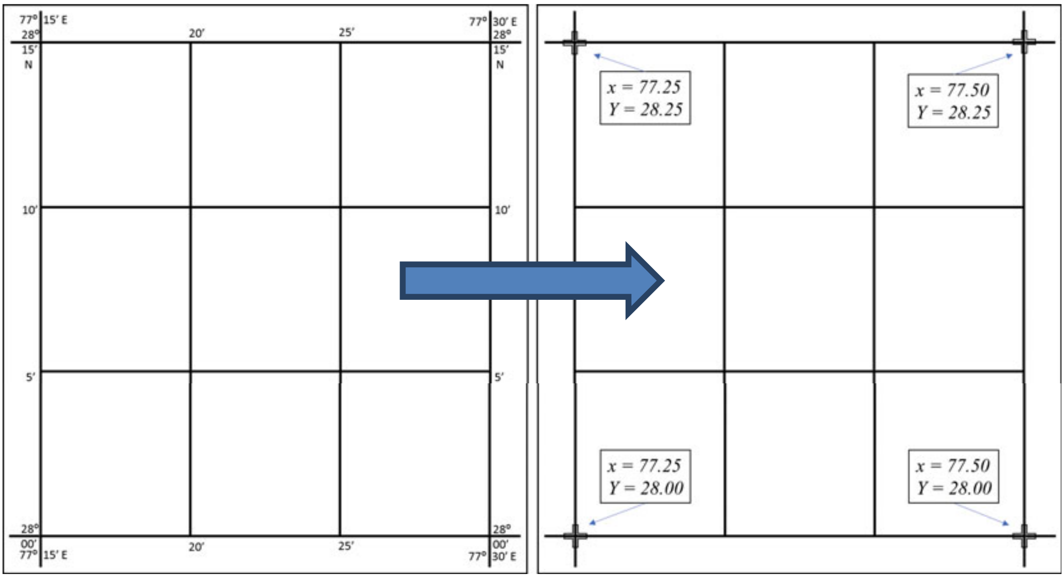
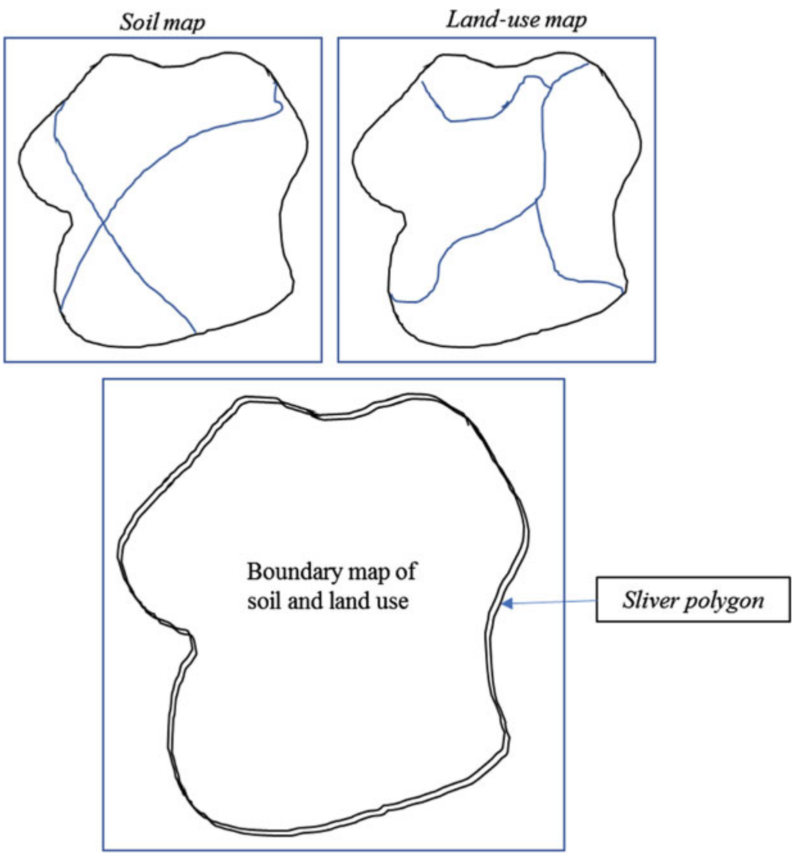


Fig. 6.1 Transformation from an unknown coordinate system into a real coordinate system

Fig. 6.2 Boundary mismatch during coordinate transformation



automatically convert analogue documents to digital files in raster formats. Their main advantages are: elimination of tedious work of manual digitising and process of converting analogue documents to digital form in a very fast manner. Basically, scanners measure the amount of light reflected from a document and encode the information in a pixel array. This is possible because different areas of a document reflect light in proportion to their colour and tonal variation, which ranges from maximum for white through the various shades of grey to a minimum for black.

Digitisation This is a process used to create digital data from non-digital or analogue data. The hard-copy database can be converted into digital vector files using a digitiser table (Fig. 6.4), which is known as manual digitisation. A device consisting of a table and a cursor known as a puck (often with crosshairs and keys) is used for capturing and recording the locations of map features as *x*–*y* coordinate pairs. It contains an electronic grid and an attached cursor. Movement of the cursor across the grid creates an electronic signal unique to the cursor's position. At any desired point, the coordinates can be relayed to the computer for storage by pressing the record button on the cursor in vector format. This direct method has some drawbacks such as missing some features during the manual digitisation process that are very difficult to identify. Overall achieving the accuracy of the map is very difficult. On the other hand, recent on-screen digitisation (Fig. 6.5) is another method for converting raster format to vector format. It has more advantages than manual digitisation such as more accuracy due to

Fig. 6.3 Large-format scanner, copier and printer (*source* http://www8.hp.com/in/en/large-format-printers/designjet-printers/t830.html)

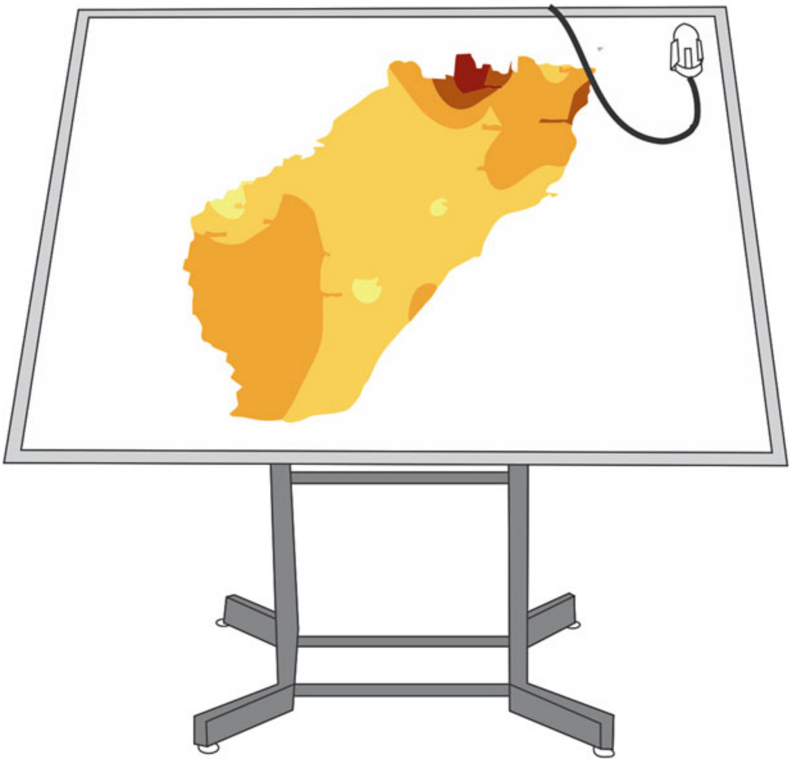


Fig. 6.4 Digitiser board

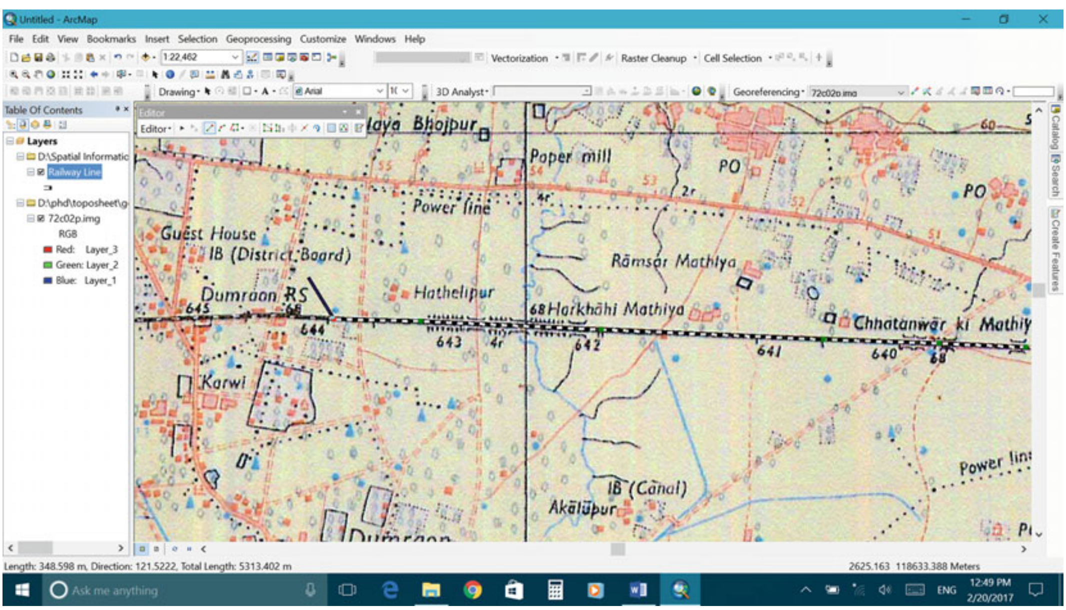


Fig. 6.5 On-screen digitisation in ArcGIS

zooming facilities on the computer. On-screen digitisation is faster than manual and editing can be done at the same time. It is more comfortable for the user and it is very easy to share the work. On-screen updation and overlay are easy from remote-sensing digital satellite data and aerial photographs.

Keyboard Entry Data can be entered into a GIS environment directly by using the keyboard on a computer. Often, data that are input by this method are non-spatial, such as map annotations or numerical or tabular data. The data entry operator may stroke the wrong key, which can lead to errors. Spatial data can also be generated directly from field data using coordinate geometry. This calculates the coordinate points from surveyed data as well as GPS data and creates point, line and polygon features.

6.5 Spatial Database Editing

During the digitisation process of a spatial database, various issues occur regarding correctness. There are two conditions in which the database requires the editing process: data entry error and outdated data that need to be updated. The data also have errors from the source data and data transferring or data conversion. It is better to rectify the errors before final mapping and analysis. Otherwise, they might affect the result and information. Basically, the process of detecting and correcting errors is known as database editing. The common errors during data entry are typing errors, missing features, duplicate features, misplaced features, missing labels, duplicate labels and irrelevant data. These errors can be easily identified by the dangles, pseudo-nodes, duplicate features and sliver polygons (Fig. 6.6).

Dangles There are two types of dangles: undershoot and overshoot of unclosed lines. The dangle usually occurs due to unclosed polygons, called undershoots. This occurs when a node is not connected to the object when it was supposed to be connected. Sometimes dangles can also occur when lines go beyond the objects when they were supposed to stop at the object, and such dangles are called overshoots.

Pseudo-nodes These are false nodes and occur when a line connects with itself instead of connecting with an object or another line due to breaking and joining of the same line feature simultaneously. They also occur when two lines do not cross but intersect along a parallel path.

Duplicate Features These occur due to features digitised twice simultaneously or copied in the same place. This occurs mostly during joining adjacent map sheets and boundaries of both map sheets, where features of both map sheets may be duplicated.

Sliver Polygons This occurs due to overlapping of two polygon layers or digitising common boundaries twice at the same time between two adjacent polygon features. In this error, a series of very small graphic polygons are formed. Sometimes these enter two adjacent maps through a separate projection and can also cause sliver polygons. An elimination process can be used to remove these errors.

6.5.1 Edge Matching

If the map is covered within a single sheet or done by a single person, then there is not a problem of matching the edge, but if it is done by several people at different places or when more than one map sheet is used, errors can occur. This requires combining all map sheets onto a single platform to make a single map with the help of edge matching. In such cases each map sheet is separately digitised and adjacent sheets are joined after editing, re-projection, transformation and generalisation. Due to this process, small differences and mismatches between adjacent map sheets occur. The joining process of the map sheets is called edge matching and involves editing of the sheet boundaries to resolve the mismatch, rebuilding the topology and deleting common boundary lines of two map sheets (Fig. 6.7).

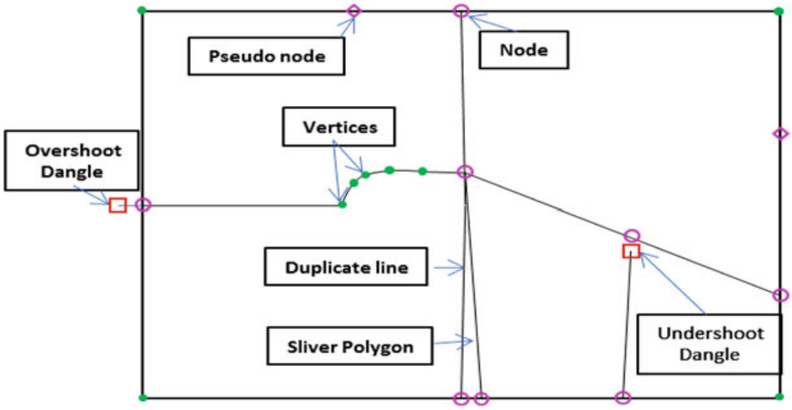


Fig. 6.6 Errors in digitisation

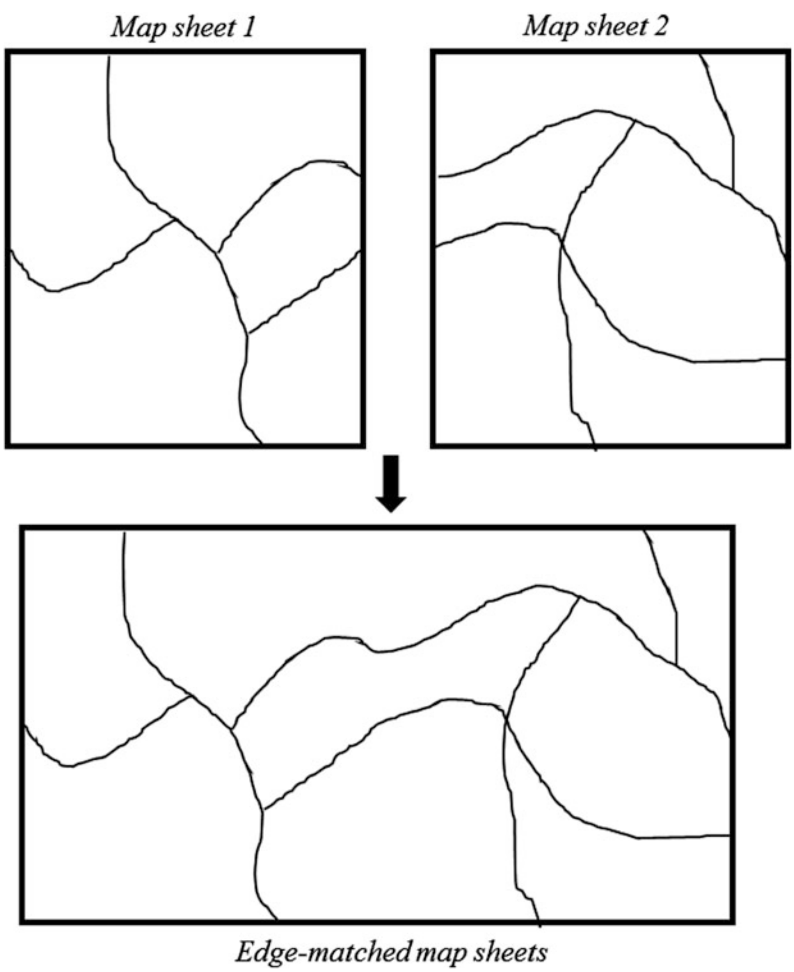


Fig. 6.7 Edge matching of two adjacent map sheets

6.5.2 Tolerances

Tolerance is the minimum or maximum variation allowed during digitising or editing geographical features. It controls the nodes, arcs and vertices. There are various tolerances which we have to manage during spatial data creation such as node-snap tolerance, dangle tolerance, arc-snap tolerance, fuzzy tolerance, weed tolerance and grain tolerance (Fig. 6.8).

Node-Snap Tolerance Node-snap tolerance decides the minimum distance between two nodes which will be joined to form a single node. If distance between two nodes is decided by 0.5 cm, then the lesser distance between two nodes will join together. Separation of two nodes needs a minimum distance of 0.5 cm or greater.

Dangle Tolerance This is the minimum length allowed for dangling arcs by the clean process, which removes dangling arcs shorter than the dangle tolerance automatically. Suppose dangle tolerance is set to 0.2 cm, then arc or line lengths of 0.2 cm and below will be automatically removed but line lengths above 0.2 cm dangle tolerance will retain, and in such cases dangle tolerance should be increased or the dangle manually removed.

Arc-Snap Tolerance The distances within a new arc will intersect an existing arc to remove undershoot dangle. Suppose arc-snap tolerance is set to 0.1 cm, then distances of 0.1 cm and below between two arcs will automatically intersect with an existing arc. Above the tolerance value arcs will not intersect, such as a dead end of a road.

Fuzzy Tolerance The fuzzy tolerance represents the minimum distance separating all arc coordinates (arc and node) in a layer. It is also defined as the distance a coordinate can move during certain operations. Fuzzy tolerance is an extremely small distance used to resolve inexact interaction locations due to the limited arithmetic precision of computers. It is used to clean overshoots, sliver polygons and coordinate thinning along arcs. Fuzzy tolerance should be smaller.

Weed Tolerance Weed tolerance is the minimum allowable distance between any two

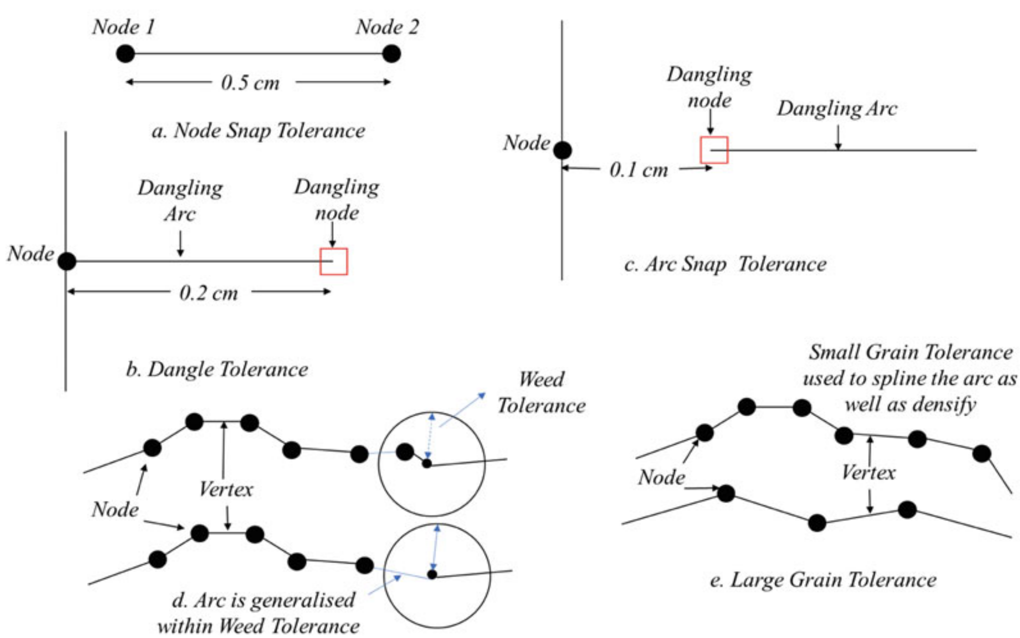


Fig. 6.8 Different tolerances

vertices along the arc. It is used to reduce the number of coordinates in an arc or generalise the existing line. Weed tolerance controls the distance between vertices along a straight line.

Grain Tolerance Grain tolerance controls the number of vertices in an arc and the distance between them. The smaller the grain tolerance the closer the vertices, and vice versa. Grain tolerance is also used to increase the number of vertices in a curve or to densify the arc.

6.5.3 Topology

Topology is a mathematical approach used in vector data models to clearly define spatial relationships between features or describe how spatial features are related to each other. In other words, it describes how nodes, arcs or polylines and polygons are connected and related to each other (Fig. 6.9 and Table 6.4). It defines spatial relationships based on the following principles:

1. ***Connectivity and Direction*** These describe line or polyline features, such as roads, which are connected to each other to form a road network. Each line or polyline has two nodes: from-node (begin node) and to-node (end node). The two lines or polyline are joined at nodes. In other words, topology of line identifies the connectivity with nodes and direction, i.e. a line is started from which node and ends at which node.
2. ***Adjacency and Contiguity*** This describes whether two area features are next to each other. In other words, it describes whether adjacent areas share a common boundary or indicates which polygons are on the left (left-polygon) and which are on the right side (right-polygon) of an arc or chain.
3. ***Containment or Nestedness*** This describes whether a point, line or area feature completely lies within another area feature, like a lake located within a park. Specifying what simple spatial objects are within a polygon, they could be nodes, chains or other smaller polygons.

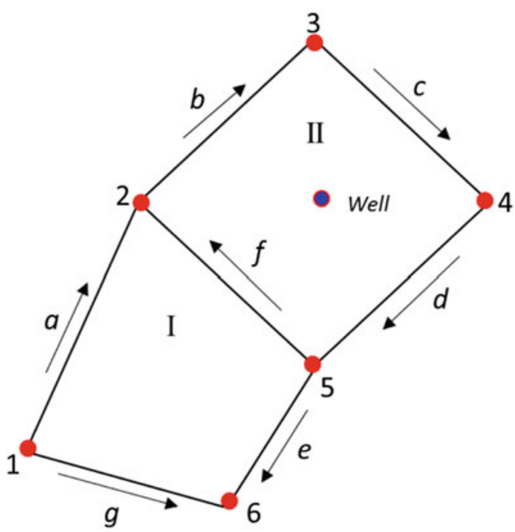


Fig. 6.9 Topological relationship of elements

Topology deals with spatial properties of the feature. The features will change in shape and size but the neighbourhood relationships between features cannot be changed. There are in all eight spatial relationships of 2-dimensional features such as disjoint, meets, equals, inside, covered by, contains, covers and overlaps. These relationships are used for queries against a spatial database.

6.6 Non-spatial Databases: Adding, Joining and Linking of GIS Databases

Once the spatial database is created, it needs to create a non-spatial database because it describes the characteristics of a spatial database. Suppose you have created a line feature as spatial data, the line feature alone cannot explain what it represents – it is a railway line or road network or canal network. So you have to add or join the 'name' or other information as a non-spatial database or attribute database to the spatial feature. There are three methods to provide non-spatial data or attributes to spatial data:

Table 6.4 Topological relationship between point, line and polygon

Connectivity		Direction			Adjacency			Nestedness	
Node	Chain	Chain	From node	To node	Chain	Left polygon	Right Polygon	Polygon	Nested node (point)
1–2	a	a	1	2	a	0	I	II	Well
2–3	b	b	2	3	b	0	II		
3–4	c	c	3	4	c	0	II		
4–5	d	d	4	5	d	0	II		
5–1	e	e	5	1	e	0	I		
2–5	f	f	5	2	f	I	II		
1–6	g	g	1	6	g	I	0		

1. Creating attribute data in a 'table' within the GIS software or other software like Microsoft Excel, dBase or any data management software.
2. Adding attribute data in the spatial feature within the GIS software.
3. Joining the existing digital non-spatial databases in GIS software.

Creating attribute data within the GIS or other software requires the creation of a table. A table has a series of rows and columns to store attributes. Rows define the attributes of each feature and columns (field) further define their characteristics. While creating a table you must determine specific parameters, such as name of the attribute, type of attribute and column width to add descriptions. The type of attribute may be in characters or numeric. At least one column of a table must have a common field (field_id) to perform, relate or join processes with the table of spatial features.

Another method of attribute-data entering is to directly enter the descriptive information in the feature attribute table by adding the column or field and their specifications. There is no need to perform a joining procedure by this method because you are directly entering attributes with spatial features. The drawback here is repetition of information that can occur with the same feature. For example, the name of an island such as Andaman or Nicobar refers to a number of islands, so one needs to enter 'name' in a number of times.

6.6.1 Joining Spatial and Non-spatial Databases (Attribute Data Joining)

The feature identification number can be attached to the graphical entities directly while digitising the features. Manual entering of simple identifiers as part of normal digitisation is easy. The same identification number should be entered in the attribute tables which should be unique in nature in both spatial and non-spatial databases. Before applying the linkage operation, it is necessary to check the quality of data carefully so that it should not contain the duplicate, missing or wrong identifier in both spatial and non-spatial databases. Each and every graphical entity should have a single set of non-spatial data. Conceptually, when we are joining the attribute table with the spatial feature, the columns of both files should merge together and create a new output file consisting of spatial attributes or a non-spatial database. The record in the data is matched according to a common identification number (ID) (Table 6.5).

6.7 Data Linkage

The main characteristic of GIS is to link different types of data sets. The data linkage can be classified into two parts: exact matching and non-exact matching. Suppose you have two data sets of the same area with different attributes. The

Table 6.5 Spatial and non-spatial table joining

Spatial data		
Village id	X	Y
1		
2		
3		
3		
4		

+

Attribute data				
Village id	Village name	Population	Sex-ratio	Population density
1				
2				
3				
4				

↓

New table consisting of both spatial and non-spatial data							
Village id	X	Y	**Village id**	Village name	Population	Sex-ratio	Population density
1			**1**				
2			**2**				
3			**3**				
3			**3**				
4			**4**				

Dataset 1 Population characteristics

Population Characteristics							
Village id	X	Y	Village id	Village name	Population	Sex-ratio	Population density
1			1				
2			2				
3			3				
3			3				
4			4				

Dataset 2 Amenities characteristics

Amenities Characteristics							
Village id	X	Y	Village id	Drinking water	Post office	School	hospital
1			1				
2			2				
3			3				
3			3				
4			4				

Combine dataset showing population and amenities characteristics

Population Characteristics								Amenities Characteristics							
Village id	X	Y	Village id	Village name	Population	Sex-ratio	Population density	Village id	X	Y	Village id	Drinking water	Post office	School	hospital
1			1					1			1				
2			2					2			2				
3			3					3			3				
3			3					3			3				
4			4					4			4				

Fig. 6.10 Exact matching

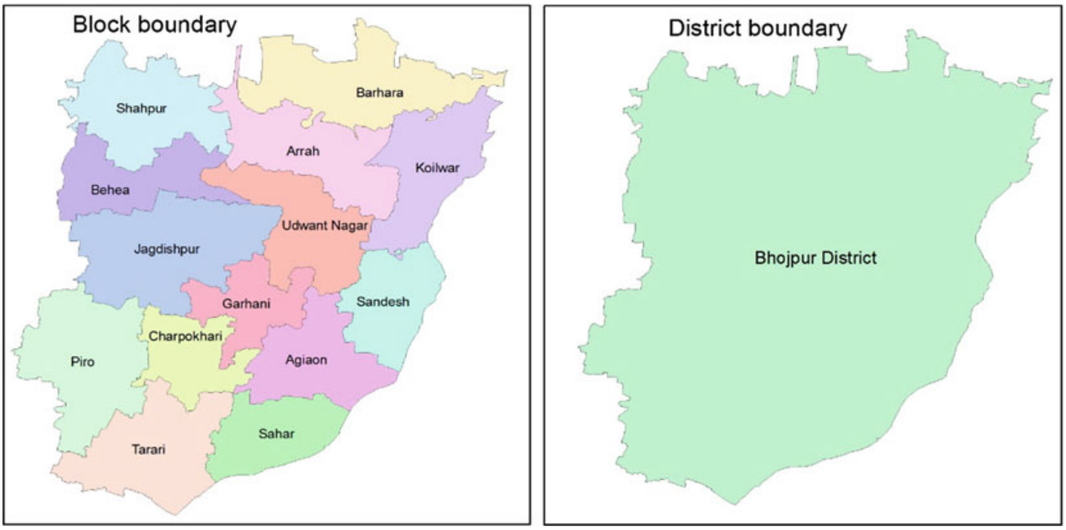


Fig. 6.11 Hierarchical matching

first data set contains population characteristics and the other data set contains amenities available for the same area. Both data sets can be matched together with at least one common ID (Fig. 6.10).

The non-exact matching can be classified as hierarchical and fuzzy matching. Sometimes we create the lower units of a data set, for example a village boundary map, with their attributes. If we need higher hierarchy, such as with block-level, tehsil-level or district-level maps, we can add the village-level data set into a higher level or group the lower village-level data set into a higher block level, which is basically known as hierarchical matching (Fig. 6.11).

Generally, boundaries of different thematic maps do not match with each other. Some maps have administrative boundaries that can be matched but boundaries of the physical features cannot be matched, such as groundwater quality, rainfall, soil type and crops boundaries. If we want to know the groundwater quality and soil type of the same area then we have to merge all these data sets into a single map for multi-layer spatial analysis. Such matching is known as fuzzy matching (Fig. 6.12).

6.8 Conclusion

The proper planning of the project is most important while creating the digital database in a GIS environment. The spatial data such as types of maps, scale, features, coordinate system and non-spatial data should be properly chosen according to the needs of the study. There are various input sources to convert analogue data into digital data such as scanning of maps, digital remotely sensed data, digital data from secondary sources and GPS data. The conversion of digital raster data into vector data is the digitisation process and it can be from a digitiser table or on-screen digitisation. The various tolerances should be set for various features before starting the digitisation process. During vectorisation, various errors occur and these errors are corrected by identifying dangles, nodes, sliver polygons and duplicate features. Sometimes the errors also occur while joining two adjacent maps, and this requires the edge-matching process to correct. Topology is the most important feature of GIS, and it provides relationships such as connectivity, contiguity and containment

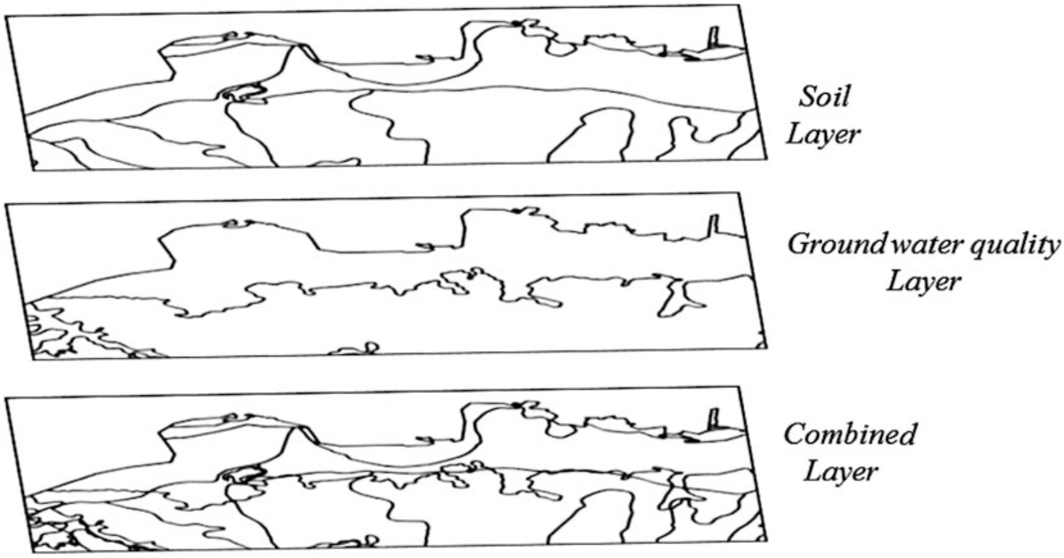


Fig. 6.12 Fuzzy matching

between the features for spatial analysis purposes. In the past this had to be established after creating the spatial feature but now it can be specified while creating the feature file, such as point, line and polygon features, in the computer software.

The non-spatial data can also be created in a GIS environment by using GIS software and other software such as Microsoft Excel and dBase. The non-spatial data are attached to spatial data through the common field in both data sets, in the GIS software. The database can also be used to create another data set by a data linkage process in the same coordinate system. It can be classified into two parts: exact matching and non-exact matching. In exact matching, it is known when the spatial feature is matched in both data sets and attributes are appended in a new data set. Non-exact matching is also classified as hierarchical and fuzzy matching, which merges data sets to create a new one in a hierarchy and appends different data sets which are not matching with each other via fuzzy matching.

Questions

1. Discuss the relevant points while choosing the database for a GIS environment.
2. Discuss the procedure for database creation in a GIS environment.
3. Discuss the methods of spatial database entering into the GIS software.
4. Discuss the various types of errors in vectorisation processes and suggest their remedies.
5. What is meant by tolerances in GIS? Discuss the type of tolerance that can be managed during spatial data creation.
6. What is topology? Discuss the various topological relationships between spatial features.
7. How we can manage non-spatial databases in a GIS environment?
8. What is meant by data linkage? Discuss the type of data linkages available in a GIS environment with suitable examples.

Reference

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Spatial Data Analysis

7

Abstract

In the previous chapters, you have learnt and understood about the creation of digital data sets in the GIS environment. Further, digital data sets can be used for mapping and extracting information by spatial analysis for better planning of the Earth's resources and phenomena as well as identifying the new associations between them to increase our understanding of the real world. After reading this chapter you should be able to understand the following:

- The need for spatial analysis
- Methods of spatial analysis in single and multiple layers
- Query and reasoning in a GIS environment
- Measurement from the data sets of various features
- Transformation of data sets by buffering, topological overlay and spatial interpolation
- Network analysis
- Data manipulation

Keywords

Spatial analysis · Proximity analysis · Overlay analysis · Thiessen's polygon · DEM · Network analysis · Spatial data manipulation

7.1 Introduction

The real world produces many questions regarding the processes and phenomena in the physical environment, such as why urban areas are more air-polluted than their surroundings. Why do particular diseases occur in specific areas? Why is crime increasing in a particular location? Why do different forests cover different places? What are the reasons behind climate change? Why do different crops grow in different seasons and places? There are endless queries regarding our real-world system. To answer these queries, we can model the real-world systems through spatial analysis processes by cause-and-effect relationships among a data set. These models illuminate underlying trends in the geographic data and thus make new information available. Besides map generation, spatial analysis is one of the major capabilities of GIS. GIS uses spatial (map) and non-spatial (attribute) data for analysis. It requires logical connections between map features and their attribute data; and operational procedures built on the spatial relationships among map features. Analysis is the process resolving and separating the reference system into its parts to illuminate their nature and interrelationships, and to determine general principles of behaviour. Spatial information

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(location) is an added value in the analysis process. To solve various spatial queries, various interrelated parameters and criteria are required; it may be single or multi-layer spatial analysis that produces the models (Singh and Kumar 2012). Spatial analysis can be based on vector or raster databases or a combination of both. Spatial analysis is used to resolve many real-world phenomena and processes by developing and applying manipulation and modelling or analysis criteria. It reveals new and previously unidentified information. Spatial modelling involves cyclical processing, retrieving one or more maps from the database which are used to create a new map. The new map then becomes part of the database and is available for subsequent processing. Effective spatial analysis is basically dependent upon an intelligent user, not just a powerful computer. Therefore, a GIS enhances the process of spatial analysis by providing tools which can be combined in meaningful sequences to develop the new models. The result of geographic analysis can be communicated with maps, reports or both.

7.2 Methods of Spatial Analysis

According to Aronoff (1989), there are many functions for analysis in GIS such as measurement, retrieval and classification functions; overlay functions; neighbourhood functions and connectivity functions. Longley et al. (2001) have included six methods of spatial analysis such as queries and reasoning; measurements; transformations; descriptive summaries; optimisation techniques and hypothesis testing in spatial analysis. Spatial analysis can be done on one layer known as a *single-layer operation.* In this operation, queries and alterations are performed on a single layer. Suppose you have a district boundary map and you want to know which district has the largest area. The answer to this query will be searched within a district boundary map and display the largest district. The creation of a buffer layer on any feature (point, line and polygon) is also one of the good examples of a single-layer operation. The analysis can be done on more than one layer, known as a *multi-layer operation.* When two or more layers are superimposed or overlaid with the same coordinate system then it is known as a multi-layer operation or topological operation. In this process, new coverage or a layer is created with the overlaid layer, and the new intersection is created wherever two lines or polygons cross. The new topology will create new spatial relationships between objects to be updated in the new layer. Point-in-polygon, line-in-polygon and polygon-in-polygon are examples of topological or multi-layer operations.

7.2.1 Queries and Reasoning

The query is a set of conditions to search in the database that can be spatial and/or non-spatial. The user may form their questions based on their attributes in the town table such as *'Name like "Arrah"'*. These queries may be obtained by the SQL (Standard Query Language) querying method or by the tools available in MapInfo, ArcGIS or any other GIS software. Logical and conditional operators are used for querying the information. There are various options available in different software packages, such as new selection, adding more queries to previously selected features, removing from selected features and filtering by reselecting from the current selection. The selection of data based on the geometry of a feature (spatial) can also be performed in a map window by using rectangle, polygon, circle and line. These spatial and non-spatial queries produce both spatial information in one window and attributes information in another window (Fig. 7.1). Reasoning is the more complex form of query such as finding the best route from one location to another location. Another example of a complex query is 'find the districts connecting the NH-8 in Haryana'. Buffer analysis is one of the complex types of query, for

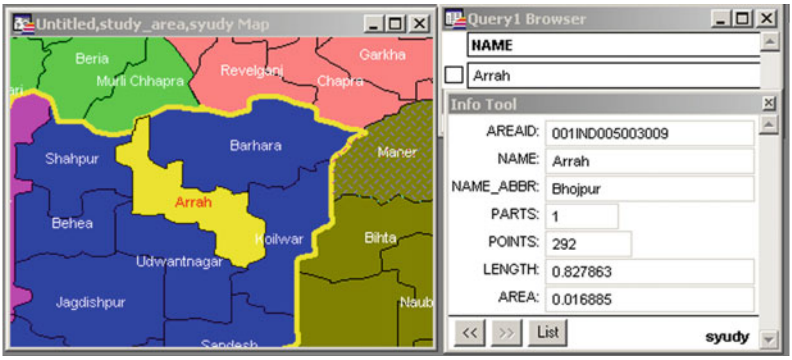


Fig. 7.1 Simple query

example 'find the primary school within 3 km from my house'.

Logical/Boolean Operations Overlay analysis manipulates spatial data organised in different layers to create combined spatial features according to logical conditions with the help of logical operators such as *AND*, *OR*, *NOT* and *XOR* (*exclusive*). These logical operators enable users to choose their requirement to identify the potentiality of an area. For example, select *Land use of single crop (and) water quality in good condition* to suggest alternate land use. Each operation is characterised by specific logical checks of decision criteria to determine whether a condition is true or false. For example, if A and B are two boxes (features), then statements in SQL may be A *AND* B, A *OR* B, A *NOT* B, A *XOR* (*NOR*) B (*exclusive*) (Fig. 7.2). The shaded areas represent the true statements. This can be applied to single or multi-layer operations.

Conditional Operations This is the selection of a feature based on certain conditional operations in attribute data by SQL query. For example, if you want to select villages having a population *less than or equal to* 1000 people or select the districts that *contain* the NH-8, then such conditional operations can be applied to determine

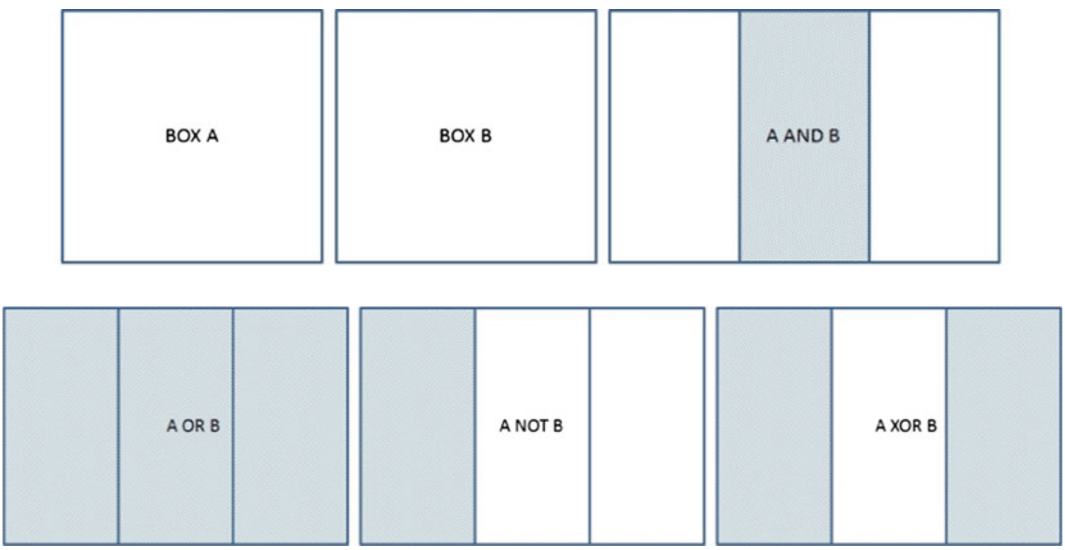


Fig. 7.2 Logical/Boolean operators

the requirement. There are many conditional operations used in GIS such as:

EQ	=	Equal to
NE	< >	Not equal to
GE	> =	Greater than or equal to
LE	< =	Less than or equal to
GT	>	Greater than
LT	<	Less than
CN		Containing
NC		Not containing

7.2.2 Measurement

Measurement is a simple numerical value of the graphical features such as distance between two locations, length of the road or any linear feature, area of a polygon, polygon centroid, perimeter, slope and aspect, direction etc. All these measurements are calculated by GIS software. GIS databases are in vector and raster format so the measurement of both formats is different. Let us assume, from Fig. 7.3a, the distance between A and B location is calculated by Pythagoras' theorem using *Euclidean distance* or shortest path (aerial distance) by drawing a straight line between two locations. The given formula is used for distance measurement:

$$AB = \sqrt{AC^2 + CB^2}$$

Another method to calculate distance is by *Manhattan distance*, a distance along raster cell sides from one point to another point or two shortest sides in the right angle of a triangle in a raster cell or *cathetus* distance. In other words, two line segments in the right angle of a raster cell are used to calculate distance. The total distance between DE is the sum of the two cell sides of a raster cell (Fig. 7.3b). The distance calculation of a curved surface of the Earth requires the spherical formula by using the radius of the Earth:

$$D = R\cos^{-1}[\sin \emptyset 1 \sin \emptyset 2 + \cos \emptyset 1 \cos \emptyset 2 \cos(\lambda 1 - \lambda 2)]$$

where D is distance between two points on the curved surface of the Earth, and R is a radius of the Earth.

The area is calculated by the geometry of a feature. These features are in the form of rectangles, triangles, circles, parallelograms and trapezoids. The perimeter of a polygon is calculated by the sum of straight line length. The area of a polygon can also be calculated by the following formula:

$$A = 1/2 \sum_{i=1}^{n} y_i(x_{i+1} - x_{i-1})$$

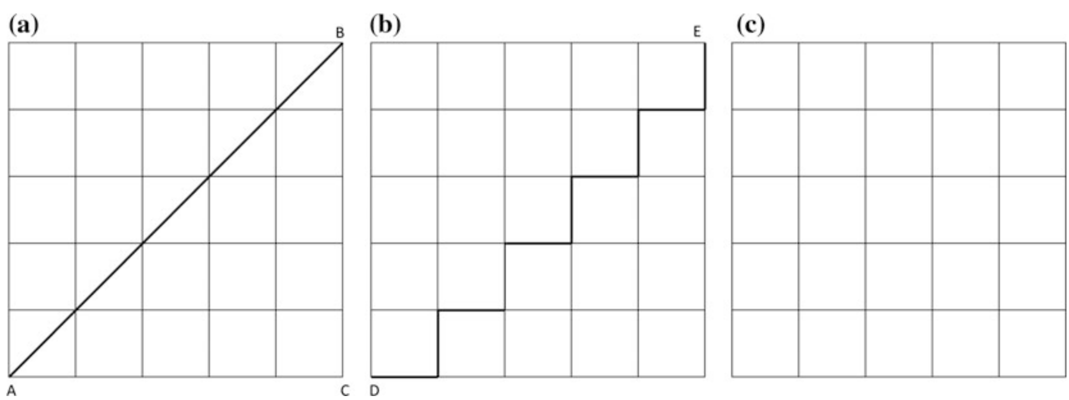
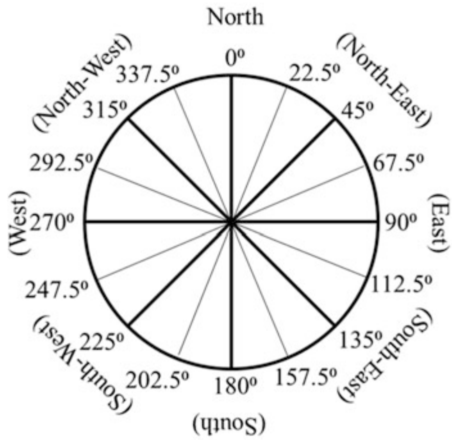


Fig. 7.3 Measurement of distance **a** in vector (Pythagorean distance) **b** in raster (Manhattan distance) and **c** measurement of area in raster format by counting the raster cells multiplied by cell area



Aspect Range (in Degree)	Direction
0–22.5	North
22.5–67.5	North-East
67.5–112.5	East
112.5–157.5	South-East
157.5–202.5	South
202.5–247.5	South-West
247.5–292.5	West
292.5–337.5	North-West
337.5–0	North
–1	Flat surface

Fig. 7.4 Aspect and direction

where x_i, y_i represent the breaks in the polygon that surrounds the area. In raster data, the polygon is calculated by summing the number of cells and multiplying by the cell size (Fig. 7.3c). Suppose an image has 25 cells and each cell size is 1 km^2, then the total area of an image is 25 km^2. The slope is measured in percentage or an angle of degrees shows the gradient or steepness of surface. Aspect is a direction in which a unit of surface facing is usually expressed in degrees and calculated from North (Fig. 7.4).

Arithmetic operators such as subtraction, addition, division, multiplication, square root etc. are used on both spatial and non-spatial databases in GIS software. These functions are also used in all geometric calculations involving coordinates, distance, area and direction.

7.2.3 Transformation

This includes buffering and topological overlay such as point-in-polygon, line-in-polygon, polygon-in-polygon and spatial interpolation.

Buffering and Proximity Analysis This is a function that creates a zone around geographical features such as point, line and polygon; and measures distance in linear units such as metres, kilometres, feet, miles etc. A buffer is useful for proximity analysis and it is possible in raster and vector formats. In vector, the buffer boundary is more accurate than the raster format data because vector databases have smooth boundaries. It is performed on any geographical feature to generate one (single buffer) or more surrounding polygons (multiple ring buffers) with constant or variable distance (Fig. 7.5).

For example, a 3 km buffer zone around a wildlife sanctuary or park to protect the environment; a 500 m buffer zone around a national highway for risk assessment; a 5 km buffer zone around a school or fire station or police station to provide facilities. This kind of polygon around spatial features is called a buffer or buffer analysis, and is primarily used for proximity analysis. The buffer area or polygon is also used in manipulating the spatial feature by updating (merging new features by cut and paste), clipping (cutting out a spatial feature) and splitting (breaking the spatial feature file into small files) an area of interest for further analysis such as land use in a buffer for environmental impact assessment around a thermal power plant.

Overlay Analysis (Topological Overlay) This means two or more layers are put together for analysis purposes. Basically the real world in terms of GIS is the combination of various points, lines and polygons features – e.g. aerial

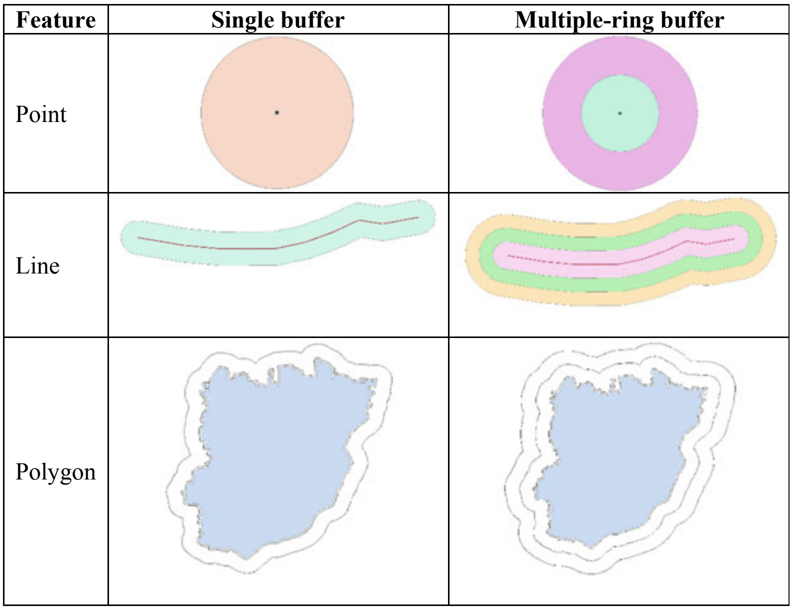


Fig. 7.5 Buffer around point, line and polygon features

photographs or satellite imagery which contain all the features or reality of the Earth. When we want to map different features (entities) by different layers then each layer can overlay with each other to produce the real world in the map. Topographical sheets are one example of overlay analysis, where most of the features are represented by points, lines and polygons overlaid according to their symbology (Fig. 7.6).

Point-in-Polygon This is an overlay containing a point feature layer and a polygon layer is overlaid to create a new point layer in which a boundary is decided by the polygon layer but not copied in the point layer. This operation determines what points lie inside or outside the polygon. For example in 'Number of elevation peaks in the particular district', elevation peaks are the point feature consisting of only *x–y* coordinates whereas a district has a polygon or enclosed entity. So this operation determines the number of point entities in the polygon entity (Fig. 7.7). The number of tube-wells located in the South-West district of Delhi or number of trees planted in a particular zone, are some of the many examples of point-in-polygon operation.

Line-in-Polygon This operation is similar to the point-in-polygon operation. The line feature's layer and polygon feature's layer are used for an overlay type of analysis (Fig. 7.8). The output layer is a line feature with a new arc-node topology. The polygon layer defines only the boundary of the line feature and the polygon is not copied in the output layer. This operation determines the line features which lie inside or outside the polygon feature. It has some distinctive applications such as development of urban areas along roads or railways, the length of roads or railway lines in particular districts, development of metro rail in the National Capital Region (NCR) etc. Suppose you want to know the length of the National Highway in Bihar, then you need two layers: the road network map with its attributes and a Bihar state map. Once you overlay these two layers and perform the above query, the resultant will be your answer.

Polygon-in-Polygon This operation is the most important overlay where two or more polygon layers are overlaid to create a new polygon feature but only two layers can be overlaid at a time (Fig. 7.9). It does not mean that you cannot overlay more than two layers. Here, you can keep

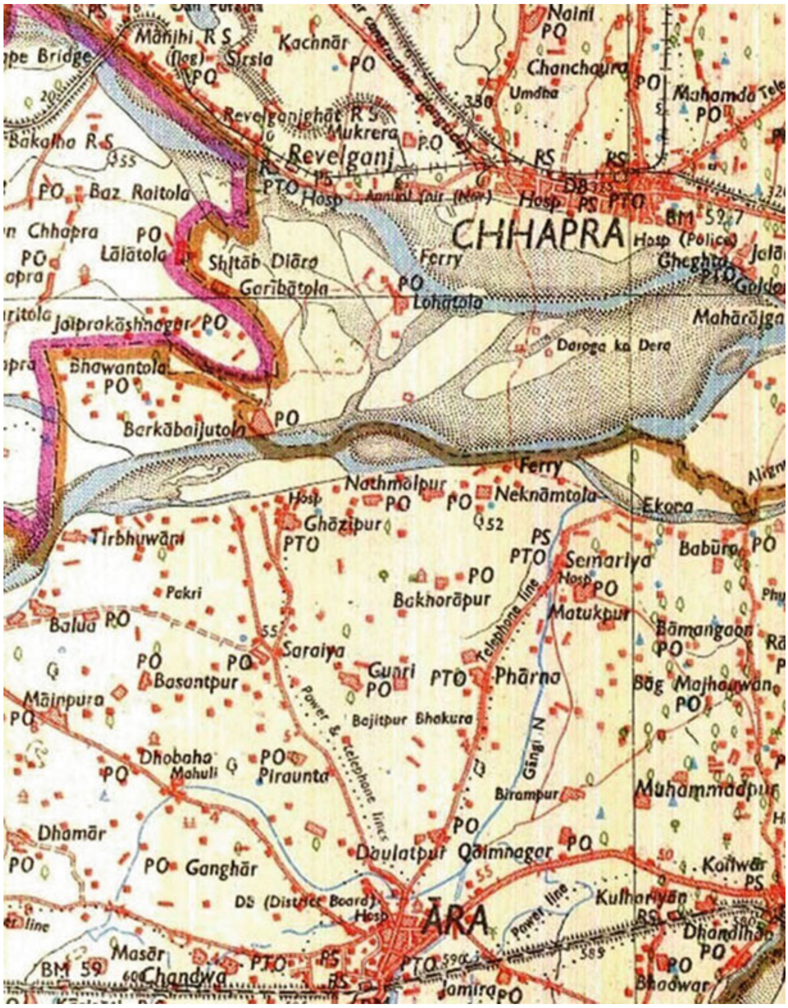


Fig. 7.6 Point, line and polygon features in a topographical sheet (*source* Survey of India)

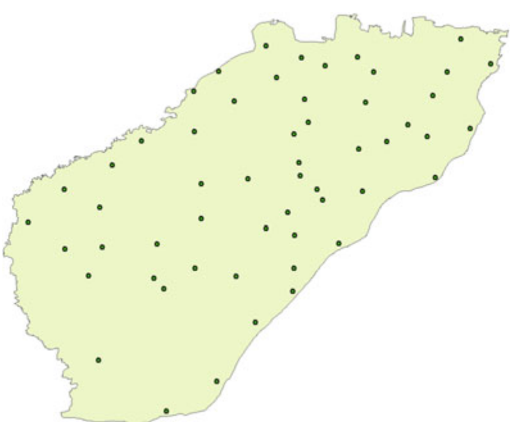


Fig. 7.7 Point in polygon feature

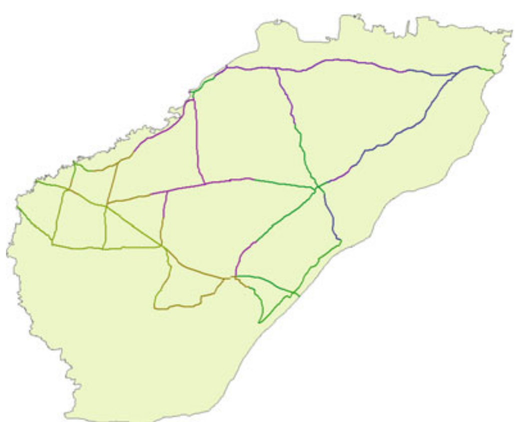


Fig. 7.8 Line (road)-in-polygon feature

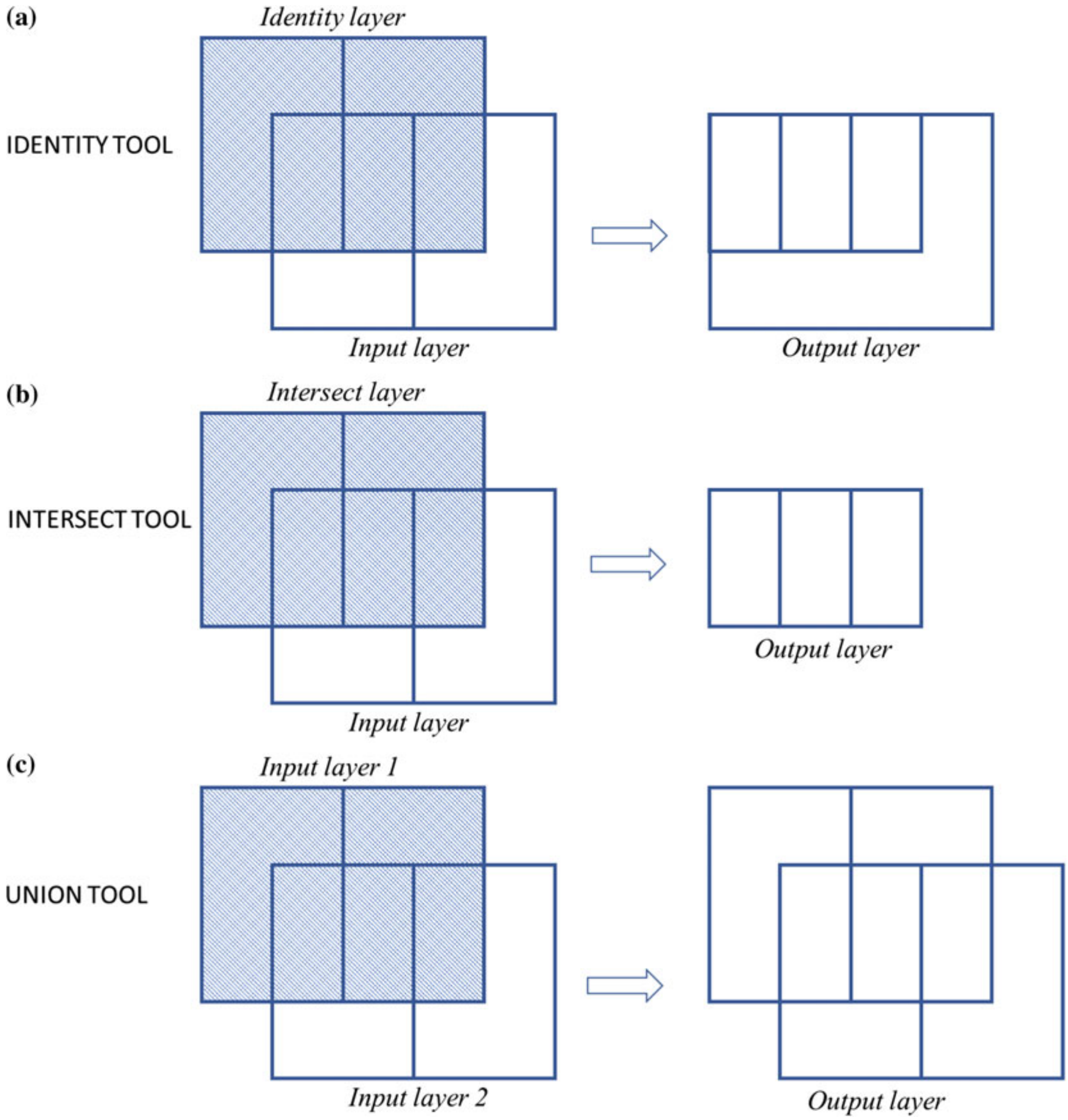


Fig. 7.9 **a** Identity **b** Intersect and **c** Union overlay systems

both layers separate or you can merge them to make a single layer. If you want to keep two layers separate then a single-layer query can be performed.

In GIS software, *union*, *identity* and *intersect* tools are performed in this polygon-in-polygon operation. The *union* tool computes a geometric union of the two input layer features. All features and attributes of both layers will be written to the output layer. The *identity* tool performs geometric intersection of two layers. All features of the input layer, as well as those features of the identity layer that overlap the input layer, are preserved in the output layer. The *intersect* tool computes a geometric intersection of the input features, and features or portions of features which overlap in all layers and/or feature classes will be written to the output layer.

For example, if you have two layers, such as soil and forest layers, then the query will be *What type of soil is covered under forest cover?* Or

What types of forest are found in red soil? Once you merge both layers with the *union* tool, then the output layer has a combination of the entire overlaid feature in a single layer as well as a new data topology, or relationships are created, known as composite layers, and the feature attribute table is also appended for each and every layer. The SQL query can be perform on this appended layer. For example, if you append four layers such as land use, groundwater quality, slope and rainfall in a single layer then the query will be *Select an area where land use is kharif crop, groundwater quality is good, slope is less than 3° and rainfall is more than 1000 cm.* This type of query is very useful in the modelling of resources.

7.3 Spatial Interpolation

Spatial interpolation is a method of constructing new data points within the range of a discrete set of known data points; or the procedure of estimating the values of properties at unknown sites within an area covered by known observations. Thus, interpolation fills the gap of the non-continuous spatial data, e.g. in the interpolation of point features, showing elevations to create a contour map. In reality, most databases are not continuous; they may be stratified, patchy or randomly distributed. Here the role of interpolation is to fill the gap between these randomly distributed databases. This predicts values for unknown values from a limited number of sample data points. Spatial interpolation predicts unknown values for any geographic point data, such as elevation to create contours; estimating climatic data such as temperature or rainfall (Fig. 7.10); pollution levels such as air pollution, noise pollution and so on.

7.3.1 Thiessen's Polygon

This is one of the interpolation methods for defining spatial boundaries around point. Thiessen's polygons define individual areas of influence around each point, also known as Voronoi

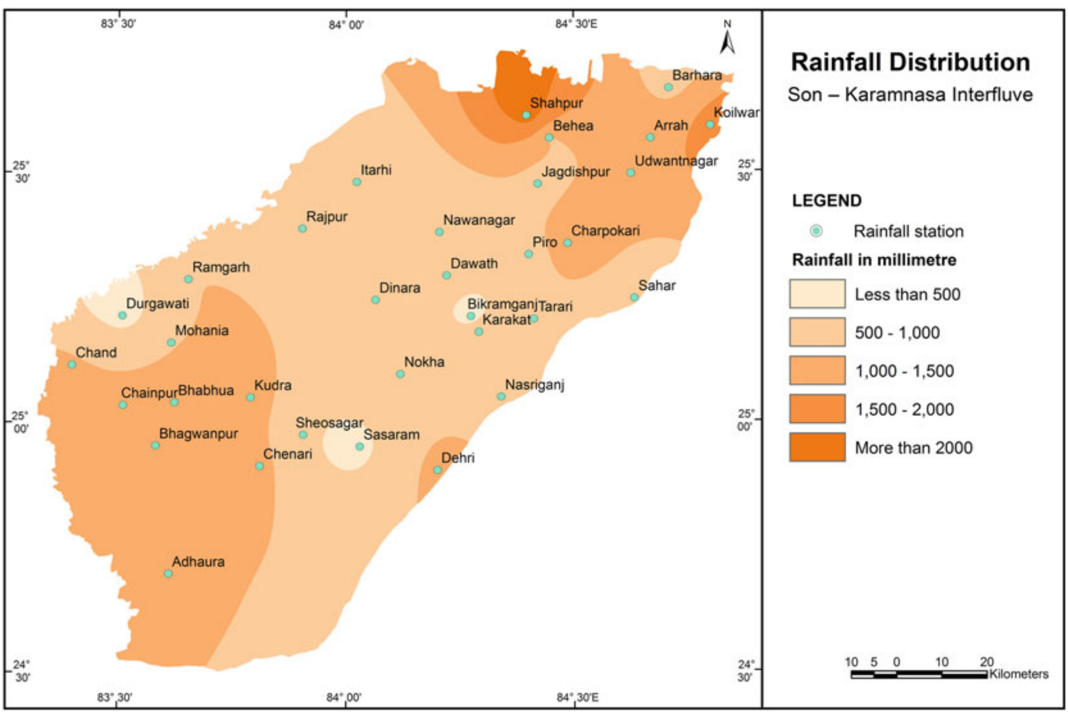


Fig. 7.10 Interpolation of rainfall data (point)

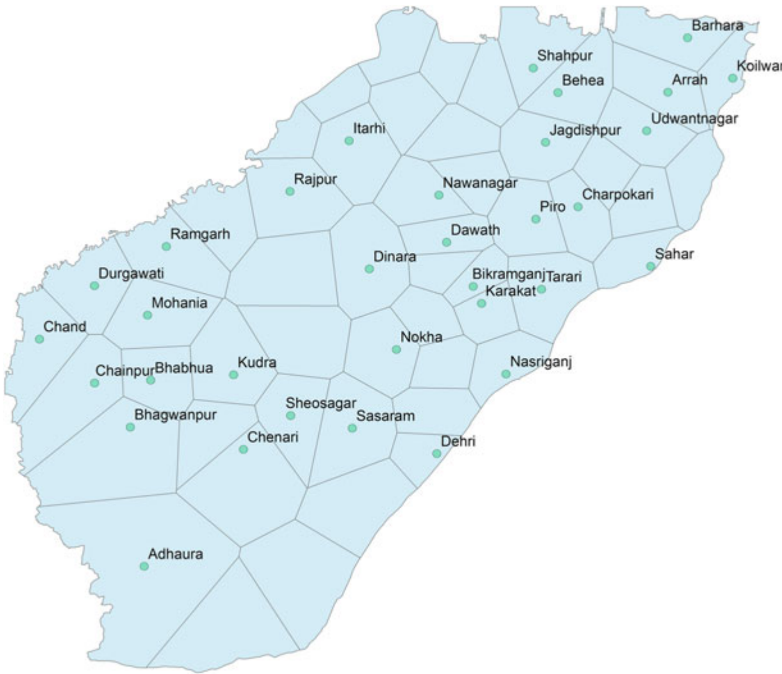


Fig. 7.11 Thiessen's polygons created from points

polygons or Dirichlet cells. It is a polygon whose boundaries define the area that is closest to each point relative to all other points. This is a local rather than global interpolator because it uses the nearest point while interpolating boundaries between them. The boundary between two adjoining polygons is created by subdividing lines joining the nearest neighbour points into two equal parts – in other words, joining half of the distance between two nearest points by straight lines to create Thiessen's polygon. So, it is an exact technique of interpolating sharp boundaries between two interpolated polygons. The shape of Thiessen's polygons depends on the regular or irregular spacing points. If the points are located in equal spacing or a regular square shape, then Thiessen's polygons will be a square shape. The irregular spacing of point data generates irregular polygons (Fig. 7.11). They are mostly used to generate soil maps based on different sample points. The boundary between two soil types is assumed to be half of the distance between two soil sample points. They are also used to delineate a rainfall region from a rain-gauge station.

7.3.2 Digital Elevation Model (DEM)/ Digital Terrain Model (DTM)

A digital representation of the continuous variation of relief over space is known as a digital elevation model (DEM; Fig. 7.12). While the term 'terrain' implies attributes of land surface, both terms are used to represent ground-surface relief in digital vector (TIN) and raster (grid) forms by using Z value. In other words, DEM describes the elevation (Z value) of any point in a given area in digital format. A digital terrain model (DTM) includes the spatial distribution of terrain attributes. A DTM consists of a DEM as well as terrain information such as different type of land use. Generally, DEM is a raster representation in which each grid cell or pixel records the elevation data of the Earth's surface. It is created by the point data, TIN, stereo-pairs from aerial photographs and satellite imagery such as CartoDEM, which are generated by using the stereo images of the Cartosat-1 satellite, available at the Bhuvan portal of NRSC/ISRO. (The website http://bhuvan.nrsc.gov.

Fig. 7.12 Digital Elevation model by CartoDEM (*Source* www.nrsc.gov.in)

in/bhuvan_links.php provides free downloads along with technical documents.)

7.3.3 Triangulated Irregular Network (TIN)

This is one of the spatial interpolation methods to create surfaces constructed by triangulating a set of local points, used for DTM in vector format (Fig. 7.13). The TIN is created by joining adjacent points in XYZ value to form a network of irregular triangles. These points are connected with a series of edges to form a network of triangles, as the name suggests, to represent surface morphology. TIN is designed by T. K. Peucker, R. J. Fowler and J. J. Little from the Department of Geography, Simon Fraser University, Canada and D. M. Mark of the Department of Geography, University of Western Ontario London, Canada (Peucker et al. 1978) for DEM. It is used for calculating slope angle, aspect analysis and hydrological modelling.

7.4 Network Analysis

A network is a set of interconnected lines or polylines that forms a set of features through which resources can flow. Fundamentally, network analysis is used for path determination, resource allocation or distribution analysis and

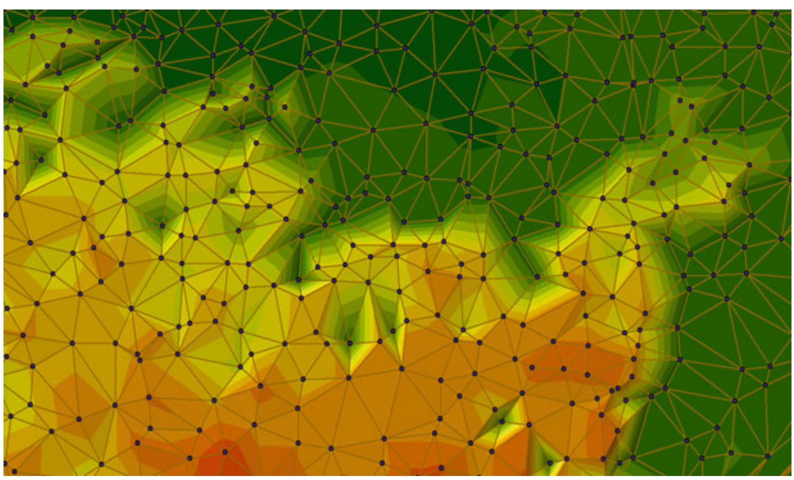


Fig. 7.13 Triangular Irregular Networks (TIN) interpolation

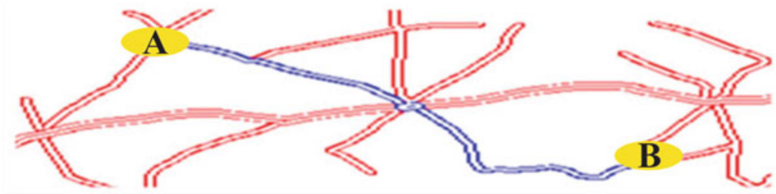


Fig. 7.14 Shortest-distance route from point A to B

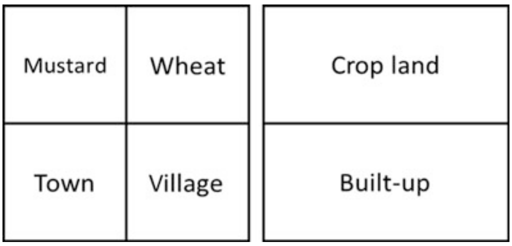


Fig. 7.15 Reclassification and dissolve of land-use class at different levels

utility locating. It is also used for identifying the most efficient routes or paths for the allocation of services (Fig. 7.14). This involves finding the shortest or least costly manner of providing assistance in visits to a location or a set of locations in a network. The 'cost' in a network analysis is frequent distance or travel time. Through network analysis you can determine the shortest route from one place to another. The most suitable example is a car navigation system which is installed in the car to identify the route. Network analysis can also be used to optimise the allocation of resources. Allocation analysis is the relationship between the demand and supply of resources over a network in the real world. In order to fulfil the supply-and-demand relationship, transformation and flow of resources must exist in a network. A very simple example is the distribution of electricity from a power house (supply) to a user (demand) through an electrical wire network. Network analysis also provides assistance in determining the location of facility points (the reverse of resource allocation), such as location of solid-waste management sites, shopping malls etc.

7.5 Data Manipulation

This is mostly for manipulating spatial data to fit into applications' specifications. Aggregating areas based on their attributes is one example of data manipulation. There are three steps for manipulation: reclassifying, dissolving and merging the area. On the basis of attributes, features such as line and polygon can be reclassified. For example, different levels of roads like national highway or state highway can be aggregated as highways. Similarly, in a polygon feature the data can be reclassified according to level, such as rabi crop and kharif crop areas into crop land and vice versa (Fig. 7.15). The dissolve is applied when there is a boundary between the same types of adjacent polygons with the same attribute. The merging option is applied to join two or more polygons into a single polygon (Fig. 7.16).

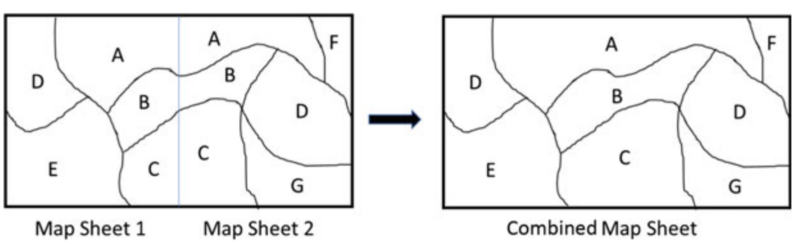


Fig. 7.16 Data merging

7.6 Conclusion

Spatial analysis is the most important feature of GIS software. It has a wide range of applications to develop understanding of the environment and for the management of resources and phenomena. There are various functions and methods of spatial analysis in different GIS software packages and most importantly these depend upon the ability of the GIS engineer to utilise and develop various functions and methods in a GIS environment. Basically, spatial analysis can be done on a single layer and/or multiple layers. The analysis ranges from simple to complex queries with different reasoning. It is very useful for the quantitative measurements of point, line and polygon features to understand the dimension of the features. It also includes the transformation process from single layer to multiple layers, such as creating a buffer zone around the point, line and polygon features as well as analysing two layers with different features such as line-in-polygon and polygon-in-polygon overlay analysis. The spatial interpolation technique is also utilised to identify unknown values from known characteristics of the spatial data such as Thiessen's polygon interpolation method, TIN and DEM. The spatial data can also be manipulated through the aggregation and merging of data sets to form new data sets. These spatial analysis methods are very useful for the geographical analysis of the data set.

Questions

1. What do you mean by spatial analysis?
2. What is a spatial query? Discuss the type of queries used in GIS.
3. What is buffer analysis? Discuss the application of buffers in various features.
4. Discuss the various types of overlay analysis used in GIS.
5. What is spatial interpolation? Why is it used in GIS?
6. Discuss the various methods of spatial interpolation in GIS.
7. Discuss the applications of network analysis in the world.

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8 Map Visualisation and Output

Abstract

The proper visualisation of a map is most important to provide information to the user community which is governed by the objective of mapping and accordingly the kind of cartographic techniques that should be applied to fulfil the requirement. This information should be recorded in various types of output in the form of maps and reports. After reading this chapter you should be able to understand the following:

- Meaning and process of visualisation
- Factors of geo-visualisation
- Geo-visualisation techniques
- GIS output by cartographic and non-cartographic methods

Keywords

Geo-visualization · Cartogram · Symbology · Map design · Non-cartographic output

8.1 Introduction

The literal meaning of visualisation is 'visual representation'. Data visualisation is a conversion of any data into visual form, e.g. tabular data into graphical representation. Similarly, map visualisation refers to a set of tools and techniques supporting spatial data analysis through the use of a visualisation process. It is also referred to as 'geographic visualisation', or 'geo-visualisation', which focuses on visualisation as it relates to spatial data that can be applied to all the stages of problem-solving in geographical analysis, from development of initial hypotheses through knowledge discovery, analysis, presentation and evaluation. Map visualisation includes not only the development of theories, tools and methods for the visualisation of spatial data but also involves understanding the usage of tools and methods for hypothesis formulation, pattern identification, knowledge construction and the facilitation of decision-making. Most of the digital data are generated today through spatial referencing. This referencing enables us to integrate enormous spatial databases of diverse information (Singh et al. 2001). At the same time, the magnitude and complexity of data sets can be brought together through their common geospatial links, and `this presents an extraordinary challenge for information science to transform these data into information and subsequently into knowledge (MacEachren and Kraak 1997).

8.2 Visualisation Process

The visualisation process can vary depending on the purpose and place of spatial data. During the visualisation process, cartographic methods and

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techniques are applied for the optimal design, production and use of maps. Visualisation can be created during any phase of the spatial-data handling process. It can be simple or complex while the production time can be short or long. The visualisation environment can also vary in nature; it can be on a stand-alone personal computer, network or on the worldwide web. The visualisation process is guided by the question *How do I say what to whom? How* refers to cartographic methods and techniques. *I* represents the cartographer or map-maker. *Say* deals with communicating in graphics the semantics of spatial data. *What* refers to the spatial data and its characteristics. *Whom* refers to the map audience and the purpose of the map. The audience may be scientists or laypeople. Map-making is not only the purpose of cartography but also should be tested on its effectiveness. The question *How do I say what to whom and is it effective?* guides the cartographic visualisation process and summarises the cartographic communication principle (Fig. 8.1).

8.2.1 Goals of Map-Visualisation

In general, map-visualisation goals can be broken down into four categories: data exploration, analysis, synthesis and presentation. These goals can be achieved through a series of tasks, subtasks, decisions and constraints. The *map-use cube* (Fig. 8.2) by MacEachren and Kraak (1997) modelled the space of visualisation goals with respect to three dimensions:

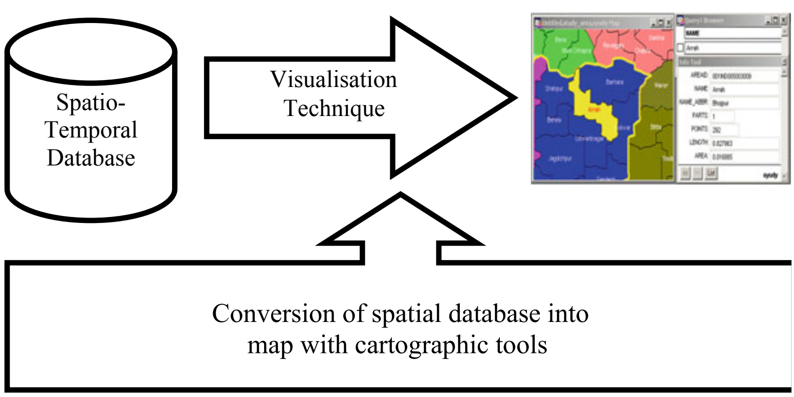
1. The *task* can range from revealing unknowns and constructing new knowledge to sharing existing knowledge.
2. The *interaction with the visualisation interface* can range from a rather passive low level to a high level where users actively influence what they see.
3. Finally, the *visualisation use* ranges from a single, private user to a large, public audience.

Exploration is an act of searching an unfamiliar or unknown area. Exploration can be seen as a private, highly interactive task to prompt thinking and to generate hypotheses and ultimately new scientific insight. The other extreme is formed by presenting knowledge in low-interaction visualisations to a wide audience. These two extremes can be described as *visual thinking* which creates and interprets graphic representations, and *visual communication* which aims at distributing knowledge in an easy-to-read graphic form. The former task is exploratory while the latter is explanatory. Presentation is via visual communication to a wide audience. As for maps, from exploration to presentation, systematic examination, analysis, evaluation and synthesis of data are required (Fig. 8.3).

8.2.2 Factors of Geo-Visualisation

There are basically three important factors for geo-visualisation: graphics and display technologies; increasing amount of geospatial data; and the rise of internet technology

Fig. 8.1 Conversion of spatio-temporal database into cartographic visualisation



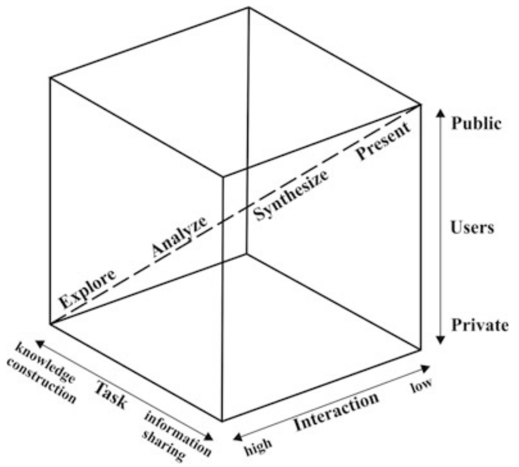


Fig. 8.2 Map-use cube (modified after MacEachren and Kraak 1997)

(Martin Nollengury 2006). The development of 3-dimensional graphics hardware in personal computing has increased the potential to visualise spatial data. Today, a huge amount of spatial data are available and day to day its availability is also increasing through various government and private institutions. The spatial data are also increasing by the development of remote-sensing and GPS technology. Increasing availability and the decreasing cost of acquiring technology, storing and processing of geospatial data have led to an increase geo-visualisation processes. The rise of the internet is a major factor in the dissemination of processes as well as open-source GIS environments such as GRASS, QGIS etc. to facilitate the geo-visualisation process.

8.2.3 Geo-Visualisation Techniques

Basically, visualisation of geospatial data consists of longitude, latitude and altitude that enable us to display 2-dimensional and 3-dimensional data. Once we add the time series data, it becomes 4-dimensional visualisation of spatial

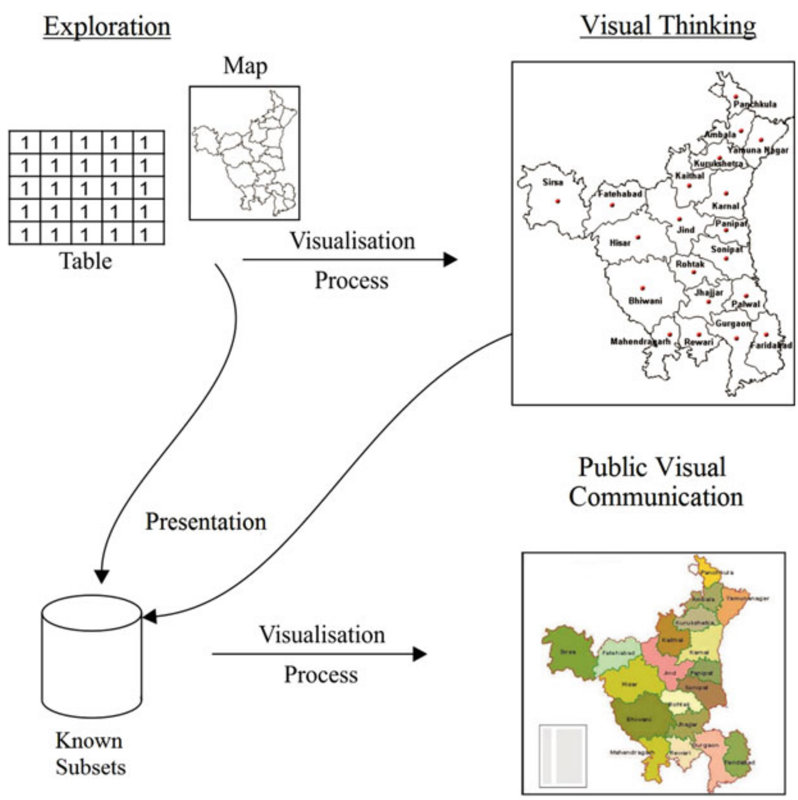


Fig. 8.3 Relationship between exploration and presentation

data. The most common visualisation of spatial data is 2-dimensional, such as a traditionally drawn map, cartogram, choropleth map, thematic map etc. The 3-dimensional display depends on the capability of a computer's 3-dimensional graphic card. The 3-dimensional view is an effective tool to perceive the environment and display while modelling the urban environment and it is widely used by architects and town planners. *Animation* is another technique of geo-visualisation which creates motion by showing still images in sequences. This provides dynamic and interactive display of the geospatial data such as animation of continental drift, movement of plates and animation of flights over terrain. Animated maps use time to add another visual dimension to the display. The successive time data can be mapped and each frame of the animation shows the single time data. Thus, the temporal changes of the attributes become visible. For smoothing the animation, the intermediate frame is interpolated on the basis of attribute data. The *interactive user interface* encompasses the most important geo-visualisation technique. This allows the authentication protocol to obtain additional information from the user as needed during the course of the authentication session. For example, the user who is learning by interaction from Google Earth data may rediscover the appropriate route from one place to another by drawing the route on a map or find other relationships in the data. This concept was also used in traditional cartographic maps by using the colour pencil or ribbon to analyse the data but it was not so effective while using more data sets at a time. Here, GIS has the capability to analyse more maps from different sources on one platform and analyse with multi-criteria techniques (Singh and Kumar 2013). For example, we can close or open new layers for our analysis such as buildings, roads, boundaries, market layers etc. So geo-visualisation is an active process in which an individual engages in sorting, highlighting, filtering and transforming data in a search for patterns and relationships.

8.3 GIS Output

The GIS output can be in the form of maps, charts, reports or a combination of all. Mapping is the best tool to display geographic relationships whereas others are more appropriate for summarising the tabular data and documenting any calculated value by geographical analysis. Cartographic and non-cartographic are the two basic types of output of GIS.

8.3.1 Cartographic Output

The most common output of GIS is the cartographic map. Cartography aims for elimination of errors and provision of correct transfer of data by the means of a graphical representation from which the user can draw the correct conclusion. A map can act both as an input as well as an output in the GIS environment. Maps are very useful to answer the questions *where?*, *what?* and *when?* Maps are the most suitable tools to answer the question *where*. If the query arises, *Where is Delhi?* and the non-map answer is *in India*, the answer is correct and may satisfy the query but this answer does not provide a geographical perspective. The administrative map of India would provide the geographical perspective. A map can answer the second question, *what?*, in a spatial context, for example, *What is the major land-use category in Delhi?* The verbal answer could be *urban land use* but it cannot reveal the spatial distribution pattern and shape of the urban land use of Delhi. The map can also answer the third question, *when?*, in a spatial context, for example, *When does Delhi have a population of more than 1.5 million?*, and the answer is *in Census 2011*, which could satisfy people, but the decadal census map can provide complete information about decadal changes. So, maps show the locations, arrangements, distribution patterns and relations with each other of the spatial features of the Earth. These can be available in the form of thematic maps such as forest maps, soil maps, population density maps, climatic maps, or in the form of a topographic map which shows the physical as well as cultural features such as contour, forests, rivers, roads, settlements etc. in a single topographical map sheet.

A map is one of the best ways to represent while communicating geographical information by using text and symbology of point (0-D), line (1-D) and polygon (2-D) features. For example, the location of villages, towns and cities are graphically represented by dots, circles, stars, squares and their combinations; linear features such as roads, railway networks and streams can be represented by various line styles like dotted-line, dash-line, solid-line-with-different-colour and line-width. The polygon features can be represented by various patterns, colours and tones. Bertin (1967/1983) identified six categories of visual variables to symbolise point, line and polygon features. These visual variables are size, value (grey-scale), texture, colour, orientation and shape (Fig. 8.4). These symbols were conceived for the purpose of storing, understanding and communicating essential geographical information. For example, blue colour depicts a waterbody. The 3-dimensional symbology of point, line and polygon features is also available in recent GIS software, especially in ArcGIS. This 3-dimensional symbology allows us to provide a sense of real-world scenarios for geographical features. So, the different types of data can be represented in different ways. Variation in quantity can be represented by the variable size of symbols. For example, a circle diagram shows the different sizes of circle representing variable sizes of population (Fig. 8.5), and the different width of roads shows the major and minor road categories. Size is represented in only point and line features. It is not used in polygon features because the size of a polygon itself represents the size. The value denotes the density or rank in the data that can be represented by colour-scale ranges between lighter to darker and should be within five to seven levels of colour scale. Otherwise, it would be difficult to discriminate between levels where lighter shade means low value and darker means large value—e.g. distribution of population density. Representation of features in different colours can increase the distinction between the spatial features in qualitative and quantitative data – e.g. a map showing different states in India by different colours in nominal order. Generally, large areas used to be shown in light colour and small areas in darker colour.

Various geometric shapes (Fig. 8.6) are also very important visual variables in showing qualitative differences in attributes, particularly in point and line features. The shape of the line can be solid, dashed or dotted and can be easily distinguished on the map. The shape of point features can be circular, rectangular, triangular

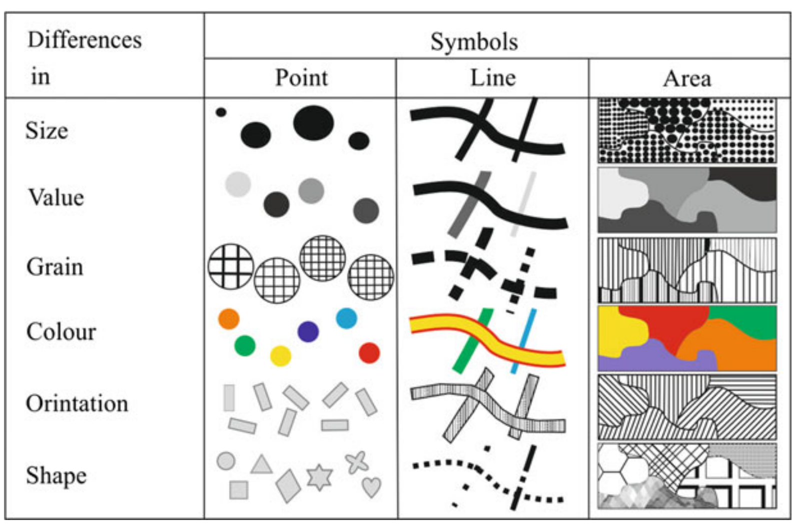


Fig. 8.4 Visual variables

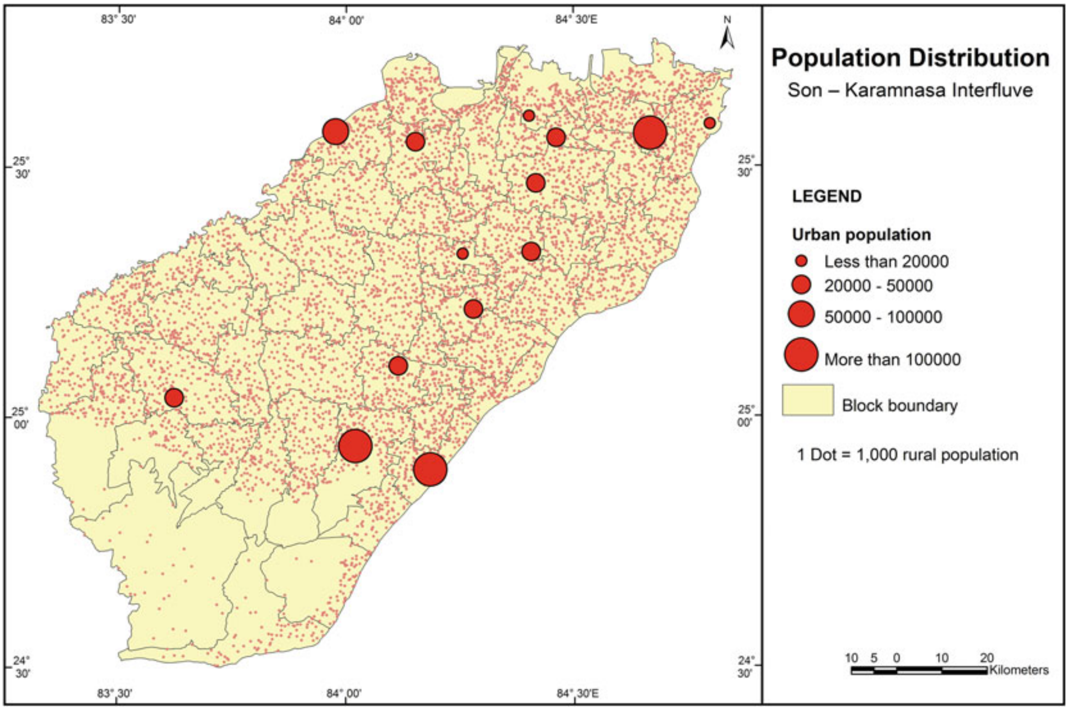


Fig. 8.5 Population distribution

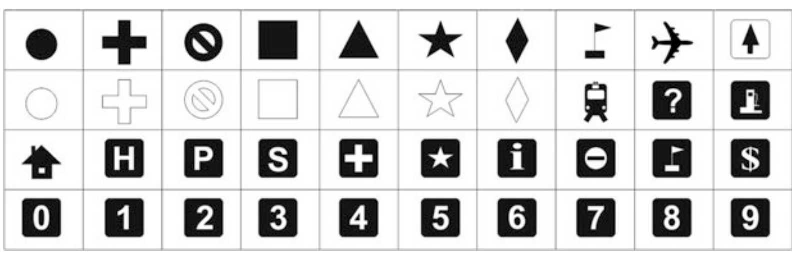


Fig. 8.6 Various geometric shapes for point symbols

etc. For example, distribution of minerals can be shown by different shapes of point features. There are various symbols available in GIS to represent various religious elements, infrastructure and facilities such as temple, church, hospital, post-office, light-house etc. (Fig. 8.6).

Orientation refers to the pattern of line direction and oriented symbols to point and line features, such as road networks, north arrow etc. Texture is also one of the important visual variables that shows density in the polygon feature. It can be shown by pattern and density of line, point and by picture. The texture may be fine to coarse, fine texture showing high value and coarse texture showing low values.

The attribute data can be quantitative and qualitative, represented by different symbology according to the level of measurements such as nominal, ordinal, ratio and interval to describe real-world phenomena. Qualitative data are represented by nominal features like the name of a road, river, worship place or town (Figs. 8.7 and 8.8).

Qualitative data can be represented by three levels of measurement: ordinal, ratio and

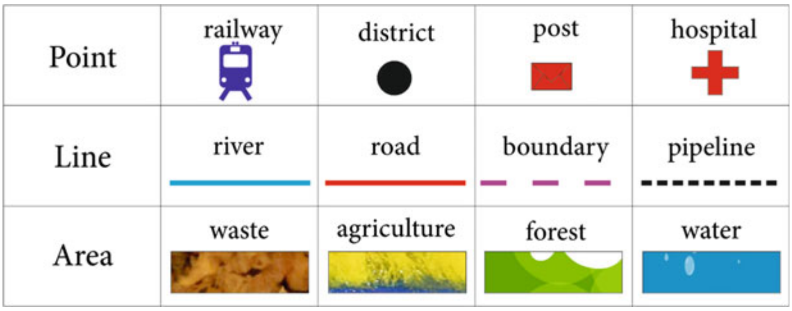


Fig. 8.7 Symbology of nominal data

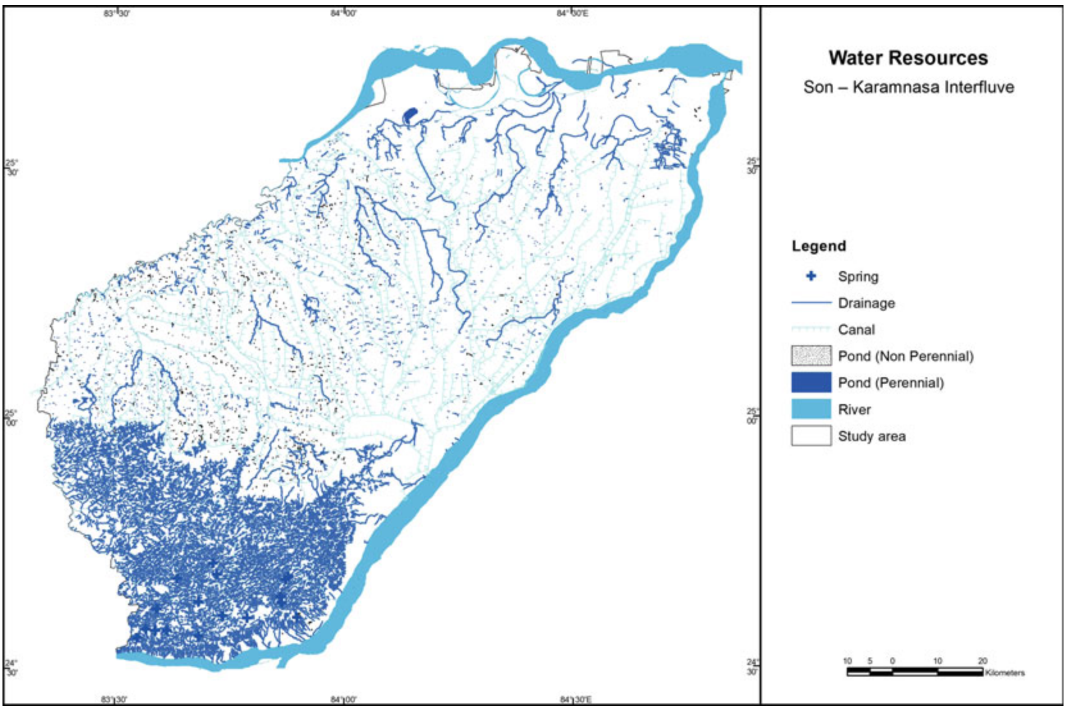


Fig. 8.8 Nominal data representation

interval. Ordinal data are arranged in hierarchical order to represent data in various categories such as high, medium or low quantity (Figs. 8.9 and 8.10), as in a population density map (Fig. 8.13).

Interval data can be placed in differently defined groups or classes and ranked in a standard unit such as the number of population (Figs. 8.11 and 8.12). For example, 50,000–100,000 people. This has a randomly selected starting point and arbitrary intervals but ratio data are indicated with exact numerical values measured on a scale in relation to a particular zero point or measured in respect to the fixed origin with a fixed interval, such as scale.

The map features presented in different symbology in a map's design and layout can enhance communication to the user community. Map design is an integration of several map elements while map layout is an arrangement of map elements on a desired paper or other medium to

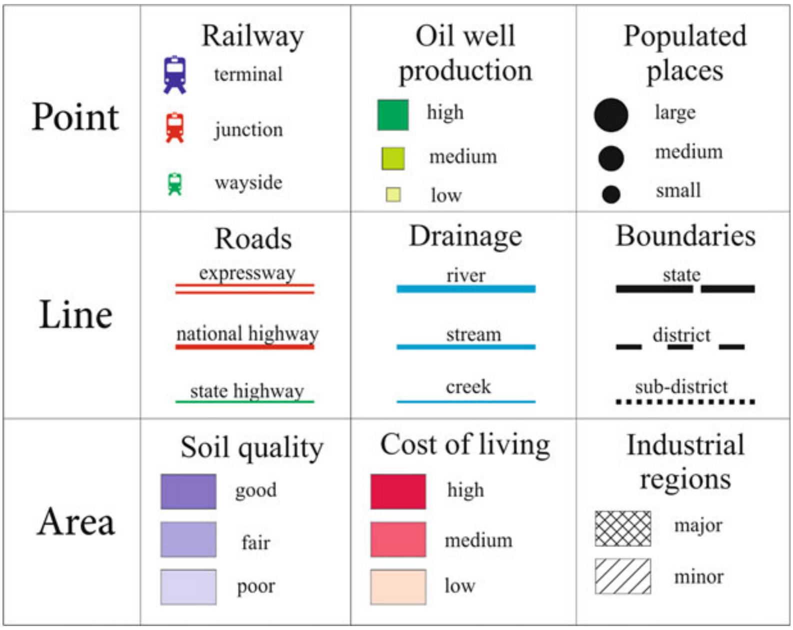


Fig. 8.9 Symbology of ordinal data

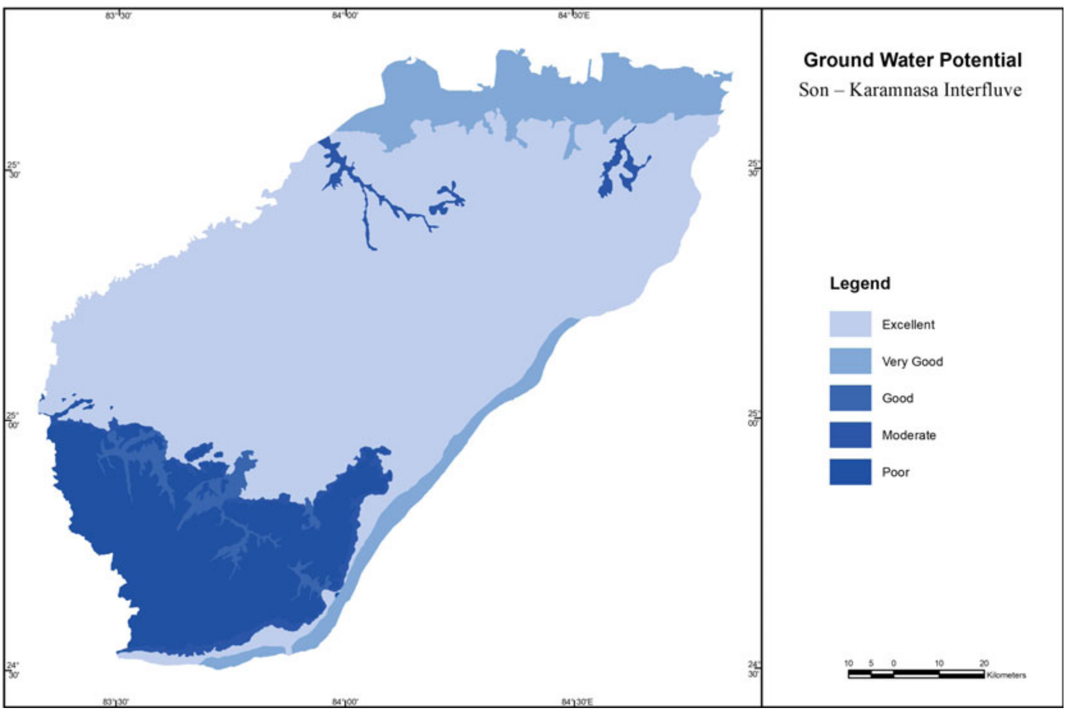


Fig. 8.10 Map representing ordinal data

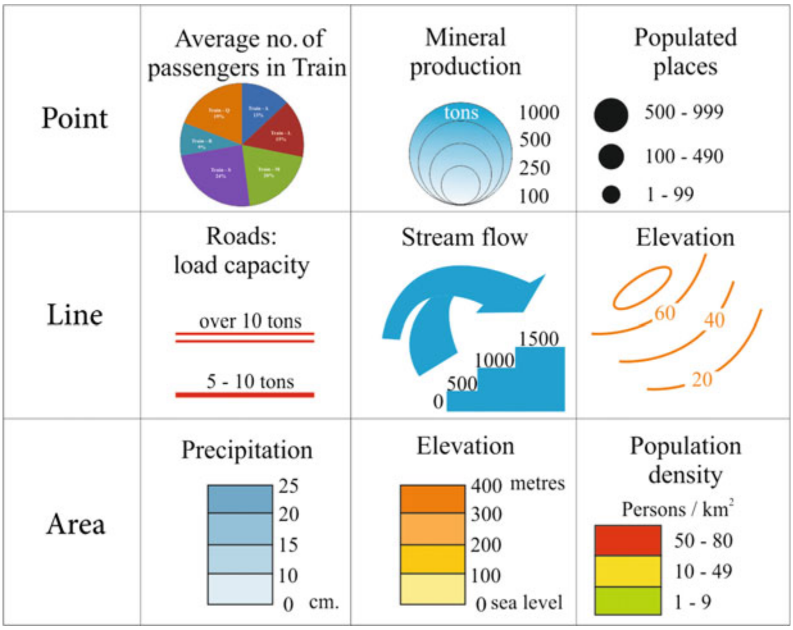


Fig. 8.11 Symbology in interval and ratio data

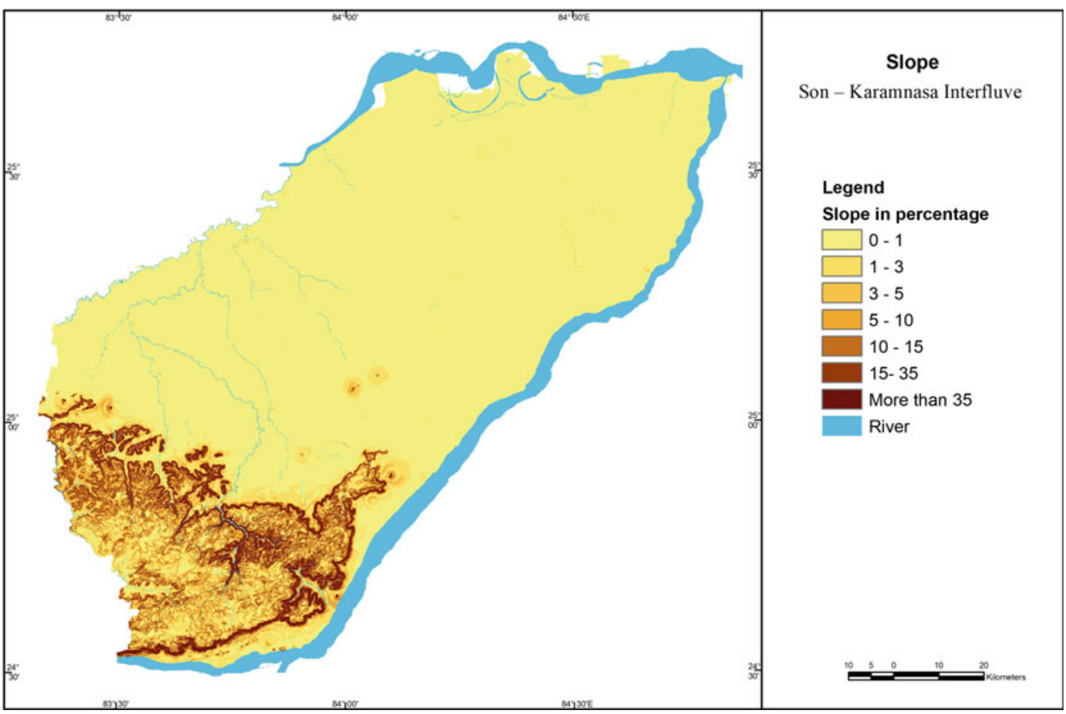


Fig. 8.12 Map showing ratio/interval data

publish. There are several map elements that are found on most maps: scale orientation, legend and data source; elements that are sensitive to context such as title, subtitle, map area, projection, cartographer name, date of production, source of data; elements that are used selectively such as neat-line, locator maps, inset maps and index maps. These map elements are most important to describe the map. The title of the map needs to be short and pronounceable and the subtitle understandable. For example, if the title is 'LAND USE/COVER' then the subtitle may contain the area name like 'Son-Karamnasa Interfluve'. The subtitle should be centrally aligned and placed below the title.

The map area is the most covered part of the map layout, also known as the map body. The map area can be single frame or multi-frame, depending upon the type of data representation. For example, if there is a single frame to show population density for one year then it should be in the centre or on any side of the page, depending on the page orientation and map extent. The temporal variation of the population density can be shown in multiple frames of the map. In the map layout, map area is more important than other elements. The legend is the most important map element of map layout. It comprises the symbology of point, line and polygon features along with their labels that describe the particular feature. Legend placement should be near the body of the particular map. If there are many map frames in a single map and a common legend is prepared, then it should be below the map frame. The orientation of the map should be depicted by the North arrow in a small size and well placed in the upper-right or -left corner of the map area. The scale-bar can be shown by the graphical and ratio methods to understand the relationship between map units and real-world units. There are different styles of scale available in GIS software. The data source should be mentioned in the lower-left or -right of the map layout. The neat-line around the entire layout should be drawn to group all the map elements in the layout. Different line styles are also available such as combinations of thick and thin lines. The latitude and longitude coordinates in lines or marks should be added according to the projection system used and should be mentioned by text in the map layout. The inset map is an important element of map layout and acts as a locater in relatively small size. The font size of different text should be according to the map layout. It should not be very large to suppress the map nor very small for visibility issues.

Designing the map layout is known as map design, and acts as a showcase of geographical data to the user and layperson (Fig. 8.13). Map layout depends upon the extent of the map. Suppose the longitudinal extent of the map is larger than the latitudinal extent, then orientation of the page should be landscape to arrange the map element accordingly, as in, for example, a map of the USA or Australia. If the latitudinal extent of the map is more than the longitudinal extent, then page orientation should be portrait, as in, for example, a map of South America or Japan.

8.3.2 Non-cartographic Output

Sometimes users need some type of representation of the spatial analysis, so there are many non-cartographic outputs from the GIS environment, such as reports, tables and charts. Tables and charts contain spatial and non-spatial information associated with the features which are sometimes necessary to explain the maps. Non-cartographic output can also be classified into graphical and statistical output. Charts are complementary to maps (Fig. 8.14) and visually summarise the information from the tables. It is helpful to understand the distribution, trend, pattern and relationship in-between the statistical data with line graphs, bar graphs, pie charts, area charts, scatter plots etc.

The output of the GIS can be a hard-copy or soft-copy map. It also serves as input for other GIS software, formats of which can easily be exported from one to another for compatibility of GIS software, such as *.kml, *.kmz, *.dxf, *.E00, *.shp, *.mdb, *.lyr etc.

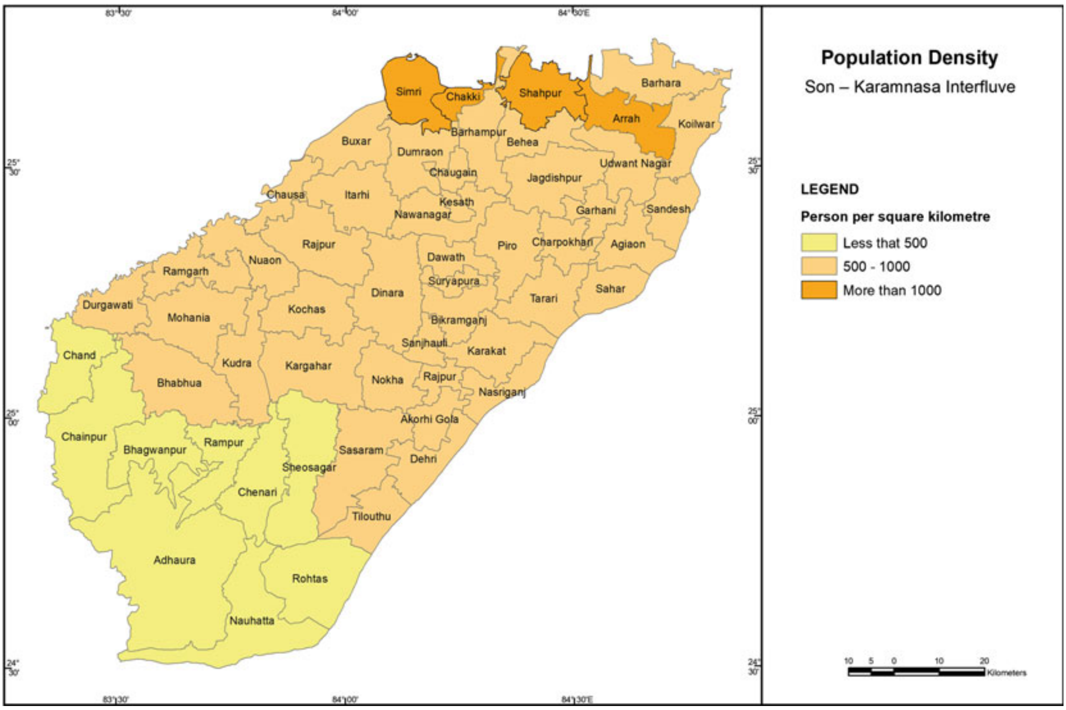


Fig. 8.13 Layout map in a landscape page

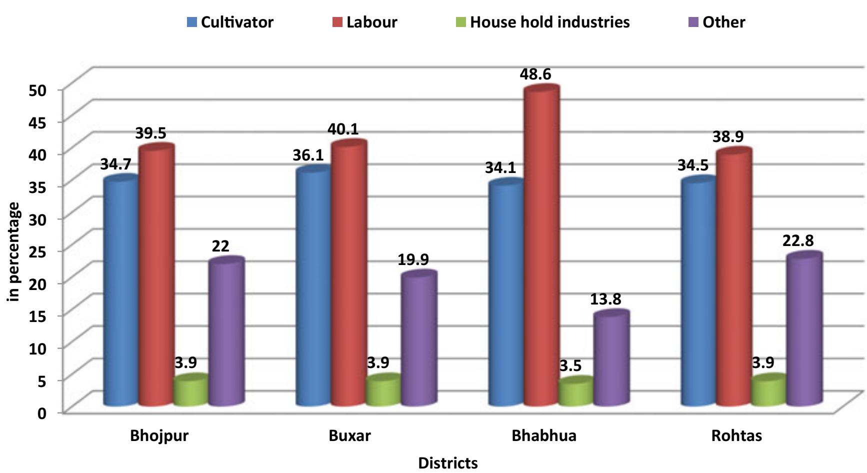


Fig. 8.14 Bar chart

8.4 Conclusion

Map visualisation is a process of visualising all the steps for decision-making for Earth's resources and phenomena. It includes all activities from thinking of the problems, hypothesis generation to final analysis of results and their presentations by exploring, analysing, synthesising and presenting the facts. Previous chapters explain the development, analysis and synthesis of spatial data. Spatial data can be presented through 2-dimensional and 3-dimensional graphics. These graphical representations can be achieved by cartographic and non-cartographic outputs. Cartographic representations need various map elements such as scale, title, subtitle, legend, sources of data and map layout. Non-cartographic representation is also done by charts, tables and reports. In this way, GIS can prove helpful in map-making and decision-making processes.

Questions

1. What is meant by map-visualisation?
2. Discuss the process of map-visualisation.
3. Discuss the types of map output in GIS.
4. Discuss the role of map elements in map layout.
5. How is the measurement of data in a GIS environment represented?

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Part II

Case Studies: Application of Spatial Information Technology for Sustainable Development Goals

9 SDG 15: Case Study – Land-Use Modelling for Micro (Block)-Level Planning

Abstract

Spatial information technology is an important tool for micro-level planning. Remote sensing provides unbiased information whereas GIS plays an important role in the decision-support system for spatial analysis and database management of natural resources. It has the ability to integrate spatial and non-spatial databases for proper management of natural resources. The present study deals with the application of remote sensing and GIS in micro-level planning for sustainable development. Indian Remote Sensing Satellite-based databases of various natural resources were used. An overlay analysis technique was used to integrate all the thematic maps. Decision rules were prepared by analysing individual and combined thematic maps to suggest alternate land-use models for agricultural land, wasteland and forest land of the Ferozpur Jhirka block of Mewat district in Haryana.

Keywords

Decision-support system · Sustainable land management · Hydro-geomorphology · Land-use model · Agro-horticulture · Agro-forestry

9.1 Introduction

Sustainable Development Goal (SDG) 15 addresses the protection, restoration and promotion of sustainable use of terrestrial ecosystems, management of forests, the reduction of desertification, and the halting and reversing of land degradation and mitigation of biodiversity degradation. The Spatial Information System in combination with remote sensing is useful to analyse and manage the natural resources located in the realm of the global ecosystem. The technique is unique, time-saving and thus very suitable for spatial planning, particularly in a land-use context, and capable of handling complex issues and large databases for manipulation and retrieval. At a micro level, block-level planning is emerging as a feasible unit for land-use planning and modelling. In this context, spatial information technology has evolved as a decision-support system for sustainable land management. All these efforts combine to ensure that the benefits of land-based ecosystems, including sustainable livelihood, will be enjoyed for generations to come.

D. Kumar et al., *Spatial Information Technology for Sustainable Development Goals*, Sustainable Development Goals Series, https://doi.org/10.1007/978-3-319-58039-5_9

9.2 Study Area

The Ferozpur Jhirka block of Mewat district of Haryana, lying within the geo-coordinates between 76° 53′ 25′ and 77° 08′ 30′ East longitude and 27° 39′ 08′ North to 27° 53′ 54′ North latitude, encompasses a total geographical area of about 323.90 km^2. It is a part of the Mewat region, which is named after the inhabitants of the Meo community. It is a distinct, ethnological and sociocultural tract. Mewat, despite having a rich history and culture, currently struggles with complex socio-economic backwardness. The factors for backwardness of the region may be poor soil conditions, dry land, inadequate irrigation facilities and a relatively low rate of literacy. Most of the study area is flat terrain. The altitude ranges from 200 to 300 m above mean sea level. The slope is gentle toward the North and North-east while it is moderately steep to very steep in the South-western part. Most of the drainage in the area is seasonal and dry. Due to the Aravalli hills, the rock formation is very old, consisting of schist and quartzite. The study area has loamy to sandy loamy soil. Hydro-geomorphologically, the study area mainly consists of alluvial plains, pediment and structural hills. The climate is of the subtropical continental monsoon type where there is a total average rainfall of 445.9 mm distributed over a period of 23–35 days and is erratic. May and June are the hottest months, while January is the coldest. Temperature variations are a high of 4–25 °C during the winter and 30–40 °C during the summer. Relative humidity is generally low. The area also experiences climate uncertainty and there is sporadic drought.

9.3 Database and Methodology

IRS-1B LISS II and IRS 1C LISS III, geo-coded FCC (scale 1:50,000)-based various thematic maps and Survey of India Topographical sheets (54A/13, 54A/14, 54E/1, 54E/2) were used for this study. GIS has mainly served as an instrument to store and analyse a wide range of natural

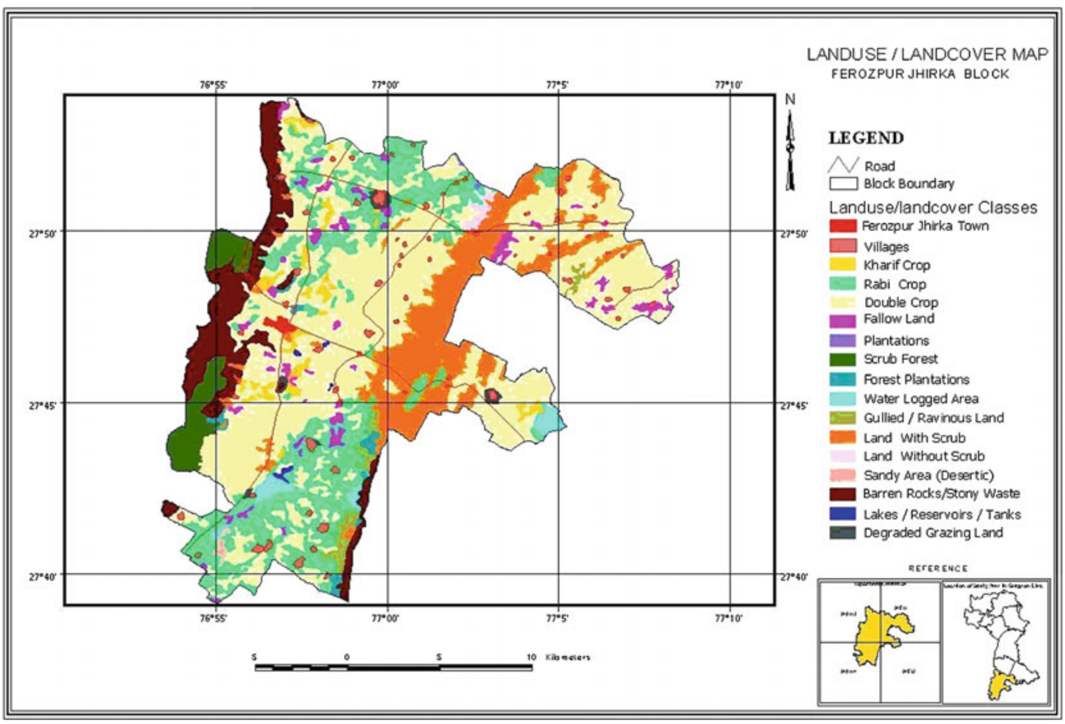

Fig. 9.1 Land use and land cover

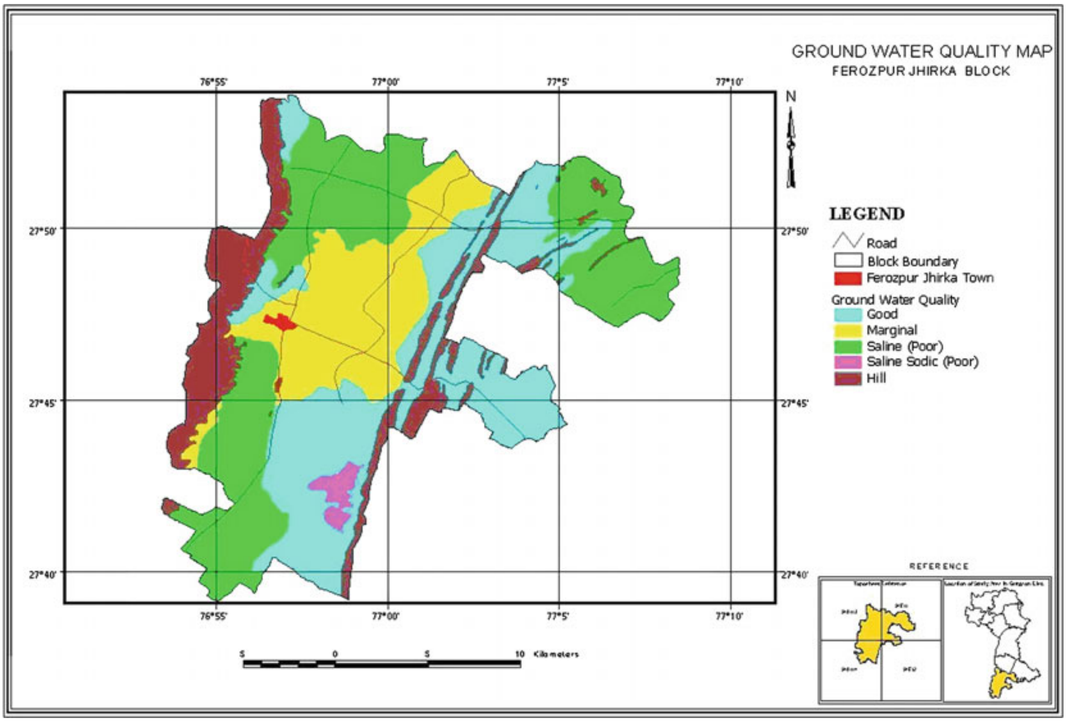

Fig. 9.2 Groundwater quality

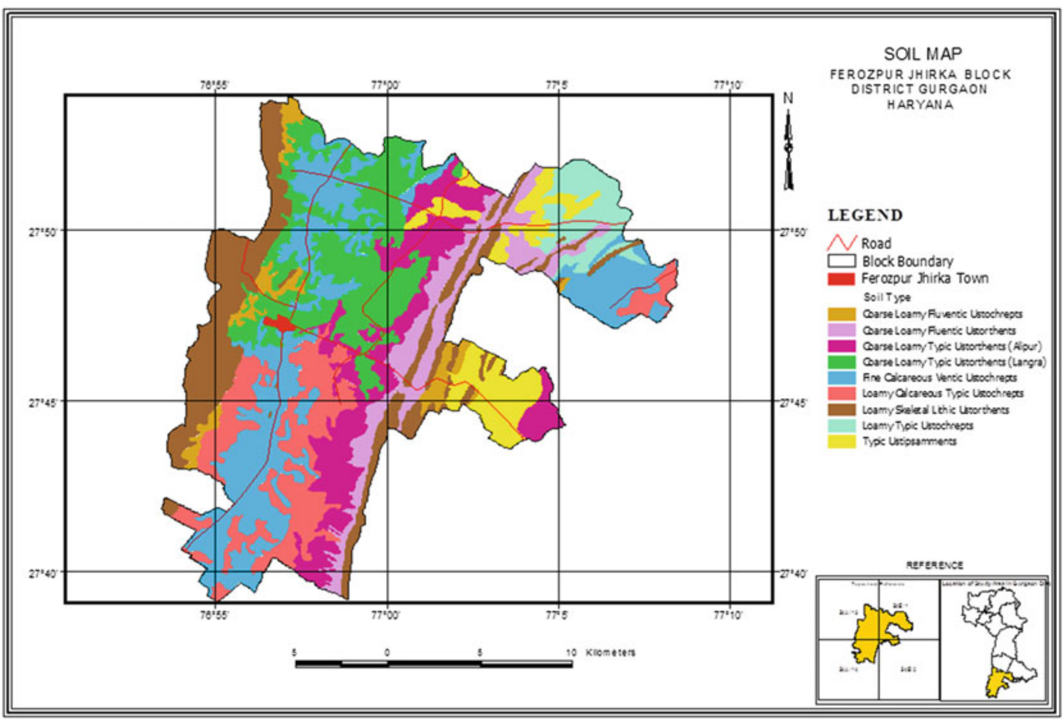

Fig. 9.3 Soil map

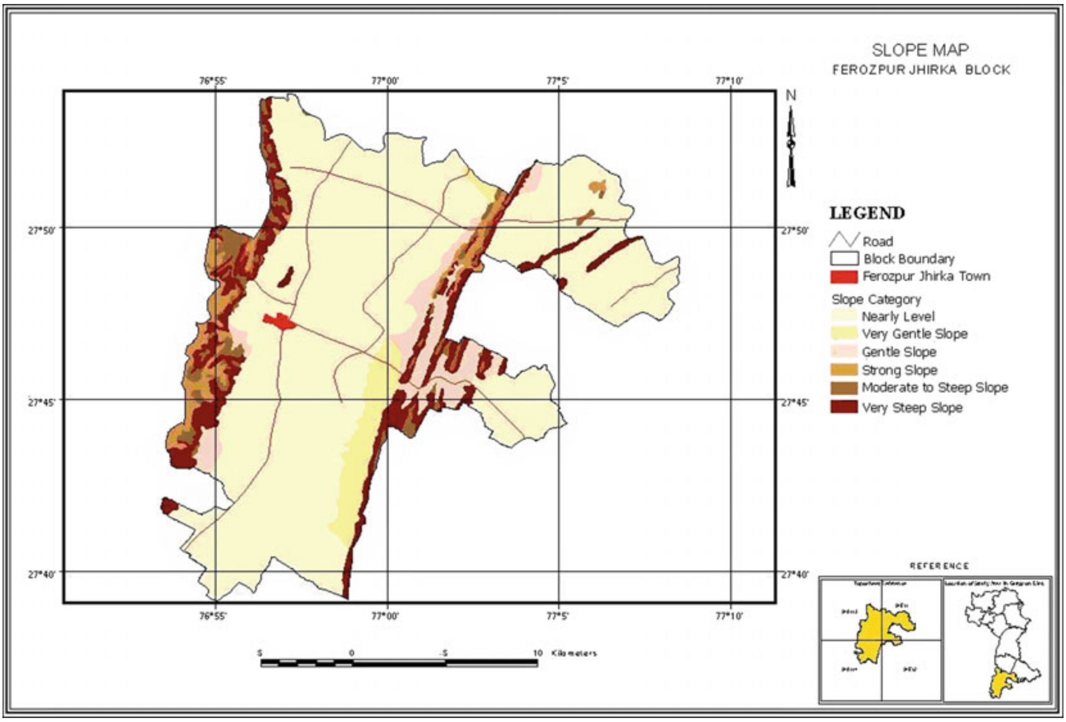

Fig. 9.4 Slope map

resource data for preparing the land-use model in a conservative, economic and productive manner. All the thematic maps were scanned to convert into analogue to raster format with 200 dpi for black-and-white map to 300 dpi for colour map. The on-screen digitisations were used to convert raster format into vector format through AutoCAD package. These vector format thematic maps were imported in ArcInfo software by ESRI for further transforming with a real coordinate system by using polyconic projection, edited with suitable topology of line and polygon, attribute data joining and finally preparation of the digital thematic maps in vector format. These final digital thematic maps present land use (Fig. 9.1), groundwater quality conditions (Fig. 9.2), soil (Fig. 9.3), slope (Fig. 9.4) and geomorphology (Fig. 9.5), and were integrated one by one for development of an integrated or composite land-units map (Fig. 9.6) by using the *union* tool for overlay analysis (Table 9.1). The decision rules were prepared by analysing individual thematic maps and combinations of various thematic maps (composite land-unit maps). A spatial query was used to implement the decision rules on individual and composite land-unit maps. A master map layout was prepared for all the thematic maps and produced in a hard-copy map.

9.4 Results and Discussion

Among the total area, 5.375 km^2, which is around 2% of the total land-use management area, has not come under land-use management because of its use by settlements and lake/pond. The total area under which the land-use model has been prepared is 318.523 km^2. Among this, 219.649 km^2 is under agricultural management, which is 67% of the total land-use management area. 83.51 km^2 of the area under forest management constitutes 26%; wasteland is 15.364 km^2, which is 5% of the total land-use management area (Fig. 9.6). Proper land management, controls of soil erosion, improved soil

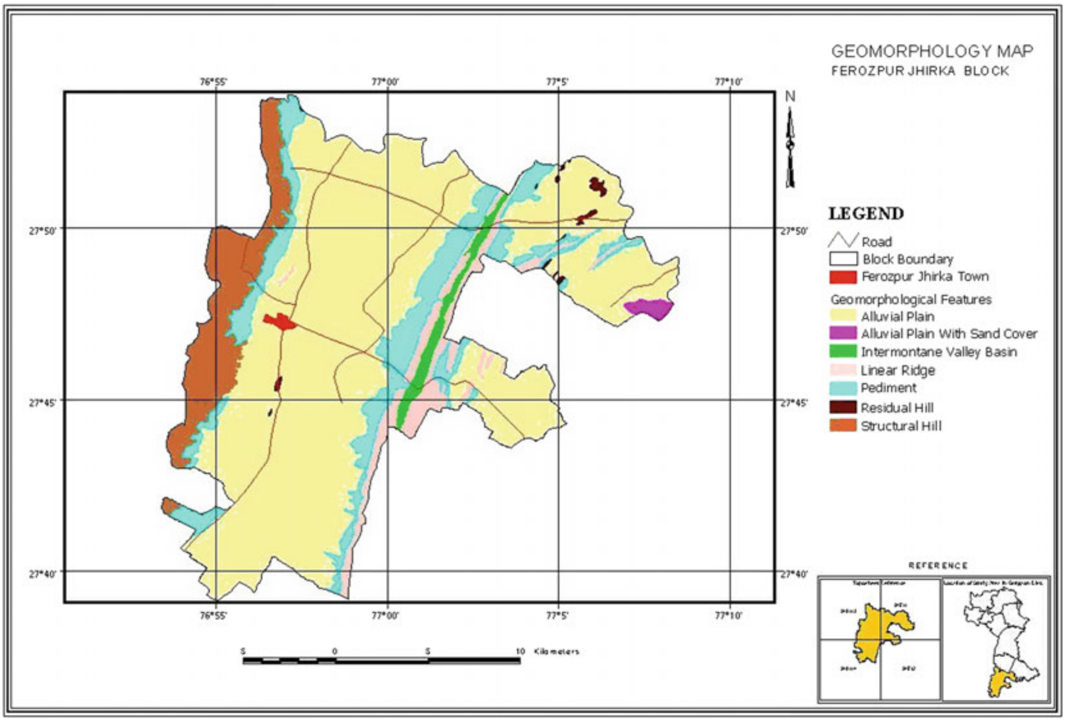

Fig. 9.5 Geomorphology map

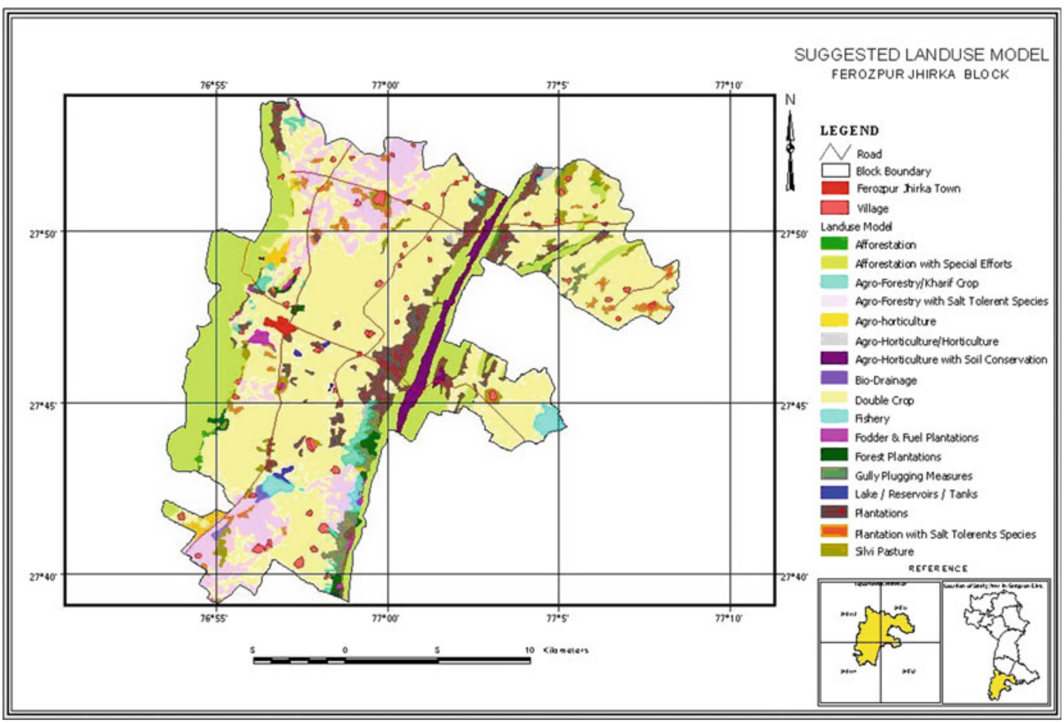

Fig. 9.6 Suggested land-use model

Table 9.1 Area under different land use after applying land-use model

Map-ID	Land use	Area (in km^2)	Area (in %)
101	Afforestation	01.112	00.34
102	Afforestation with special efforts	52.876	16.33
103	Agro-forestry/kharif	03.638	01.13
104	Agro-forestry with salt-tolerant species	29.900	09.23
105	Agro-horticulture	02.233	00.69
106	Agro-horticulture/horticulture	01.134	00.35
107	Agro-horticulture with soil conservation	06.212	01.92
108	Bio-drainage	00.629	00.19
109	Double crop	176.532	54.52
110	Fishery	03.057	00.94
111	Fodder and fuel plantation	01.389	00.43
112	Forest plantations	02.405	00.74
113	Gully-plugging measures	04.089	01.26
115	Plantation	22.246	06.87
116	Plantation with salt-tolerant species	04.871	01.50
117	Silvipasture	06.200	01.91
	Village	03.947	01.22
	City	00.836	00.26
	Lake	00.563	00.17
	Total	323.898	100

fertility and moisture retention capacity, all led to improvement of the productivity of land (Singh and Kumar 2012). The land-use model of the study area is laid out in Table 9.1.

9.4.1 Management of Agricultural Lands

The total area under agricultural management is 219.65 km^2, that is 67.8% of the total area. Double crop, horticulture, agro-horticulture, agro-forestry are suggested for alternate land-use practices. Based on the present land-use and land-cover mapping, the area is 149.877 km^2 (Table 9.2). After suggesting the land-use model, the area under double crop is increased to 176.523 km^2. This is suggested in the areas where only the single crop is grown, i.e. either *rabi* or *kharif*, but the quality of underground water is found to be good. The crop which gives more economic returns per unit use of water crops and has low-water requirements should be grown. The *kharif* crops like bajra, gwar, moong, urd, cowpea; and *rabi* crops like barley, mustard, raya and wheat.

Agro-horticulture with soil conservation measures has been suggested in an area where the slope limitation is 3–5%, groundwater quality is fresh to marginal and the geomorphic unit is pediment. The concept of agro-horticulture, i.e. growing fruit trees in combination with agricultural crops, has been suggested in these areas. Horticultural plantation is also one of the options for the farmers of these areas. The total area under agro-horticulture/horticulture is 9.579 km^2, among which 6.212 km^2 require soil conservation along with agro-horticulture because of slope limitation. The practice of agro-forestry is of particular interest in arid and semi-arid zones of India as it is in a timely manner linked with the question of increasing fuel and food production to meet the

Table 9.2 Before land-use model area under various land-use/cover classes

Map-ID	Land-use/cover	Category	Area (in km^2)	Area (in %)
1	Town/cities	Built-up land	0.838	00.258
2	Village	Built-up land	4.458	01.376
3	*Kharif* crop	Agricultural land	6.711	02.071
4	*Rabi* crop	Agricultural land	57.805	17.847
5	Double crop	Agricultural land	149.877	46.273
6	Fallow	Agricultural land	8.771	02.709
7	Plantation	Agricultural land	0.192	00.059
12	Scrub forest	Forest	11.78	03.637
14	Forest plantations	Forest	2.467	00.762
17	Waterlogged area	Wasteland	3.698	01.142
19	Gullied/ravinous land	Wasteland	4.058	01.253
20	Land with scrub	Wasteland	43.285	13.364
21	Land without scrub	Wasteland	1.462	00.451
22	Sandy area (desertic)	Wasteland	0.751	00.232
24	Barren rocky/stony waste	Wasteland	25.448	07.857
28	Degraded	Grassland/grazing land	1.727	00.533
25	Lakes/reservoirs/tanks	Others	0.57	00.176
	Total		323.898	100

needs of increasing populations, and the conservation of soil and moisture. The sandy areas in the dune vale complex and single-crop areas in the study area are the best sites for the implementation of agro-forestry. The total area under agro-forestry is 33.538 km^2 inclusive of the 29.900 km^2 that salt-tolerant species require. The concept of agro-forestry implies the integration of annual crops with perennial trees on the farm to the benefit of the agriculture (Singh and Kumar 2004). This concept originated from the realisation that the trees play a vital role in safeguarding the long-term interests of the agriculture and in making the economy viable. Trees help to preserve the fertility of the soil through the return of organic matter and fixation of nitrogen. Attention needs to be given to planting the trees on the bunds of the cropped areas. The agro-forestry system requires careful selection of both crops and tree species if a beneficial interaction is to be obtained.

9.4.2 Management of Wastelands

The study area consists of different categories of wasteland such as scrub land, gullies/ravines, waterlogged areas etc. The move should be taken to bring more of these wastelands under productive use. The main suggestion made for development of these wastelands includes silvipasture, levelling, and proper drainage systems and reclamation measures. Silvipasture is one of the alternative land-use systems available for improving the fodder resources of the study area. The total area under silvipasture and fodder and fuel is 7.589 km^2. This system offers an extra yield of grass during the rainy season and browse material in long dry spells. It also reduces soil erosion and retains moisture, improves fertility by inclusion of forage legumes and nitrogen-fixing trees, and makes available extra fuel wood or charcoal which will spare the nutrient-rich animal manure for agriculture purposes. Therefore, silvipasture is suggested in scrub land, near villages having slope limitation in a few patches and areas with poor groundwater quality. The grass species, which are native to the area, should be planted. It is also suggested that the local forest species should be planted along with grass as an additional source of fuel and fodder. The wasteland due to shifting of brick kilns can also be brought under cropping by levelling the land. Bio-drainage and plantation of tree species that control the waterlogging are also suggested where the permanent waterlogged areas are found to be with poor groundwater quality. Fish culture is one alternative for utilisation of permanent waterlogged areas where the total area under fishery is estimated as 3.057 km^2.

9.4.3 Management of Forest Land

Afforestation and gap-filling are suggested for forest-land management. A number of scattered low-height hills and ridges are found in the study area. The tops of most of these hills are barren and rocky, supporting little vegetation. Foot hills, however, have a gravely skeletal soil and scrubby vegetation mapped as degraded forest and scrub land on the land-use maps. The side slopes of ridges and scattered hills are potential sites for afforestation. Some of these areas may come under forest plantation. Such action would preserve and increase the species diversity, prevent soil erosion, conserve rain water and ameliorate the environment over the long run. The degraded forest sites as per present land-use/cover maps are suggested for gap-filling by planting the local species where required. The total area under forest management is 83.51 km^2, which is around 25.78% of the total area, the largest area after agricultural management. The plant species suggested for afforestation and gap-filling are babool, ronj, neem etc.

9.5 Conclusion

GIS in conjunction with remote-sensing data is found to be very useful in the land-use model and to provide near real-time information. The land-use model maps were prepared in such a way that no land should be kept as wasteland, with no use or no return in monitory terms or with regard to the environment under geo-environmental conditions of the study area. The prepared composite land-unit maps are helpful in better understanding the cause-and-effect relationship of not only problems and limitations but also potentialities. The decision rules were developed and applied in the composite land-unit maps for a potential land-use model. Finally, the cartographic techniques have been used in enhancing various thematic maps in order to contribute towards a potential land-use model.

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SDG 12: Case Study – Watershed Characterisation and Prioritisation for Land and Water Resource Management

10

Abstract

The advent of advance technology in remote sensing and GIS provides synoptic and near real-time information in better resolution to delineate the various natural features on the Earth's surface. This technology has been used to update the drainage of the Son-Karamnasa interfluves and demarcate the 13 watersheds. It is an ideal unit for land and water resource management. As the development of large areas is not feasible in one stretch, the region needs the prioritisation of the watershed for development processes according to their priority. Watershed prioritisation has been done by using the ranking method of the morphometric parameters in linear, areal and relief aspects in the study area. On the basis of run-off and erodibility of the watershed characteristics, the rank of each parameter has been assigned. This rank was further categorised into high, medium and low priority for land and water resource management.

Keywords

Watershed · Morphometric parameters · Drainage density · Watershed prioritisation · Resource management

10.1 Introduction

The development of land and water resources on a sustained basis and with constant increase in productivity is necessary for achieving SDG 12 to promote sustainable consumption and production patterns. A watershed is an ideal geo-physical unit needed for a multidisciplinary approach to resource management for ensuring benefits on a sustained basis. The characteristics of a watershed help us to understand and model various natural processes occurring in the watershed. Watersheds or hydrologic units are considered more efficient and appropriate for necessary surveys and investigations of various developmental programmes like soil and water conservation, command area development, erosion control in catchments, dry land/ rainfed farming, reclamation of ravine lands, major to minor storage projects as well as farm-level water harvesting structures (Kumar and Kaur 2002). Prioritisation of areas helps in addressing conservation efforts to secure maximum benefit and to make best use of available resources. Priorities are generally accorded to those watersheds which are in critical condition and adjacent to mainstream areas. Information on run-off and sediment yield could provide light on the degradation of

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watersheds and thus identify critical source areas for starting developmental programmes. Several methods are available depending upon the purpose and information availability, but the most commonly used methods are the Sediment Yield Index (SYI) by Bali and Karale (1977) and the Universal Soil Loss Equation (USLE) given by Wischmeier and Smith (1978). Some exclusive methods are also tested by different authors combining geo-physical parameters vis-à-vis shape and drainage parameters to arrive at a more comprehensive decision of watershed priority (Dutta et al. 2002). The advantages of this method are that it is quick, requires less ground-based data and has easy extrapolation.

10.2 Study Region: The Son-Karamnasa Interfluves

The research area extends between 83° 19′ 38″ East to 84° 51′ 3″ East and 24° 30′ 11″ North to 25° 45′ 34″ North. It has a well-defined natural boundary surrounded by rivers from all directions except in the South-west. It is bounded by the river Son from the East and South, the river Karamnasa flowing in the West and the river Ganga in the North. The study area is divided into 13 watersheds of varying size (Fig. 10.1). The largest watershed is WS1 and the smallest is WS12. The highest point in the study area is 640.4 m above the mean sea level in the Rohtas plateau and the maximum area is less than 200 m above the mean sea level. The slope provides favourable conditions for the cultivation of various crops. Maximum drainage is found in the southern part of the study area in the plateau region and foothills, which are mostly non-perennial, but in the plains, the large network of the Son canal system exists. The ponds are also found in the study area, being perennial and non-perennial in nature. The study area has four administrative districts: Bhojpur, Buxar, Bhabhua and Rohtas in Bihar. It is covered by Ballia, Ghazipur, Chandauli and Sonbhadra districts of Uttar Pradesh in the North and West; Garhwa and Palamau of Jharkhand in the South; Aurangabad, Arwal, Patna and the Saran district of Bihar in the East and North-east of the study area.

Geologically, the rocks belong to the middle Proterozoic sedimentary sequence of Vindhyan super-group and an unconsolidated to semi-consolidated alluvial sequence of the late Pleistocene to late Holocene age. There exist varied lithologies like shale, sandstone, limestone, conglomerates etc. Physiographically, the research area is divided into two parts: Bhojpur plain and Rohtas plateau. Bhojpur plain is a third order of Middle Ganga Plain South known as the Ganga–Son Divide East (Bhojpur plain) and Rohtas plateau is the geographically third order of Vindhyanchal Baghelkhand North Plateau known as Rohtas-Bijaigarh upland (Singh 1989). Both Grand Chord, Delhi–Kolkata main railway line and the Grand Trunk road (GT road) pass through this plain. The Indrapuri barrage on the river Son near Dehri-on-Son enhances the agricultural prosperity of the Bhojpur plain and is a prosperous rice-dominated agricultural area irrigated by the canal system. The Rohtas-Bijaigarh upland is relatively a more dissected and highly underdeveloped region. It is mostly used as summer pasture for the foothill plains. The Kaimur limestone and Amjhor pyrites tend to provide opportunities for economic development. Geomorphologically, the maximum area comes under alluvial plain with excellent groundwater potential for agricultural practices. Along the river Ganga, a large area belongs to the flood plain. There is very little area that belongs to the dissected plateau, pediments and residual hills where groundwater is poor, which does not fit agricultural use and belongs to notified forest.

10.3 Watershed Characteristics

The science of morphometry is concerned with the quantitative measurement and generalisation of land-surface geometry. The linear, areal and relief aspects of the watershed characteristics have been used for the morphometric analysis.

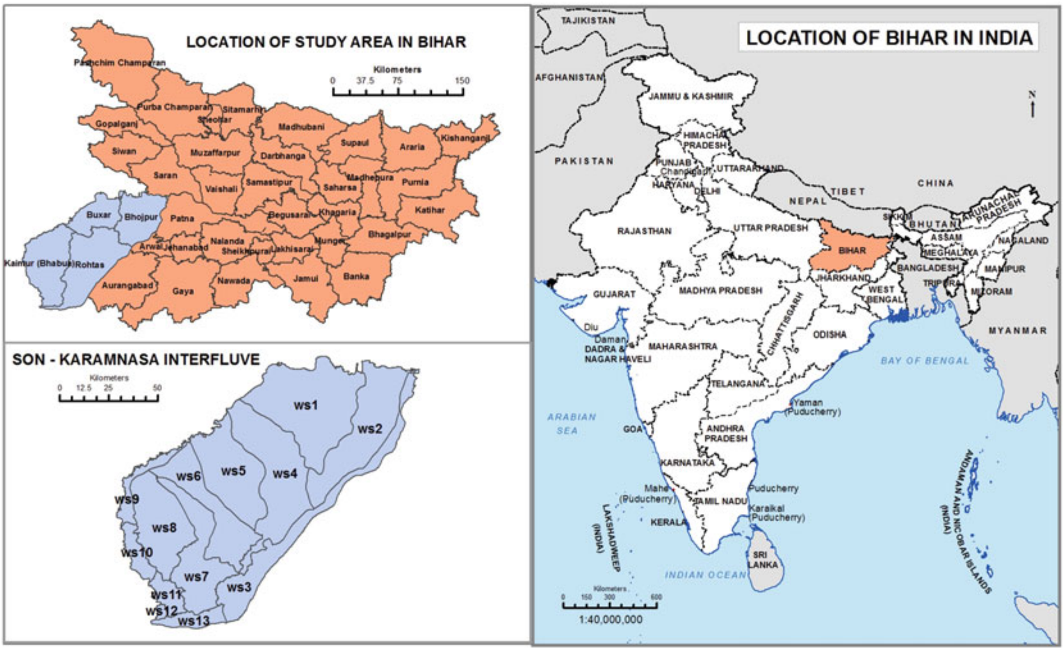

Fig. 10.1 Location of study area

10.3.1 Linear Aspects

The linear aspect of basin characteristics includes the number of streams, basin parameter, basin length, wandering ratio, overland flow, lengths of channels of all orders etc. The usefulness of ordering the channel system lays on the hypothesis that basin size, channel dimension and stream flows are proportional to the stream orders which provided investigation for quite a large number of watersheds. Two basins having different linear measurements can be compared with respect to corresponding points in their geometry through the use of dimensionless order numbers (Table 10.1).

Stream Orders There are various systems of ordering the streams that are available (Horton 1945; Strahler 1957; Shreve 1966). Strahler's system, which in fact slightly modified Horton's, was followed because of its simplicity. Accordingly, the smallest unbranched stream segment is designated as the first-order stream, the one formed by the merging of two such first-order segments, the second-order stream and so on. In this ordering, the analysis reveals that WS1 is a third-order watershed; WS2, WS4 and WS5 are fourth-order watersheds; WS1, WS3 and WS12 are fifth-order watersheds; WS6, WS8, WS10, WS11 and WS13 are sixth-order watersheds; and WS7 is the only seventh-order watershed.

Stream Numbers The numbers of streams are calculated in each watershed. The total number of streams in the Son-Karamnasa interfluves is 8655. The maximum and minimum number of streams are found in WS7 and WS9, respectively (Table 10.2). The analysis also reveals that the number of streams decreases as the stream order increases. There are more first-order streams than any other order and the first-order streams on average are shorter and occupy smaller drainage basins. The stream discharge increases systematically with order.

Bifurcation Ratio The bifurcation ratios were computed by dividing the number of stream segments of a given order by the number of stream segments of the next higher order (Schumm 1956). Horton (1945) considered bifurcation ratio as an index of relief and dissections. The data reveal that

Table 10.1 Linear aspect of the Son-Karamnasa interfluve

Watershed	Main channel length	Basin length (in km)	No. of streams of all orders	Total channel length (in km)	Basin perimeter (in km)	Mean length ratio	Wandering ratio	Mean bifurcation ratio	Length of overland flow
WS1	83.18	64.21	103	484.88	233.26	1.37	1.30	3.09	1.25
WS2	106.10	87.23	81	311.21	230.36	2.83	1.22	3.91	2.26
WS3	174.74	160.78	1068	1049.43	385.75	7.10	1.09	5.75	0.51
WS4	166.62	88.32	327	485.84	262.95	18.47	1.89	7.31	1.62
WS5	103.49	62.92	80	304.92	187.21	3.22	1.64	4.48	1.95
WS6	103.92	70.88	472	1064.54	210.01	10.85	1.47	3.42	0.46
WS7	126.95	73.19	2825	1987.04	235.19	3.11	1.74	3.71	0.25
WS8	88.00	53.09	1477	1294.34	163.14	2.50	1.66	4.14	0.41
WS9	63.76	54.63	30	83.56	178.86	5.89	1.17	5.13	1.47
WS10	49.45	30.44	511	469.24	102.67	2.20	1.62	3.43	0.25
WS11	34.35	23.55	802	1089.73	88.76	2.81	1.46	3.78	0.10
WS12	10.48	07.02	163	98.31	25.34	1.89	1.49	3.68	0.17
WS13	41.52	38.00	716	580.90	96.37	2.23	1.09	3.50	0.20

the mean bifurcation ratio varies between 3.09 and 7.31 in WS1 and WS4, respectively. It is categorised into low (less than 5), medium (5–6) and high (more than 6) classes. The lower values of bifurcation ratio are characteristic of structurally less disturbed watersheds without any distortion in drainage pattern (Nag 1998). The bifurcation ratio between 3 and 5 indicates that geologic structures have not distorted the drainage pattern of the basin. Exceeding value-pronounced structural control encourages the development of an elongated narrow drainage basin. The higher value of bifurcation ratio indicates a high run-off, less infiltration and mature nature of topography, which is the result of variation in higher- and lower-order stream segments. These irregularities are dependent on geological and lithological development of drainage basins (Strahler 1964). It was calculated by using the following formula:

$$\text{Bifurcation ratio (Rb)} = \frac{\text{Nu}}{\text{Nu} + 1}$$

where

Rb Bifurcation ratio
Nu Total number of stream segments of order ‘*u*’
Nu + 1 Number of segments of the next higher order

Stream Lengths The length of various stream segments was measured order-wise and the total length as well as the mean length of each order were computed. The mean length for the given order was obtained by dividing the total length of the total number of segments of the same order. The mean length ratio in the watershed varies between 1.37 and 18.47 in WS1 and WS4, respectively. The mean stream length of a channel is its dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler 1964). The analysis reveals that the mean length of stream is an increasing trend with increase in order.

Length of Overland Flow Horton (1945) defined this as the length of flow path, projected to the horizontal, of non-channel flow from a point on the drainage divide to a point on the adjacent stream channel. It is the length of overland flow of water before it joins a channel. It is a reverse relationship between drainage density and overland flow. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. The average length of overland flow is approximately half the average distance between stream channels and is therefore approximately equal to half the reciprocal of drainage density.

Table 10.2 Number of streams and bifurcation ratio of the watersheds

Stream order	WS1		WS2		WS3		WS4		WS5		WS6		WS7	
	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio
1	77	4.28	59	3.47	810	4.07	258	4.69	67	7.44	362	4.58	2146	4.13
2	18	3.60	17	4.25	199	4.15	55	4.23	9	3.00	79	3.43	519	4.29
3	5	2.50	4	4.00	48	4.80	13	13.00	3	3.00	23	4.60	121	4.32
4	2	2.00	1		10	10.00	1		1		5	2.50	28	3.50
5	1				1						2	2.00	8	4.00
6											1		2	2.00
7													1	
Mean		3.09		3.91		5.75		7.31		4.48		3.42		3.71
Total	103		81		1068		327		80		472		2825	

Stream order	WS8		WS9		WS10		WS11		WS12		WS13	
	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio	No. of streams	B. ratio
1	1140	4.30	25	6.25	393	4.57	600	4.03	130	5.20	518	3.62
2	265	4.73	4	4.00	86	3.74	149	3.82	25	5.00	143	3.58
3	56	4.67	1		23	3.83	39	3.55	5	2.50	40	3.64
4	12	4.00			6	3.00	11	5.50	2	2.00	11	3.67
5	3	3.00			2	2.00	2	2.00	1		3	3.00
6	1				1		1				1	
Mean		4.14		5.13		3.43		3.78		3.68		3.50
Total	1477		30		511		802		163		716	

B. ratio = Bifurcation ratio

The analysis reveals that the length of overland flow varies between 0.10 and 2.26 in WS11 and WS2, respectively. WS6 to WS13 have low (less than 0.5) overland flow, except WS9, where it is more than one. Horton noted that 'length of overland flow is one of the most important dependent variables affected by both the hydrologic and physiographic development of drainage basins'. It is calculated as:

$$\mathrm{Lo} = 1/2D$$

where

Lo Length of overland flow
D Drainage density

Wandering Ratio This is the ratio between the main stream length along the course to the straight line distance between the two extreme outlets and farthest points in the basin boundary. While this factor broadly indicates the amount of deviation of the main stream from the straight line path, it does not necessarily explain the meandering of the main stream. The wandering ratio in the watershed varies between 1.09 and 1.89 in WS3 and WS4, respectively. The low wandering ratio shows the less time of run-off and vice versa. It is calculated as:

$$\mathrm{Rw} = \mathrm{Msl}/\mathrm{Lb}$$

where

Rw Wandering ratio
Msl Main stream length along the course
Lb Basin length

10.3.2 Aerial Aspects

The aerial aspect of the drainage basin includes drainage area, drainage density, drainage texture, basin shape configuration, constant of channel maintenance (CCM) etc. (Table 10.3).

Drainage Area This represents the area enclosed within the boundary of the watershed divide. The watershed-wise analysis reveals that among 13 watersheds, WS12 has the lowest drainage area – i.e. 3328.4 ha – and WS1 has the largest drainage – i.e. 191,209.1 ha. The drainage area is probably the single most important characteristic for hydrologic design. It reflects the volume of water in the watershed that can be generated from rainfall and the length of the stream drained in it.

Watershed Shape Factor The watershed shape factor was defined as the ratio of the main stream length to the diameter of the circle having the same area as the watershed. The analysis reveals that the watershed shape factor varies between 1.59 and 4.73 in WS12 and WS3, respectively. The lower value shows the higher run-off and is circular in shape, and the higher value shows low run-off and is elongated in shape. It also reflects the drainage pattern of the study area. It is calculated as:

$$\mathrm{Sw} = L/D$$

where

Sw Watershed shape factor
L Main stream length
D Diameter of the basin

Drainage Density This expresses the closeness of the spacing of channels. It is defined as the ratio of the total length of channels of all orders in the basin to the drainage area of the basin. It is affected by factors which control the characteristics of the length of the stream like resistance to weathering, permeability of rock formation, climate, vegetation etc. The analysis reveals that the drainage density in the study area ranges between 0.22 and 4.77 in WS2 and WS11, respectively. These ranges are divided into three classes of low (less than 1.5), medium (1.5–3) and high (more than 3). The low value of drainage density is observed in regions underlined by highly resistant permeable material with vegetative cover and low relief. High-drainage density is observed in the regions of weak and impermeable

Table 10.3 Aerial aspect of Son-Karamnasa interfluves

Watershed number	Drainage density	CCM	Channel frequency	Circularity ratio	Elongation ratio	Watershed shape factor	Form factor	Texture ratio
WS1	0.40	2.49	0.05	0.12	0.78	1.67	0.47	0.44
WS2	0.22	4.51	0.06	0.16	0.48	2.51	0.18	0.35
WS3	0.98	1.02	1.00	0.36	0.23	4.73	0.04	2.77
WS4	0.31	3.25	0.21	0.17	0.51	3.72	0.20	1.24
WS5	0.26	3.89	0.07	0.16	0.62	2.66	0.30	0.43
WS6	1.08	0.92	0.48	0.21	0.50	2.94	0.20	2.25
WS7	1.97	0.51	2.80	0.23	0.49	3.54	0.19	12.01
WS8	1.21	0.83	1.38	0.15	0.70	2.38	0.38	9.05
WS9	0.34	2.94	0.12	0.73	0.32	3.61	0.08	0.17
WS10	2.04	0.49	2.22	0.45	0.56	2.89	0.25	4.98
WS11	4.77	0.21	3.51	0.39	0.72	2.01	0.41	9.04
WS12	2.89	0.35	4.79	0.74	0.94	1.59	0.69	6.43
WS13	2.44	0.41	3.01	0.41	0.46	2.39	0.16	7.43

subsurface material and sparse vegetation and mountain relief. The drainage density is calculated by using the following formula:

$$D = \mathrm{Lu}/A$$

where

D Drainage density
Lu Total stream length of all orders
A Area of the basin in km^2

Stream Frequency Stream frequency is defined as the number of streams per unit area. The analysis reveals that WS1, WS2, WS4, WS5, WS6 and WS9 have low stream frequency; WS3, WS8 and WS10 have medium; and WS7, WS11, WS12 and WS13 have relatively high stream frequency. The higher the stream frequency the more run-off and vice versa. Stream frequency is calculated by using the following formula:

$$\mathrm{Fs} = \mathrm{Nu}/A$$

where

Fs Stream frequency
Nu Total number of streams of all orders
A Area of the basin in km^2

Constant of Channel Maintenance (CCM) This is defined as the ratio between the area of a drainage basin and the total length of all the channels expressed as per km^2. It is equal to the reciprocal of drainage density. This parameter indicates the number of m^2 of watershed surface required to maintain one linear metre of channel. CCM is inverse to the drainage density. The analysis reveals that the values of the CCM vary between 0.21 and 4.51 in WS11 and WS2, respectively. It means that 0.21 and 4.51 m^2 surfaces require maintenance of 1 m of the channel in WS11 and WS2, respectively. The higher value indicates that the channel capacity should be large enough to carry a higher discharge resulting from the bigger drainage area. It is calculated as:

$$C = 1/D$$

where

C CCM
D Drainage density

Drainage Texture This is the total number of stream segments of all orders per perimeter of that area (Horton 1945). It is the coarseness or fineness of the dissection of the drainage network. The drainage texture of the watersheds varies between 0.17 and 12.01 in WS9 and WS7, respectively. Smith (1950) has classified drainage density into five different textures: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8). According to Smith's classification method, WS1, WS2, WS4, WS5 and WS9 have very coarse density; WS3 and WS6 have coarse; WS4 has moderate; WS12, WS13 have fine; and WS7 and WS8 have very fine (Table 10.3). Horton recognised infiltration capacity as the single most important factor which influences drainage texture, and considered drainage texture to include drainage density and stream frequency. It is calculated as follows:

$$\mathrm{Rt} = \mathrm{Nu}/P$$

where

Rt Drainage texture
Nu Total number of streams of all orders
P Perimeter in km

Form Factor This is defined as the ratio of basin area to the square of basin length (Horton 1945). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). In the study area, it ranges between 0.04 and 0.69 in WS3 and WS12, respectively. The WS9 and WS3 have a low form factor; WS2, WS4, WS5, WS6, WS7, WS10 and WS13 have medium; and WS1, WS8, WS11 and WS12 have high. The analysis also reveals that the smaller the value of form factor, the more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas elongated sub-watersheds with low form factors have lower peak flows of longer duration. Flood flows of such elongated basins are easier to manage than those of the circular basin. The form factor is a dimensionless parameter and is computed as:

$$\mathrm{Rf} = A/\mathrm{Lb}^2$$

where

Rf Form factor
A Area of the basin in km^2
Lb Basin length

Circulatory Ratio Basin circularity ratio is defined as the ratio of the basin area to the area of a circle having a circumference equal to the perimeter of the basin. It is influenced by the length and frequency of streams, geological structures, land use/cover, climate, relief and slope of the basin. The circulatory ratio approaching to 1 resembles the basin shaped like a circle. The circularity ratio in the study area ranges between 0.12 and 0.74 in WS1 and WS12, respectively. It is computed as the ratio of basin area to the area of a circle having the same perimeter as the basin. The higher circularity ratio also indicates the larger amount of flow and vice versa. It is calculated as follows:

$$\mathrm{Rc} = 4 * \mathrm{Pi} * A/P^2$$

where

Rc Circulatory ratio
Pi Pie value i.e. 3.14
A Area of the basin in km^2
P Perimeter in km

Elongation Ratio This is defined as the ratio between the diameter of a circle with the same area as the basin and basin length. The value of elongation ratio with 1 resembles the circular shape of a basin. A circular basin is more efficient in run-off discharge than an elongated basin (Singh and Singh 1997). The value of elongation ratio in the study area varies between 0.23 and 0.94 in WS3 and WS12, respectively and is associated with a wide variety in climate and geology. Values close to 1.0 are typical of regions of very low relief whereas those of 0.6 to 0.9 values are associated with high relief and steep ground slope (Strahler 1964). Higher value of elongation ratio indicates mature- to old-stage topography and has a circular shape. It is calculated as follows:

$$\text{Elongation Ratio (Re)} = 2\sqrt{(A/\text{Pi})}/\text{Lb}$$

where

Re Elongation ratio
A Area of the basin in km^2
Pi Pie value, i.e. 3.14
Lb Basin length

10.3.3 Relief Aspects

The parameters covering the relief aspects of the basins and channel networks are as follows:

Basin Relief This is the maximum vertical distance from the stream mouth to the highest point on the divide. Basin relief has been defined in several ways. Schumm (1956) measured it along the longest dimension of the basin parallel to the principal drainage line whereas Strahler (1954, 1957) obtained it by determining the mean height of the entire watershed divide about the outlet. In the Son-Karamnasa interfluve, basin relief ranges between 38.44 and 593.96 m in WS1 and WS7, respectively. WS1, WS2 and WS5 have low basin relief; WS9 to WS11 and WS12 have medium; and WS3, WS4, WS6 to WS8 and WS13 have high. Relief is an indicator of the potential energy of a given watershed about a specified datum available to move water and sediment down slope. It is calculated as:

$$\text{Maximum basin relief} = \text{He} - \text{Le}$$

where

He Highest point in the basin
Le Lowest point in the basin

Relief Ratio The ratio between the basin relief and the basin length is known as relief ratio. In a normal-shaped basin, the relief ratio is a dimensionless height – the length ratio is equal to the tangent of the angle formed by the intersection at the basin mouth of a horizontal plane passing through the highest point on the divide. The relief ratio in the watershed varies between 0.03 and 1.75 in WS12 and WS2, respectively (Table 10.4).

The WS1 and WS2 have the highest relief ratios; WS5 has medium; and the others have low. This parameter permits comparison of the relief of the two basins without regard to the

Table 10.4 Relief aspect of Son-Karamnasa interfluve

Watershed	Highest value (in m)	Lowest value (in m)	Basin relief (in m)	Relief ratio	Relative relief
WS1	89.09	50.65	38.44	1.67	0.16
WS2	98.18	48.25	49.93	1.75	0.22
WS3	583.42	44.43	538.99	0.30	1.40
WS4	510.71	59.93	450.78	0.20	1.71
WS5	145.87	59.51	86.36	0.73	0.46
WS6	487.38	61.75	425.63	0.17	2.03
WS7	626.73	32.77	593.96	0.12	2.53
WS8	482.20	59.69	422.51	0.13	2.59
WS9	322.13	51.62	270.51	0.20	1.51
WS10	445.10	92.69	352.42	0.09	3.43
WS11	623.42	354.10	269.31	0.09	3.03
WS12	632.04	354.10	277.94	0.03	10.97
WS13	644.55	89.96	554.59	0.07	5.75

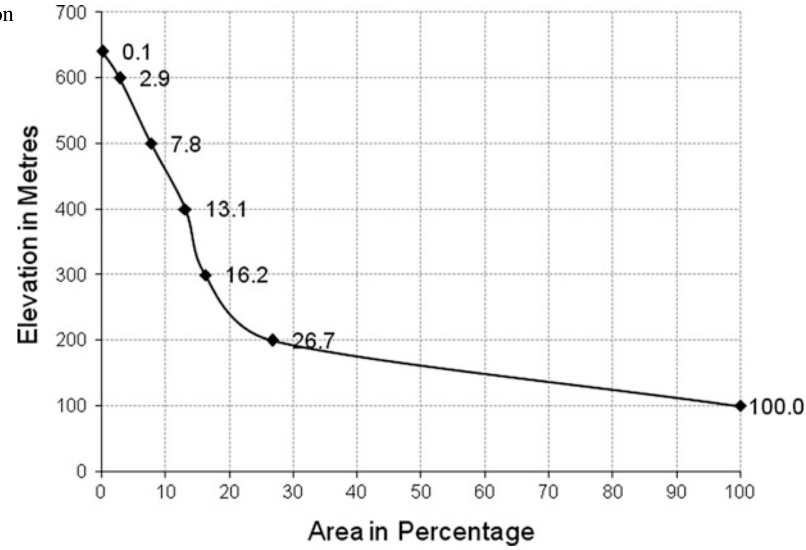

Fig. 10.2 Area and elevation of the Son-Karamnasa interfluve

scale of the topographical sheet. It measures the overall steepness of the watershed and can be related to its hydrologic characteristics. It is calculated as:

$$\text{Relief ratio (Rh)} = H/\text{Lb}$$

where

Rh Relief ratio
H Total relief (relative relief) of the basin in km
Lb Basin length

Area Elevation Relation Distribution of areas between contours in a drainage basin is of interest for comparing drainage basins and to understand the storage and flow characteristics of the basin. For that purpose, an area distribution curve can be obtained by a computer system itself in-between contours. The mean elevation is determined as the weighted average of elevations between adjacent contours. In the Son-Karamnasa interfluve, about 73.26% of the area below 200 m above mean sea level is almost plain. Around 26.74% of the area above 200 m above mean sea level has a very high slope (Fig. 10.2).

Relative Relief This is defined as the ratio of the basin relief to the length of the perimeter. Relative relief is an indicator of the general steepness of a basin from summit to mouth. The analysis reveals that the value ranges between 0.16 and 10.97 in WS1 and WS12, respectively. It has an advantage over the relief ratio in that it is not dependent on the basin length. It is calculated by using the formula given by Melton (1957) as below:

$$\text{Rr} = 100H/5280P$$

where

Rr Relative relief
H Basin relief
P Perimeter

10.4 Watershed Prioritisation

The morphometric analysis is a significant tool for prioritising micro-watersheds even without considering the soil map (Biswas et al. 1999). Drainage patterns refer to spatial relationships among streams or rivers, which may be influenced in their erosion by inequalities of slope,

Table 10.5 Prioritisation of watershed in the Son-Karamnasa interfluve

Watershed	Drainage density	Channel frequency	Mean bifurcation ratio	Circularity ratio	Elongation ratio	Form factor	Texture ratio	Watershed shape factor	Length of overland flow	Compactness ratio	Total value	Compound value	Priority
WS1	9	13	1	13	2	2	10	2	5	3	60	6	4
WS2	13	12	8	10	10	10	12	6	1	6	88	8.8	10
WS3	8	7	12	6	13	13	7	13	6	13	98	9.8	13
WS4	11	9	13	9	7	7	9	12	3	8	88	8.8	11
WS5	12	11	10	11	5	5	11	7	2	4	78	7.8	9
WS6	7	8	2	8	8	8	8	9	7	9	74	7.4	8
WS7	5	4	6	7	9	9	1	10	9	11	71	7.1	7
WS8	6	6	9	12	4	4	2	4	8	2	57	5.7	3
WS9	10	10	11	2	12	12	13	11	4	12	97	9.7	12
WS10	4	5	3	3	6	6	6	8	10	10	61	6.1	5
WS11	1	2	7	5	3	3	3	3	13	5	45	4.5	2
WS12	2	1	5	1	1	1	5	1	12	1	30	3	1
WS13	3	3	4	4	11	11	4	5	11	7	63	6.3	6

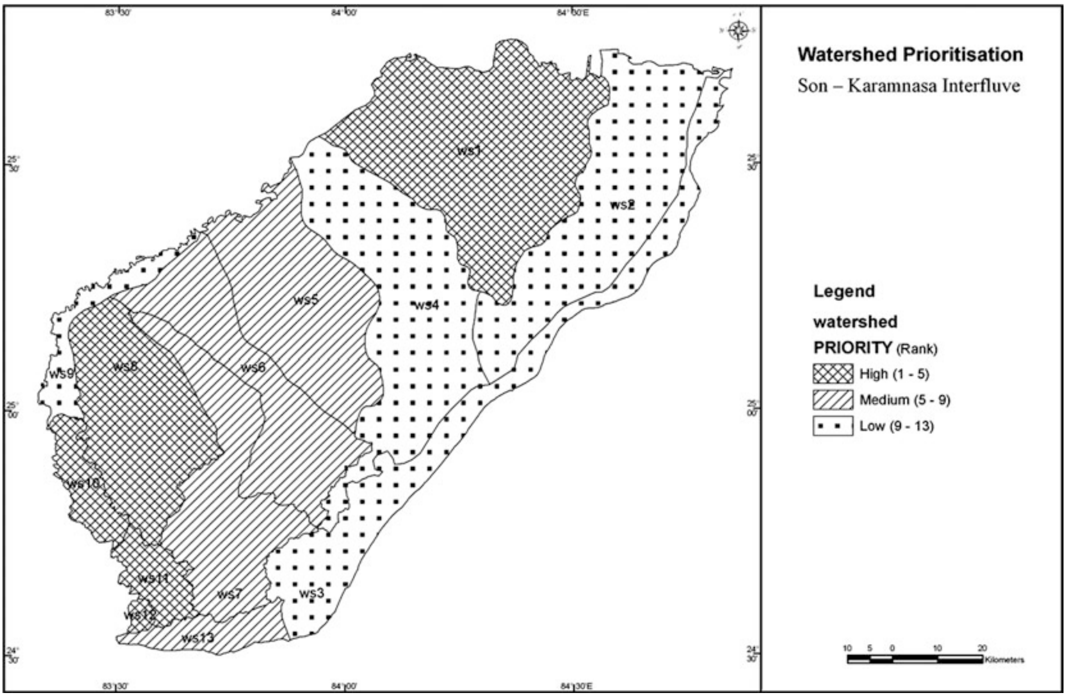

Fig. 10.3 Watershed prioritisation

soil, rock resistance, structure and the geologic history of a region. Linear parameters have a direct relationship with run-off and erodability. The higher the value, the more erodability. The highest value of the linear parameter was rated as rank 1, the second highest value as rank 2 etc. On the other hand, the shape parameters have an inverse relation with run-off and erodability, i.e. the lower the value, the more erodability. Thus, the value of the parameter was rated as rank 1 and the second lowest as rank 2 etc. The ranks of all the morphometric parameters were added up for each of the watersheds to arrive at a compound parameter. The priority of the watershed has been determined by ranking the compound value—i.e. a lower compound value has higher priority (Table 10.5; Fig. 10.3). The analysis reveals that there are three categories of priorities of the watershed: high (WS1, WS8 and WS10 to WS12), medium (WS5 to WS7 and WS13) and low (WS2 to WS4 and WS9).

10.5 Conclusion

Remote sensing and GIS have proven to be efficient tools in drainage delineation and analysing morphometric characteristics. The morphometric parameters of different aspects, such as linear and relief, show different characteristics of the watershed. These different characteristics can be used to interpret the geologic conditions responsible for how the pattern is controlled by, and in turn has an influence on, the hydrology of the drainage basin. The ten morphometric parameters – drainage density, stream frequency, texture ratio, bifurcation ratio, watershed shape factor, overland flow, circularity ratio, elongation ratio, form factor and compactness ratio – are used for prioritisation of the watershed in high, medium and low categories. The land and water resource development plan should be applied on the basis of priority of the watershed.

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11 SDG 13: Case Study – Monitoring and Assessment of Flood-Inundated Areas

Abstract

Spatial information technology has the capability to monitor and assess natural calamities such as floods, droughts, forest fires, cyclones etc. Floods are one of the most devastating natural calamities, causing extensive damage to life, property, soil, biodiversity, cropland etc. Floods are weather-related disasters, which are usually difficult to predict as definite trends in river basins, especially with regard to the time and place of occurrence, are not stable. The present study deals with the application of remote sensing and GIS in flood monitoring and assessment of flood-inundated areas in the middle Ganga plain in Bihar, India. Overlay analysis and image classification methods have been used for better understanding the flood-inundated areas in *kharif* as well as *rabi* seasons. The analysis reveals 238,191.6 ha of land affected by flood. Near real-time information can be very useful for suitable planning that can minimize damage from floods.

Keywords

Disaster · Monsoon · Flood mapping · Middle ganga plain · Crop damage assessment

11.1 Introduction

Sustainable Development Goal (SDG) 13 urges action to combat climate change and its impacts, to address natural calamities, and unprecedented effects disproportionately burdened by the poorest and the most vulnerable. Urgent action is required to combat these natural disasters for humankind. Weather-related disasters such as floods alone accounted for 47% of all weather-related disasters during 1995–2015, affecting 2.3 billion people. Among these, 95% live in Asia. In 2007, floods killed 3300 people in India and Bangladesh alone. In 2010, flooding killed 2100 people in Pakistan and another 1900 in China, while in 2013 some 6500 people died due to floods in India. Floods are major natural calamities. Monsoon floods are common in Indian rivers, which are governed directly by the effects of monsoon rhythm. Bhan et al. (2001) have assessed flood-inundated areas in West Bengal. For quick appraisal of the dynamic nature of a flood plain, it is necessary to use remote-sensing data either in visual or digital interpretations for correct estimates in order to make environmental assessments in an effective way (Singh and Kumar 2004). Waterlogging is one of the major land-degradation processes that

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restrict the economic and efficient utilisation of land resources. Since independence, various irrigation schemes were launched to fulfil the requirement of water for agriculture and drinking purposes. Obstruction of natural drainage by way of construction of roads, railways, aerodrome, various structures etc. is reason to consider monsoon run-off on the upstream. Intensive irrigation without adequate drainage subsequently results in the rise of groundwater tables (Mehta 2000). Goyal et al. (2005) attempted to estimate waterlogging and salt-affected areas in the command area of the Ravi–Tawi irrigation complex in the Jammu region. Waterlogging and subsequent salinisation and/or alkalisation are the major land-degradation problems in the irrigation commands of the semi-arid regions. Information on the nature, extent and spatial distribution of waterlogged areas is thus a prerequisite for restoration of fertility in the soil. Dwivedi et al. (2007) have delineated and monitored the spatial distribution patterns of waterlogged areas in the Mahanadi command stage-I area, covering parts of Orissa by using multi-spectral, multi-temporal satellite imagery.

11.2 Study Area

The present study area is part of the middle Ganga plain and is categorised into 13 watersheds; administratively it covers four districts of South-west Bihar, i.e. Bhojpur, Buxar, Bhabhua and Rohtas. The total annual average rainfall ranges between 1100 and 1200 mm (Kumar 2017). It is also a confluence zone of many rivers that contribute to flooding in low-lying areas. The study area is covered by a river from all directions, and waterlogging problems frequently occur along the river, and usually coincide with the maturity period of the *kharif* crops. In fact, the acreage of the flood-affected area has increased since independence in Bihar. In 1952, the flood-affected area was 2.5 million ha. It increased to 6.9 million ha in 1994 and to about 9.0 million ha in 1999. It appears that heavy rainfall in Nepal has contributed to the floods in North Bihar through several tributaries emerging in Nepal and flowing through the state of Bihar before joining the Ganga (Rai 2002). In South Bihar, one of the worst flood-affected areas is Bhojpur, which is surrounded by the river Ganga in the North-west and the river Son in the East, South and South-east. The river Ganga is joined by many tributaries in the North and gets flooded in the rainy season. It is difficult for it to receive additional water from the river Son and river Ghaghara, which flow from South to North and from North-west to South-east, respectively and join the river Ganga near Patna. In monsoon, both rivers get heavily flooded and because of weak embankments, water overflows spread where most of the district becomes completely inundated and submerged underwater, causing irreparable damage to life, property and animals. The river Karamnasa, though small and seasonal, swells in rainy season causing floods in its surroundings (Bawa 1980).

11.3 Data Sources and Methodology

Remote-sensing technologies are useful and desirable tools to apply during the planning processes. The primary objective of remote-sensing methods is to provide planners and disaster management institutions with a practical and cost-effective way to identify the extent of floodplains and other susceptible areas and to assess the extent of disaster impact over entire river basins. The method can be used in sectoral planning activities and integrated planning studies, and for damage assessment. The satellite remote-sensing method is one of many flood hazard assessment techniques. For mapping of the flood area of the Son-Karamnasa interfluve, IRS-P6, LISS-III, Path & Row is 103/54 and 104/54 dated 31 October and 5 November 2004, 28 February and 5 March 2005 images are used.

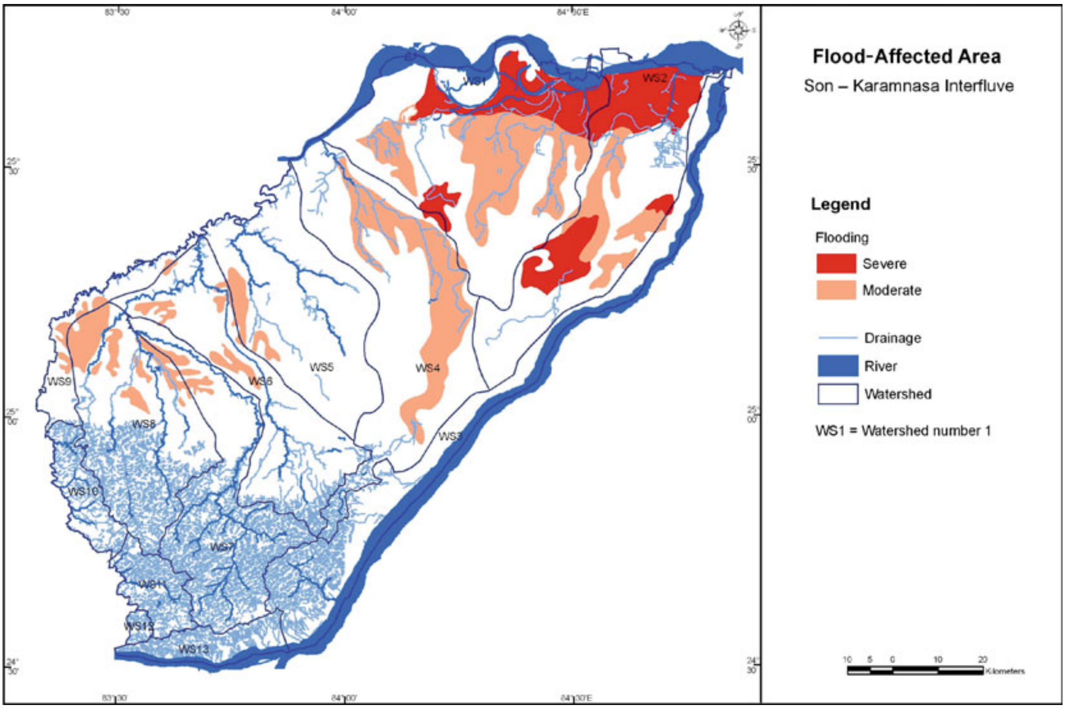

Fig. 11.1 Flood-affected area

Overlay analysis and image-classification methods have been used for better understanding the flood-affected areas.

The flood areas are identified by using overlay analysis of temporal satellite data. In this approach, two Infrared band images are taken. The first image belongs to the *rabi* season (post-flood) data and the second from the *kharif* season (flood period). The composite of these two period data shows numerous colours, black showing the permanent waterbody, red the flood-inundated area in *kharif* season and yellow the areas not affected by the flood. The shades between red and yellow show the flood-affected areas in *rabi* season (Fig. 11.1).

11.4 Analysis and Results

In the Son-Karamnasa interfluve, flooding is considered a serious limitation for agriculture, especially in the northern part of the study area. Past experiences show that the study area comes under low-lying and back-water from the river Karamnasa. The Ganga and Son are considered the main reasons for floods in the area. The tri-junction of the river Ganga and its tributaries – i.e. river Ghaghara and Son – also lead to floods in the region (Haldar et al. 1997). The analysis reveals that there are 238,191.6 ha of land affected by the flood which constitutes

Table 11.1 Areas of different flood intensity

Flooding	Area (in ha)	Area (in %)
Moderately (duration 2–4 months)	160,039.9	14.6
Severe (duration more than 4 months)	78,152.7	7.1
Total	2,38,191.6	21.7

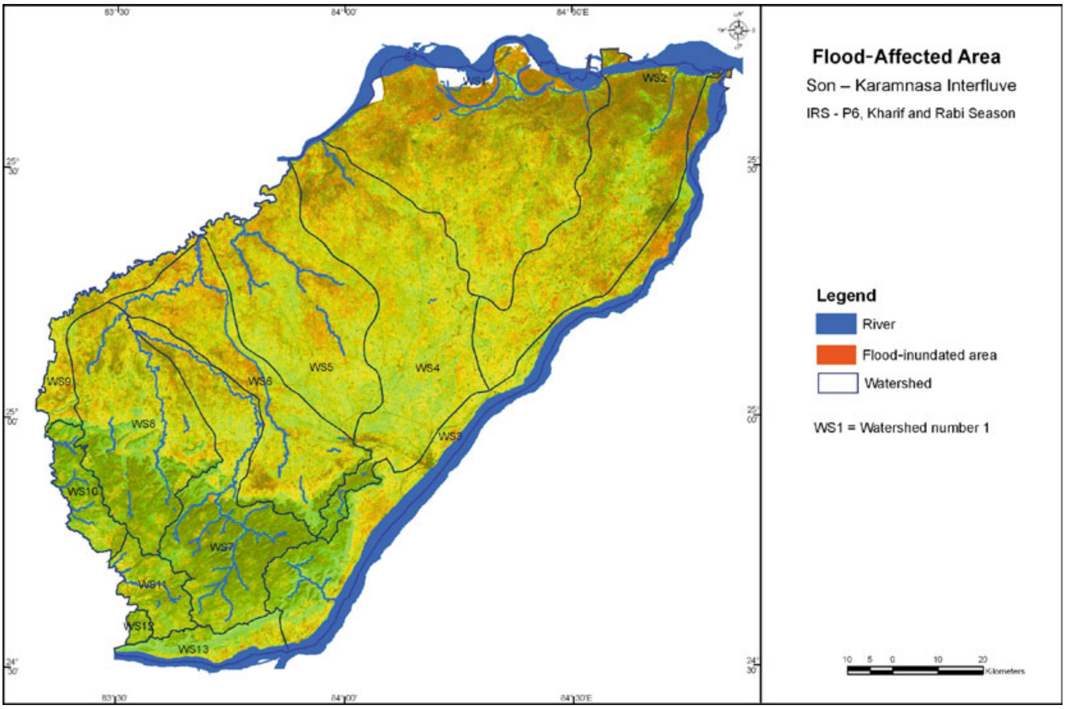

Fig. 11.2 Severity of flood-affected areas

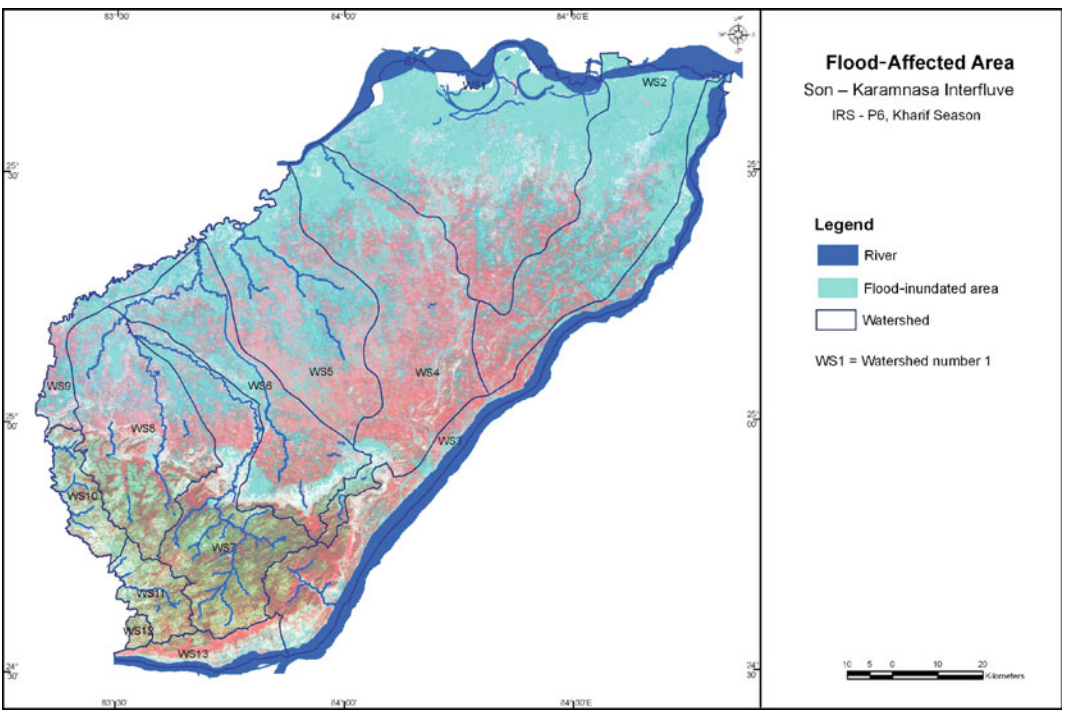

Fig. 11.3 Flood-inundated areas (based on satellite imagery of 2004)

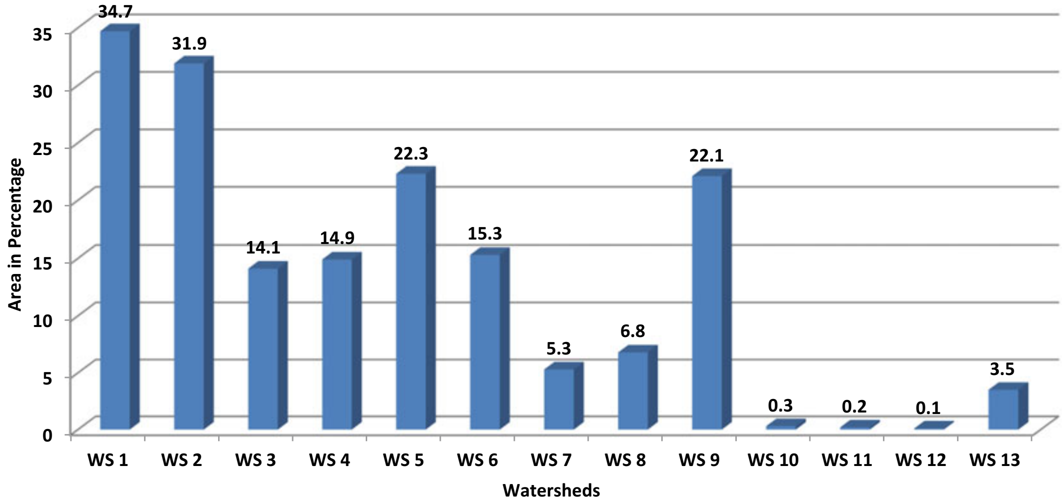

Fig. 11.4 Watershed-wise flood-inundated areas

21.7% of the study area (Table 11.1). Among these, 160,039.9 ha of area has moderate floods and 78,152.7 ha of area has severe floods. Severe floods (more than four months) occur along the river Ganga and river Son in the Bhojpur and Buxar districts (WS1 and WS2) in the northern part of the study area. Bhabhua and Rohtas districts have moderate floods occurring in less than four months, concentrated mainly along the river Karamnasa and its tributaries.

The image-classification method also shows that 18.7% of the total study area is affected by floods (Fig. 11.2). Among this percentage, 5.8% and 4% of the area is affected in WS1 and WS2, respectively. WS4 and WS5 have 2.1% and 2.4% area affected by flood, respectively. The watershed-wise image analysis also reveals that WS1 and WS2 have maximum areas, i.e. more than 30% of the watershed area under floods affected in the current year (Fig. 11.3). In the low-lying areas, the water of the river gets easily spread over the area and, due to poor drainage conditions, waterlogging occurs more than three to four months, and effects the *kharif* as well as *rabi* crops. WS10 to WS13 have less than 5% flood-affected area (Fig. 11.4). These areas are the highlands of the Son-Karamnasa interfluve which covers Kaimur and Rohtas plateau.

11.5 Conclusion

The application of spatial information technology in the monitoring and assessment of flood-inundated areas is very helpful for the management of flood-affected areas. Remote-sensing-based analysis reveals that floods in the study area occur in the low-lying zone along the rivers in the months of September to November, which effects the *kharif* crops and sometimes the *rabi* crops also. The overlay analysis in GIS provides the statistical assessment of watershed-wise flood-inundated areas. Information about the flood-inundated areas is very important in order to plan necessary preventive measures and preparedness for the same. Adequate planning can minimise damage from floods, for which the latest spatial information technology is required.

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SDG 9: Case Study – Infrastructure Assessment for Sustainable Development

12

Abstract

Infrastructure development plays a vital role in achieving Sustainable Development Goals (SDGs) and poverty reduction. The government of India has initiated many rural development schemes from time to time to enhance infrastructure, but after seven decades of independence, there is inadequate basic infrastructure in rural India, where 70% of the Indian population live and provide food security. The study is a part of Bihar State in India covering four districts, Bhojpur, Buxar, Bhabhua and Rohtas, which were selected for green revolution. According to the Census of India (Primary census abstract for Uttaranchal, Bihar and Jharkhand. Office of the Registrar General, India, Government of India, New Delhi, 2001), there were 7,385,362 people constituting 8.9% of the total population of Bihar State and among these 89% of the population are rural. The basic infrastructure was analysed spatially with the help of spatial information techniques to determine the distribution pattern as well as the level of infrastructure development. The results show that infrastructure facilities are not uniformly available. The analysis reveals that there was large regional disparity in infrastructure development.

Keywords

Green revolution · Remote sensing · Geographic information system · Ranking method · Infrastructure

12.1 Introduction

SDG 9 urges the building of resilient infrastructure, the promotion of inclusive and sustainable industrialisation and the fostering of innovation. It also addresses important aspects of sustainable development. Infrastructure development is one of the basic indicators for sustainable development and provides the basic physical facilities for society. The prosperity of an area as well as its people depends on the availability of infrastructure facilities. Thematic information about the infrastructure is also required in the development and implementation process. Similarly, this information is prerequisite to understand the distribution pattern and concentration of basic amenities available in the study area, and to assess the level of development or backwardness (National Remote Sensing Agency 1995). Basic infrastructure and services such as education, health, drinking water, communication and

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electricity facilities etc. play a vital role in the development process. The absence of these basic amenities indicates the level of backwardness. In respect of these facilities, the distance a villager has to travel to reach such facilities and the mode of transport available for such travel can be an indicator for the inadequacy of such facilities or services, also indicating the level of development. Remote sensing provides the spatial database of various resources and GIS helps in formulating urban development plans (Singh and Grover 2014; Singh et al. 2014). These are used interactively in a complementary way in infrastructure assessment and development.

12.2 Study Area

The extent of the study area lies between 83° 19′ 38′ East to 84° 51′ 03′ East longitude and 24° 30′ 11′ North to 25° 45′ 34′ North latitude covering four districts of administration, i.e. Bhojpur, Buxar, Bhabhua (Kaimur) and Rohtas of Bihar State in India. Earlier the study area was known as Shahabad district and selected for green revolution (Chopra 1986). In 1972, the Shahabad district was bifurcated into two districts, viz. Rohtas and Bhojpur. In 2001, these two districts were further divided into two parts each: Bhojpur district was subdivided into Bhojpur and Buxar districts; Rohtas district was subdivided into Rohtas and Bhabhua. Physiographically, it is broadly divided into alluvial plains and plateaus where alluvial plains are considered productive land for agriculture, producing good crops.

This region is considered the best wheat-growing and rice-bowl area in the state. The Rohtas plateau is a relatively more dissected and highly underdeveloped region. The foothill plains are mostly used for summer pastures. The Kaimur limestone and Amjhor pyrites tend to provide opportunities for economic development (Singh 1989). There are 28 perennial and 62 non-perennial rivers and streams in the study area. The Indrapuri barrage on the river Son enhances the agricultural prosperity of the southern part of the Bhojpur plain. There are three sources for obtaining underground water: surface well, deep tube-well and springs (Kumar 2008). The months of April and May are extremely hot, and monsoon marks its presence from the end of June to the end of September. The cold weather begins from the month of November and remains till March. The maximum average temperature in summer is 39 °C and the minimum 16 °C during winter. The average rainfall recorded during monsoon period is in the proximity of 1000 mm. There is very little rainfall in the months of October, January and February. The irrigated and un-irrigated areas, except the hills and forests, are being exploited for cultivation. Rice, wheat, barley, grams and pulses are the main crops of the study area. The study area is connected with roads and railways with all the major towns in the state as well as country. According to Census of India (2001), the total population of the study area was 7,370,214, that is 8.9% of the total population of Bihar State. The population density of the study area was 696 people per km^2 while the literacy rate was 58.8%, and among these 73.7% were males and 42.2% were females in the census year 2001. The land of the study area is naturally rich, but the people are poor due to the regional disparities in the distribution pattern of the infrastructure.

12.3 Data Sources and Methodology

Various databases have been used from different agencies—Survey of India, National Atlas & Thematic Mapping Organisation, Bihar Remote Sensing Application Centre, National Remote Sensing Centre, District Administration, Statistics and Agriculture Departments of Bhojpur, Rohtas, Bhabhua and Buxar districts in Bihar, Census of India etc. The primary survey was done for the field verifications and collection of the coordinate information was done using global positioning system (GPS) by transit survey method along the road network in the study area.

Various methodologies were put to use for the study. The hard-copy database was converted into raster format and digitised in a GIS environment with different thematic layers, such as administrative boundaries of the study area, roads, railways, canals, drainage, rivers etc. on a 1:50,000 scale. These different maps were geo-referenced with polyconic projection to prepare for analysis. The drainage and road network map was updated by digital image processing from the satellite data of IRS-P6 LISS III. The Path/Row is 103/54 and 104/54, dated 31 October 2004 and 5 November 2004 for *kharif* season, 28 February 2005 and 5 March 2005 for *rabi* season, which is procured from the National Remote Sensing Centre. The level of infrastructure development has been calculated by facilities such as education, health, drinking water, postal service, telegraph and telephone connection, transport communication and power availability in the study area. The ranking method was used to find the level of infrastructure development. The greater the value, the higher the rank and vice versa (Table 12.1).

12.4 Results and Analysis

The study area is very rich according to geo-environmental conditions. The analyses of individual amenities are given below.

12.4.1 Education Facility

An average of 56.9% (Fig. 12.1) of villages have education facilities, such as primary, middle, secondary, senior secondary, college, training school and other education facilities of the study area. The village-wise availability of education facilities has been categorised into high, medium and low. The analysis reveals that most of the blocks in the Bhojpur district have a high (more than 70% of villages) education facility. The analysis also reveals that the numbers of educational facilities in the villages are decreasing towards the western and southern parts of the study area. SDG 4 addresses inclusive and equitable quality of education and promotes lifelong learning opportunities for all. This SDG focuses on the acquisition of foundational and higher-order skills at all stages of education and development; greater and more equitable access to quality education at all levels; technical and vocational education and training; and the knowledge, skills and values needed to function well and contribute to society.

12.4.2 Medical Facility

Medical facilities such as allopathic, ayurveda, unani, homeopathic hospitals, dispensary, child and family welfare centres, primary health centres, are all available in the study area. On average, 9.9% villages in a block level have medical facilities. The analysis reveals that Bhagwanpur and Rampur blocks in the plateau area have fewer (less than 5% of villages) medical facilities. The analysis also reveals that the central part of the study area has fewer medical facilities, including the blocks Chausa, Itarhi, Kesath, Kochas, Dinara, Dawath, Bikramganj, Sanjhaulu, Karakat and Garhani (Fig. 12.2). SDG 3 seeks to ensure healthy lives and promotes well-being for all at all ages of life by improving reproductive, maternal and child health; ending the epidemics of major communicable diseases; reducing non-communicable and environmental diseases; achieving universal health coverage; and ensuring access to safe, affordable and effective medicines and vaccines for all. This should be possible by increasing medical facilities for the villages.

12.4.3 Drinking Water Facility

SDG 6 aims to ensure availability and sustainable management of water and sanitation for all. In 2015, 91% of the global population had access to an improved drinking water source. There are various sources of drinking water facilities in the study area such as tap, well, tank, tube-well, hand pump, river, canal, lake spring and other drinking water sources in the study area. On average, 79.6% of villages in the study area have drinking water facilities available from different sources. The highest, 82.9%, of villages lie in the Rohtas district and the lowest, 72.2%, of villages in the

Table 12.1 Infrastructure facilities

Block/district name	Number of villages	Education No. of villages (%)	Medical No. of villages (%)	Drinking water No. of villages (%)	Post and telegraph No. of villages (%)	Communication No. of villages (%)	Power/electricity No. of villages (%)	Ranking
Sahpur	137	70 (51.1)	17 (12.4)	86 (62.8)	25 (18.3)	16 (11.7)	22 (16.1)	21.3
Arrah	115	84 (73.0)	18 (15.7)	90 (78.3)	28 (24.4)	26 (22.6)	41 (35.7)	37.2
Barahara	79	56 (70.9)	9 (11.4)	58 (73.4)	19 (24.1)	10 (12.7)	5 (6.3)	24.8
Koilwar	71	58 (81.7)	9 (12.7)	61 (85.9)	36 (50.7)	17 (23.9)	43 (60.6)	45.2
Sandesh	54	41 (75.9)	15 (27.8)	47 (87.0)	21 (38.9)	22 (40.7)	8 (14.8)	42.3
Udwantnagar	76	63 (82.89)	5 (6.6)	69 (90.8)	19 (25.0)	25 (32.9)	22 (29.0)	38.7
Behea	98	59 (60.2)	5 (5.1)	78 (79.6)	21 (21.4)	15 (15.3)	46 (46.9)	29.0
Jagdishpur	91	64 (70.3)	5 (5.5)	77 (84.6)	26 (28.6)	23 (25.3)	2 (2.2)	30.3
Piro	109	98 (89.9)	21 (19.3)	101 (92.7)	40 (36.7)	16 (14.7)	15 (13.8)	41.7
Charpokhari	90	57 (63.3)	6 (6.7)	73 (81.1)	17 (18.9)	10 (11.1)	1 (1.1)	21.8
Garhani	54	44 (81.5)	0 (0.0)	48 (88.9)	16 (29.6)	7 (13.0)	11 (20.4)	30.5
Agiaon	72	64 (88.9)	7 (9.7)	68 (94.4)	18 (25.0)	30 (41.7)	17 (23.6)	42.7
Tarari	115	86 (74.7)	7 (6.1)	92 (80.0)	25 (21.7)	19 (16.5)	14 (12.2)	26.3
Sahar	56	49 (87.5)	9 (16.1)	51 (91.1)	15 (26.8)	13 (23.2)	0 (0.0)	39.2
Bhojpur district	**1217**	**893 (73.4)**	**133 (10.9)**	**999 (82.1)**	**326 (26.8)**	**249 (20.5)**	**247 (20.3)**	
Simri	156	56 (35.9)	15 (9.6)	88 (56.4)	25 (16.0)	12 (7.7)	46 (29.5)	17.0
Chakki	28	10 (35.7)	2 (7.1)	10 (35.7)	2 (7.1)	1 (3.6)	9 (32.1)	11.3
Barhampur	94	25 (26.6)	16 (17.0)	64 (68.1)	24 (25.5)	16 (17.0)	26 (27.7)	26.5
Chaugain	23	20 (87.0)	3 (13.0)	20 (87.0)	8 (34.8)	2 (8.7)	9(39.1)	39.0
Kesath	15	12 (80.0)	0 (0.0)	15 (100.0)	4 (26.7)	6 (40.0)	10 (66.7)	41.3
Dumraon	93	55 (59.1)	15 (16.1)	68 (73.1)	19 (20.4)	9 (9.7)	42 (45.2)	29.0
Buxar	142	66 (46.5)	9 (6.3)	101 (71.1)	24 (16.9)	8 (5.6)	53 (37.3)	18.2
Chausa	73	36 (49.3)	1 (1.4)	51 (69.9)	12 (16.4)	3 (4.1)	14 (19.2)	12.5
Rajpur	236	107 (45.3)	18 (7.6)	175 (74.2)	25 (10.6)	4 (1.7)	36 (15.3)	12.5
Itarhi	167	91 (54.5)	7 (4.2)	132 (79.0)	19 (11.4)	12 (7.2)	48 (28.7)	18.5
Nawanagar	107	68 (63.6)	9 (8.4)	95 (88.8)	25 (23.4)	19 (17.8)	25 (23.4)	33.0
Buxar district	**1134**	**546 (48.2)**	**95 (8.4)**	**819 (72.2)**	**187 (16.5)**	**92 (8.1)**	**318 (28.0)**	
Ramgarh	126	56 (44.4)	32 (25.4)	94 (74.6)	19 (15.1)	8 (6.4)	84 (66.7)	25.2
Nuaon	107	46 (43.0)	10 (9.4)	82 (76.6)	13 (12.2)	10 (9.4)	53 (49.5)	21.3
Kudra	159	79 (49.7)	42 (26.4)	130 (81.8)	15 (9.4)	9 (5.7)	70 (44.0)	26.5
Mohania	209	95 (45.5)	55 (26.3)	158 (75.6)	24 (11.5)	36 (17.2)	110 (52.6)	29.3
Durgawati	108	65 (60.2)	14 (13.0)	90 (83.3)	9 (8.3)	9 (8.3)	77 (71.3)	28.5
Chand	137	66 (48.2)	19 (13.9)	115 (83.9)	13 (9.5)	26 (19.0)	32 (23.4)	27.0
Chainpur	177	83 (46.9)	12 (6.8)	147 (83.1)	26 (14.7)	19 (10.7)	52 (29.4)	23.0
Bhabhua	286	131 (45.8)	21 (7.3)	218 (76.2)	28 (9.8)	27 (9.4)	98 (34.3)	18.5
Rampur	150	58 (38.7)	5 (3.3)	115 (76.7)	11 (7.3)	17 (11.3)	19 (12.7)	11.5

(continued)

Table 12.1 (continued)

Block/district name	Number of villages	Education No. of villages (%)	Medical No. of villages (%)	Drinking water No. of villages (%)	Post and telegraph No. of villages (%)	Communication No. of villages (%)	Power/electricity No. of villages (%)	Ranking
Bhagwanpur	122	55 (45.1)	2 (1.6)	94 (77.1)	3 (2.5)	4 (3.3)	47 (38.5)	13.0
Adhaura	131	71 (54.2)	13 (9.9)	106 (80.9)	2 (1.5)	10 (7.6)	3 (2.3)	16.2
Bhabhua district	**1712**	**805 (47.0)**	**225 (13.1)**	**1349 (78.8)**	**163 (9.5)**	**175 (10.2)**	**645 (37.7)**	
Kochas	176	77 (43.8)	2 (1.1)	135 (76.7)	9 (5.1)	28 (15.9)	4 (2.3)	11.0
Dinara	229	117 (51.1)	9 (3.9)	180 (78.6)	37 (16.2)	24 (10.5)	15 (6.6)	16.8
Dawath	66	47 (71.2)	2 (3.0)	60 (90.9)	7 (10.6)	3 (4.6)	7 (10.6)	19.5
Suryapura	48	28 (58.3)	6 (12.5)	39 (81.3)	5 (10.4)	0 (0.0)	6 (12.5)	18.8
Bikramganj	100	59 (59.0)	1 (1.0)	81 (81.0)	13 (13.0)	18 (18.0)	24 (24.0)	23.2
Karakat	150	107 (71.3)	2 (1.3)	128 (85.3)	31 (20.7)	22 (14.7)	34 (22.7)	26.7
Nasriganj	52	47 (90.4)	9 (17.3)	51 (98.1)	22 (42.3)	14 (26.9)	15 (28.9)	48.3
Rajpur	39	33 (84.6)	13 (33.3)	36 (92.3)	9 (23.1)	8 (20.5)	5 (12.8)	40.7
Sanjhauli	45	36 (80.0)	2 (4.4)	41 (91.1)	10 (22.2)	5 (11.1)	17 (37.8)	33.2
Nokha	87	66 (75.9)	11 (12.6)	80 (92.0)	19 (21.8)	23 (26.4)	17 (19.5)	38.0
Kargahar	257	126 (49.0)	22 (8.6)	198 (77.0)	26 (10.1)	25 (9.7)	14 (5.5)	16.0
Chenari	155	62 (40.0)	15 (9.7)	113 (72.9)	11 (7.1)	21 (13.6)	48 (31.0)	17.8
Nauhatta	68	47 (69.1)	9 (13.2)	65 (95.6)	6 (8.8)	5 (7.4)	18 (26.5)	28.7
Sheosagar	199	104 (52.3)	16 (8.0)	156 (78.4)	33 (16.6)	34 (17.1)	45 (22.6)	24.7
Sasaram	171	103 (60.2)	9 (5.3)	144 (84.2)	21 (12.3)	24 (14.0)	67 (39.2)	27.8
Akorhi Gola	58	49 (84.5)	3 (5.2)	53 (91.4)	13 (22.4)	13 (22.4)	28 (48.3)	39.0
Dehri	58	50 (86.2)	7 (12.1)	58 (100)	20 (34.5)	30 (51.7)	51 (87.9)	49.7
Tilouthu	66	35 (53.0)	10 (15.2)	58 (87.9)	11 (16.7)	14 (21.2)	55 (83.3)	37.8
Rohtas	38	28 (73.7)	5 (13.2)	34 (89.5)	10 (26.3)	9 (23.7)	23 (60.5)	43.5
Rohtas district	**2062**	**1221 (59.2)**	**153 (7.4)**	**1710 (82.9)**	**313 (15.2)**	**320 (15.5)**	**493 (23.9)**	

Source Analysis derived from Census of India (2001)

Buxar district have this facility. The analysis reveals that less than 75% of villages in most of the blocks in Buxar district have drinking water facilities (Fig. 12.3).

12.4.4 Transport Communication

Transport communication includes bus and railway services, navigation by waterway through rivers and canals etc. A huge number of benefits is accredited to rural road and transport development, including increased agricultural production, growth of dairying, rural industrialisation, better education and higher life expectancy etc. On average, 13.7% of villages have direct transport communication facilities either by bus or rail services (Fig. 12.4). The highest percentage of villages, 20.5%, is in Bhojpur district while the lowest, 8.1%, is in Buxar district, which have

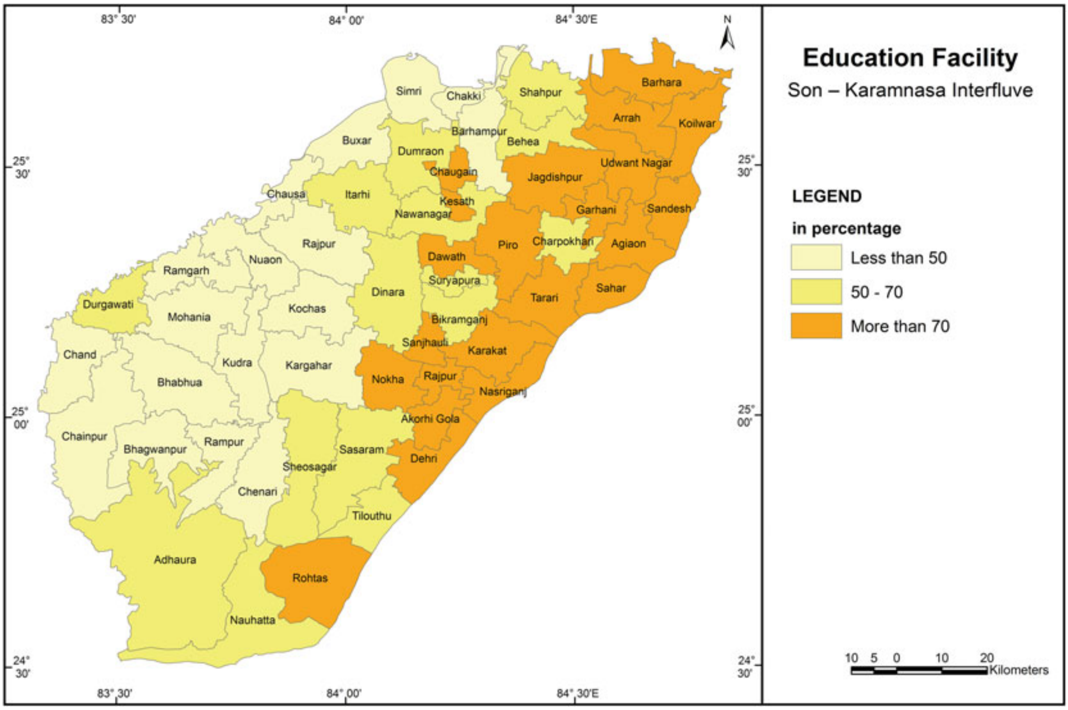

Fig. 12.1 Educational facility

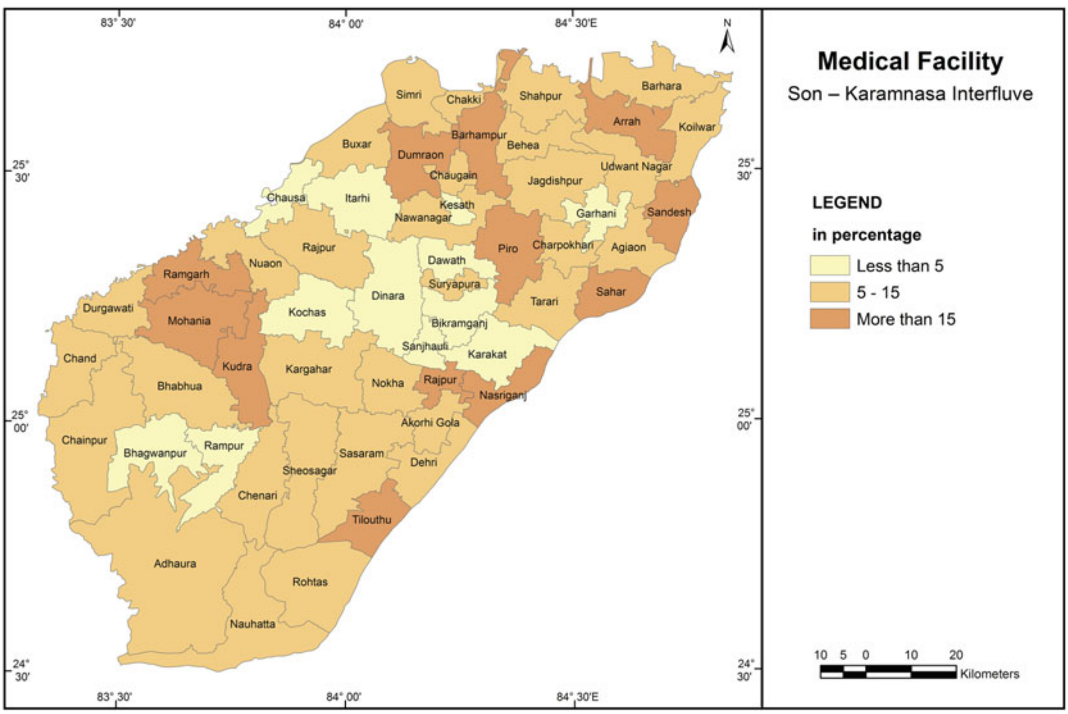

Fig. 12.2 Medical facility

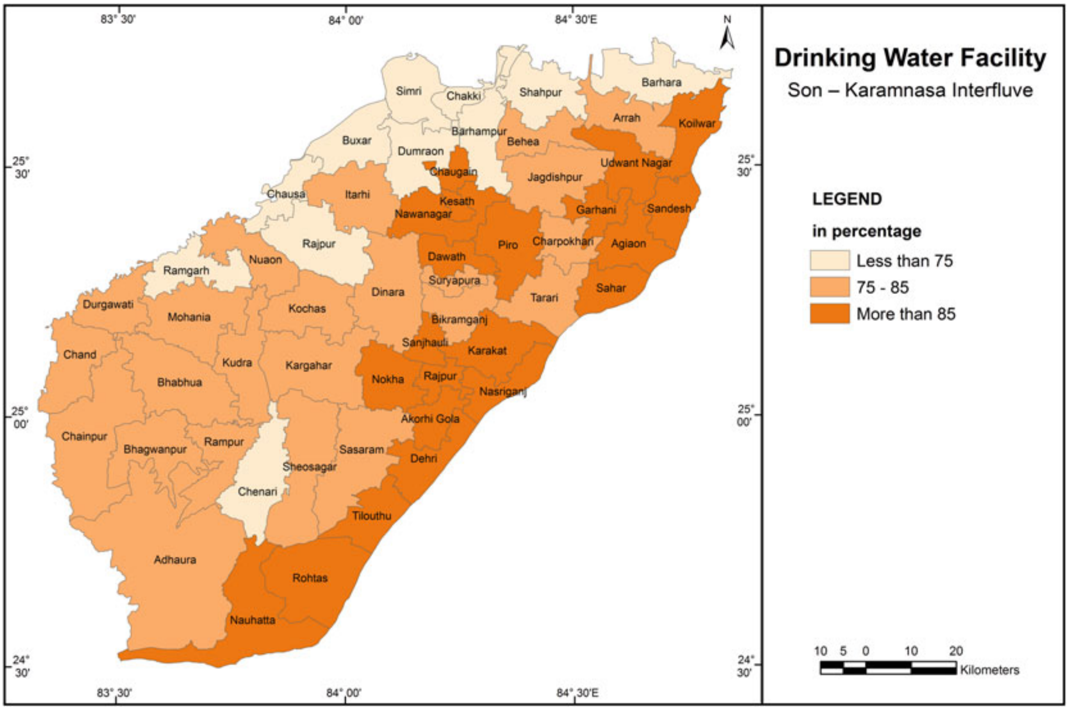

Fig. 12.3 Drinking water facility

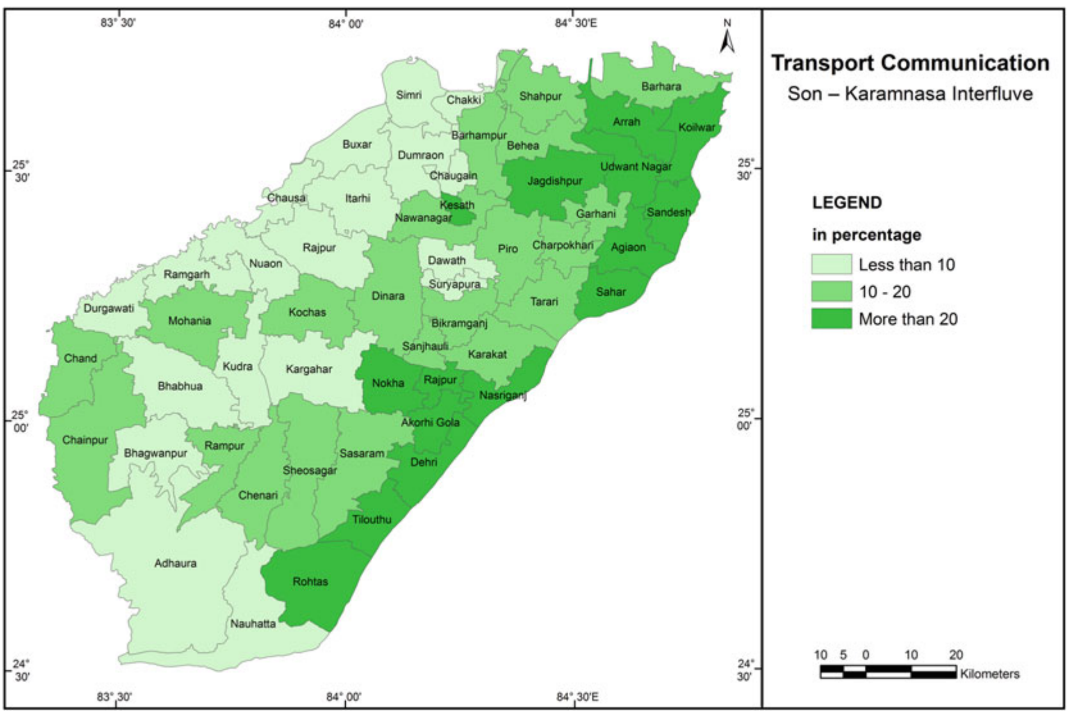

Fig. 12.4 Transport communication facility

direct approaches with bus and rail services. The analysis reveals that most of the blocks in Buxar and Bhabhua district are less (less than 10% of villages) developed in terms of transport communication.

12.4.5 Post, Telegraph and Telephone Facility

Of the 16.2% of villages that have postal facilities such as post office, telegraph office and number of telephone connections, the distribution of these facilities varies. The maximum, 26.8%, villages in the Bhojpur district and minimum, 9.5%, villages in Bhabhua district in the study area have these facilities. The analysis reveals that all blocks except Ramgarh block in the Bhabhua district have less than 15% of these facilities (Fig. 12.5). The analysis also reveals that these facilities are decreasing towards the South-west.

12.4.6 Power/Electricity Facility

SDG 7 urges access to affordable, reliable, sustainable and modern energy for all. Energy access varies widely across nations. Some 27.8% of villages in the study area have electricity facilities, like availability of electricity for domestic, agricultural and other uses. The district-wise distribution of electricity shows that the maximum, 37.7%, of villages are in Bhabhua district and the minimum, 20.3%, in Bhojpur district have electricity facilities. The block-wise analysis reveals that Dumraon and Kesath blocks in Buxar district, and Behea and Koilwar blocks in Bhojpur district, have more than 40% villages that can avail themselves of these facilities (Fig. 12.6).

12.4.7 Irrigation Facility

Water is the single most important requirement for the growth of plants. Crops can be raised

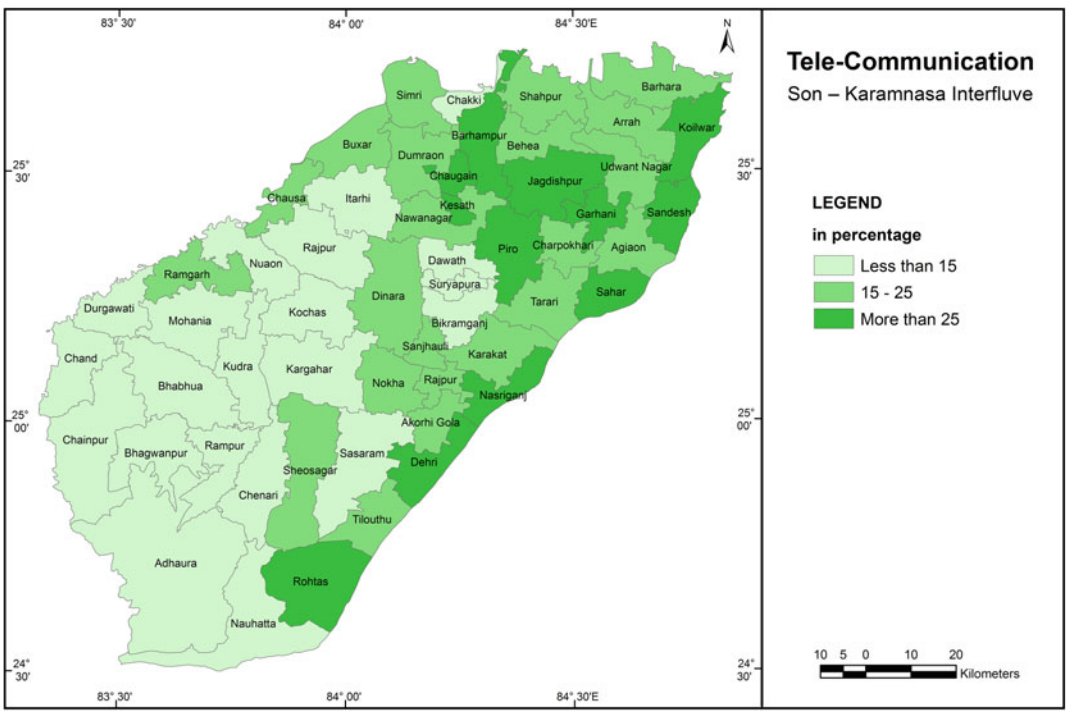

Fig. 12.5 Tele-communication

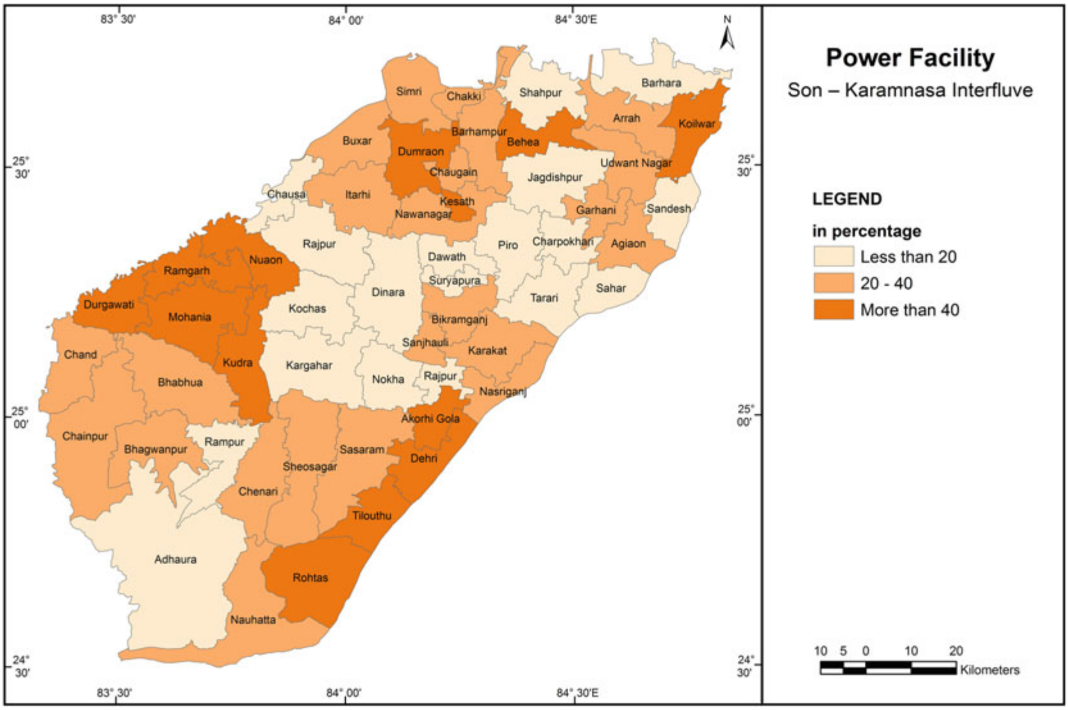

Fig. 12.6 Power facility

successfully only if water is available in adequate quantity either from rain or surface flow or below ground. Rainfall in most parts of the country is confined mainly to the four rainy months from June to September where in the remaining months water requirements have to be met from ground or surface-water resources (Ministry of Agriculture and Irrigation 1976). In the study area, there are 237,249.3 ha of land found to be irrigated and 40,716.3 ha of land un-irrigated. Among the total irrigated land, 66.2% of land is irrigated by the Son canal, 9% by well, 14.9% by tube-well, 2.5% by tank, 1.1% by river, 0.1% by lake and 6.4% by other sources including waterfall. The analysis also reveals that a maximum of 38.5% irrigated area falls under Rohtas district and the lowest, i.e. 17.5%, irrigated area under Buxar district. The irrigated area also varies among blocks (Fig. 12.7). The district-wise distribution of irrigation by different sources also varies. Lakes, rivers and tube-wells are the main sources of irrigation in Bhojpur. Tube-wells and canals are major sources in Buxar. Wells and tanks are the main sources of irrigation in Bhabhua, whereas canals, wells, rivers, tanks and lakes are the major sources of irrigation in Rohtas. There are close relationships between the irrigated areas and net-sown areas. The northern part of Buxar and Bhojpur districts and blocks has less sown area because of less irrigation from different sources.

12.4.8 Infrastructure Assessment

The ranking method is used to assess the infrastructure development in the study area. The analysis shows that the eastern portion of the study area is more developed and is decreasing toward western and southern blocks in the study area, except for some blocks in the Bhabhua districts (Fig. 12.8).

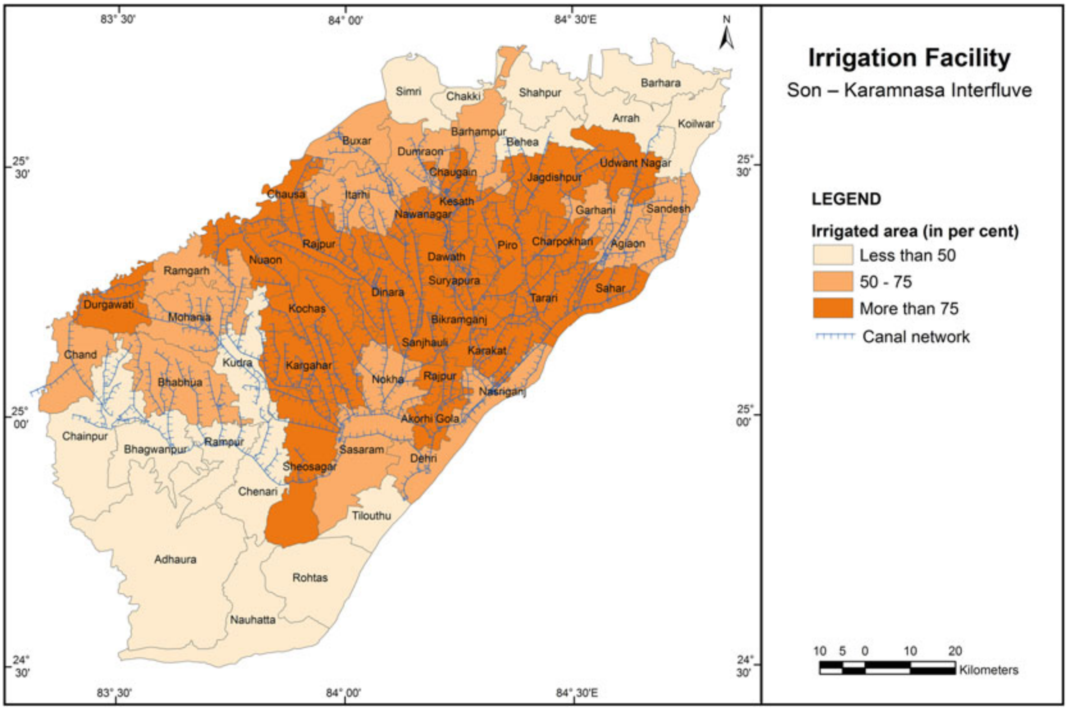

Fig. 12.7 Irrigation facility

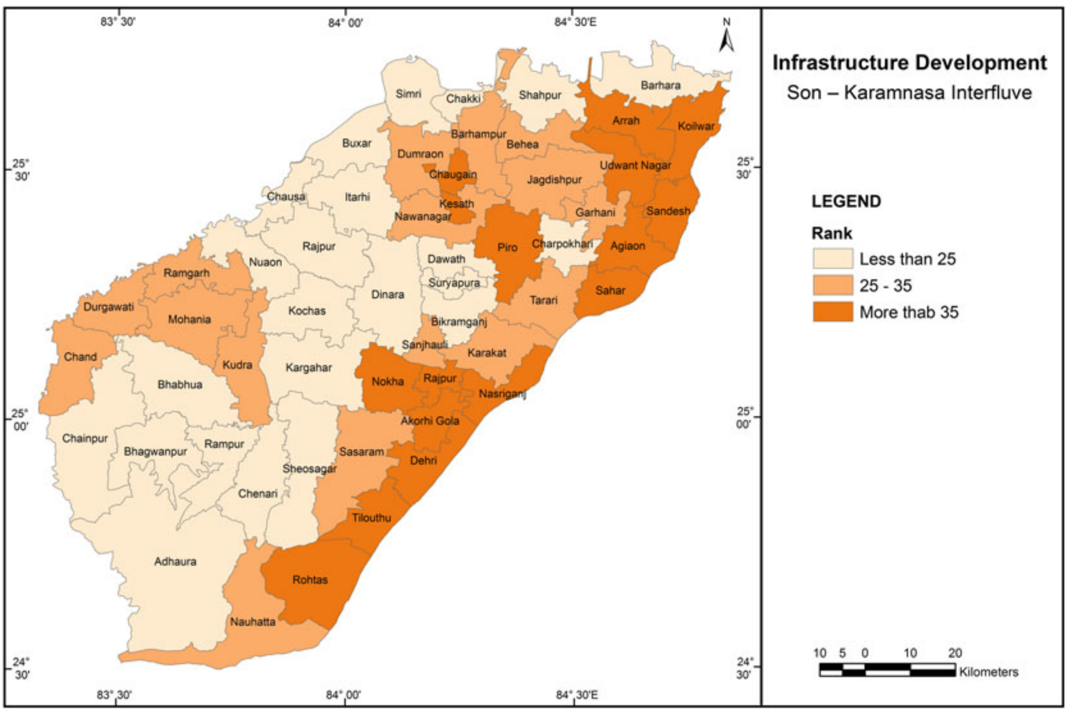

Fig. 12.8 Infrastructure development

12.5 Conclusion

Inadequate basic infrastructure is the major obstacle to progress. Various government programmes were initiated during Five Year Plans since independence to improve the infrastructure in rural areas as well as the special plans for backward areas. The Rashtriya Sam Vikas Yojana (RSVY) and Pradhan Mantri Awas Yojana (PMAY) were established to provide affordable homes to people belonging to economically weaker sections and lower-income groups; Sansad Adarsh Gram Yojana (SAGY) was set up to develop socio-economic and physical infrastructure by a Member of Parliament for the development of villages as 'Adarsh Gram'; Pradhan Mantri Gram Sinchai Yojana (PMGSY) was set up to improve water-use efficiency to provide 'Per Drop More Crop'; Pradhan Mantri Jan Aushadhi Yojana (PMJAY) was initiated to provide medicine at an affordable cost across the country; Digital India was established to provide government services to citizens electronically by improving online infrastructure; Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) was set up to provide power to rural households and adequate power to agricultural consumers; Atal Mission for Rejuvenation and Urban Transformation (AMRUT) was set up to provide basic services to households and build amenities in cities; Swadesh Darshan Yojana was set up to develop a world-class tourism infrastructure; Pilgrimage Rejuvenation and Spiritual Augmentation Drive (PRASAD) was set up to create spiritual centres for tourism development within the nation and many more were introduced to meet rural infrastructural needs. Among the infrastructure facilities, drinking water to some extent is found to be inadequate. Health facilities are available only in 9.9% of villages, education facilities in 56.9%, power (electrification) in 27.8%, post, telegraph and telephone in 16.2%, and transport communication in 13.7% of villages. The irrigation facility is not adequate in the northern and southern part of the study area. Thus, human resources in this region are very rich and demographic characteristics are almost the same throughout the study area except the plateau region, but the infrastructural development is neither adequate nor uniformly distributed.

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SDG 2: Case Study – Crop Modelling for Sustaining Agricultural Productivity

13

Abstract

Many developing countries are facing challenges in coping with national food security and environmental sustainability. India is also facing the same problem. Spatial information technology provides an opportunity to automate databases in the field of agriculture to cope with issues around food security and environmental sustainability. Western Uttar Pradesh in India, covering Saharanpur, Muzaffarnagar and Meerut districts, recorded high agricultural growth during the second wave of the 'green revolution' in the 1980s. However, rapid urbanisation and developmental processes are increasingly in conflict with other forms of land use, especially agriculture. This study addresses the spatial pattern of land use over a decade and soil and climatic characterisation of the region. The land-use/cover changes were captured by integrating satellite imagery (IRS-1D and IRS P6) of winter and summer (monsoon) seasons for the years 1998 and 2010. Spatial patterns of major soil and climate parameters were integrated into homogeneous agro-ecological units (38 classes) and 417 land units. Crop areas and their yield of sugarcane, rice, wheat and maize were assessed. Potential yields of these crops of the region were computed by using crop simulation models; and current yields were obtained through field survey in selected land units and other collateral data. A few agri-technological levels were tested for the fertiliser and irrigation inputs required to bridge yield gaps in rice and wheat in selected land units. It is argued that augmenting production through assessment of biophysical potential of a region can ensure food security and environmental sustainability.

Keywords

Food security · Land-unit classification · Crop simulation model · Decision-support system · Crop yield · InfoCrop software

13.1 Introduction

SDG 2 urges zero hunger, pursuing the end of hunger and all forms of malnutrition and sustainable food production by 2030. This requires the promotion of sustainable agriculture for food security. The efficient management of available resources in variable weather conditions is essential to increase productivity of agriculture when the focus of agricultural production is changing from quantity towards quality and sustainability (Chakraborty et al. 2012). Solutions to these new challenges require consideration of numerous components which interact to effect crop growth. These force farmers and agricultural advisors to deal with increasing bulks of information. They need to analyse vast

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and sporadically located information resources (Kumar et al. 2009; Singh and Kumar 2013). As information technology has opened up new challenges to automate data for analysis, computer programs that simulate crop growth or yield of crops under different management regimes help farmers make technical decisions to manage their crops better (Singh et al. 2014). Crop modelling can play a significant role in system approaches by providing a powerful capability for scenario analyses. Effective crop modelling must encompass a scientific approach to enhance understanding with an application-orientation to retain a focus on prediction and problem-solving.

The decision-support systems based on crop simulation models are normally site-specific. In policy formulation, however, spatial variability of crop production often needs to be evaluated due to different soil conditions, weather conditions and agricultural practices within a target region (Priya 2000; Singh and Kumar 2012). In order to develop a decision-support system, biophysical processes and human interactions such as adaptive changes of agricultural practice should be considered. However, crop simulation models usually need site-specific characteristics such as weather elements, physical and chemical parameters of soil, water management and agronomic practices as input data. The applicability of these models can be extended to the much broader spatial scales by combining them with a Geographic Information System (GIS) (Singh and Murai 1998). For the crop modelling in the current research, soil units and agro-ecological units are identified based on geo-environmental characteristics (Jha and Singh 2008). Similarly, the land units are identified through integration of the block boundaries with agro-ecological units.

13.2 Study Area

The study area extends between 77° 5′ 2′ East to 78° 7′ 45′ East longitude and 28° 44′ 10′ North to 30° 24′ 21′ North latitude. The total geographical area (TGA) is 10,287 km^2. It is a doab region stretching between the river Yamuna in the West to the river Ganga in the East. The study area has three administrative districts: Saharanpur, Muzaffarnagar and Meerut of Uttar Pradesh. It is surrounded by Dehradun and Roorkee districts of Uttarakhand State in the North and North-east; Yamunanagar, Kurukshetra, Karnal and Panipat districts of Haryana State in the West; Bijnor, Moradabad districts in the East; Bagpat district in the South-west; Ghaziabad in the south districts of Uttar Pradesh (Fig. 13.1).

13.3 Methodology

The overlay analysis was used to generate soil units, agro-ecological units and land units (Fig. 13.2). The soil-unit map was prepared by overlaying layers of soil pH, organic carbon content and texture in a GIS environment. This generated 38 different soil units, distributed over 183 polygons (Fig. 13.3). An agro-ecological region map was prepared by overlaying the soil units with rainfall patterns of the area. The 38 classes of soil units were intersected with 5 classes of rainfall regions, resulting in 78 agro-ecological units, distributed over 234 polygons (Fig. 13.4). The smallest homogeneous manageable unit was termed a land unit, which was generated by the integration of 78 agro-ecological units with 37 administrative block boundaries. After integration, 417 land units were produced (Fig. 13.5). The land units were utilised to generate statistics such as crop production, land-unit area under rice, sugarcane, maize and wheat. Finally, land-unit-wise crop yield of these crops is calculated by using the formula given in Fig. 13.6. Each characteristic of the soil unit served as input in the InfoCrop model to calculate the estimated yield. The InfoCrop model is calibrated and validated with estimated yield that is equal to actual yield. Then the potential yield is generated for each crop. The yield gap is calculated with the differences between the potential yield which is generated from the InfoCrop model and actual yield calculated from the statistics provided by the

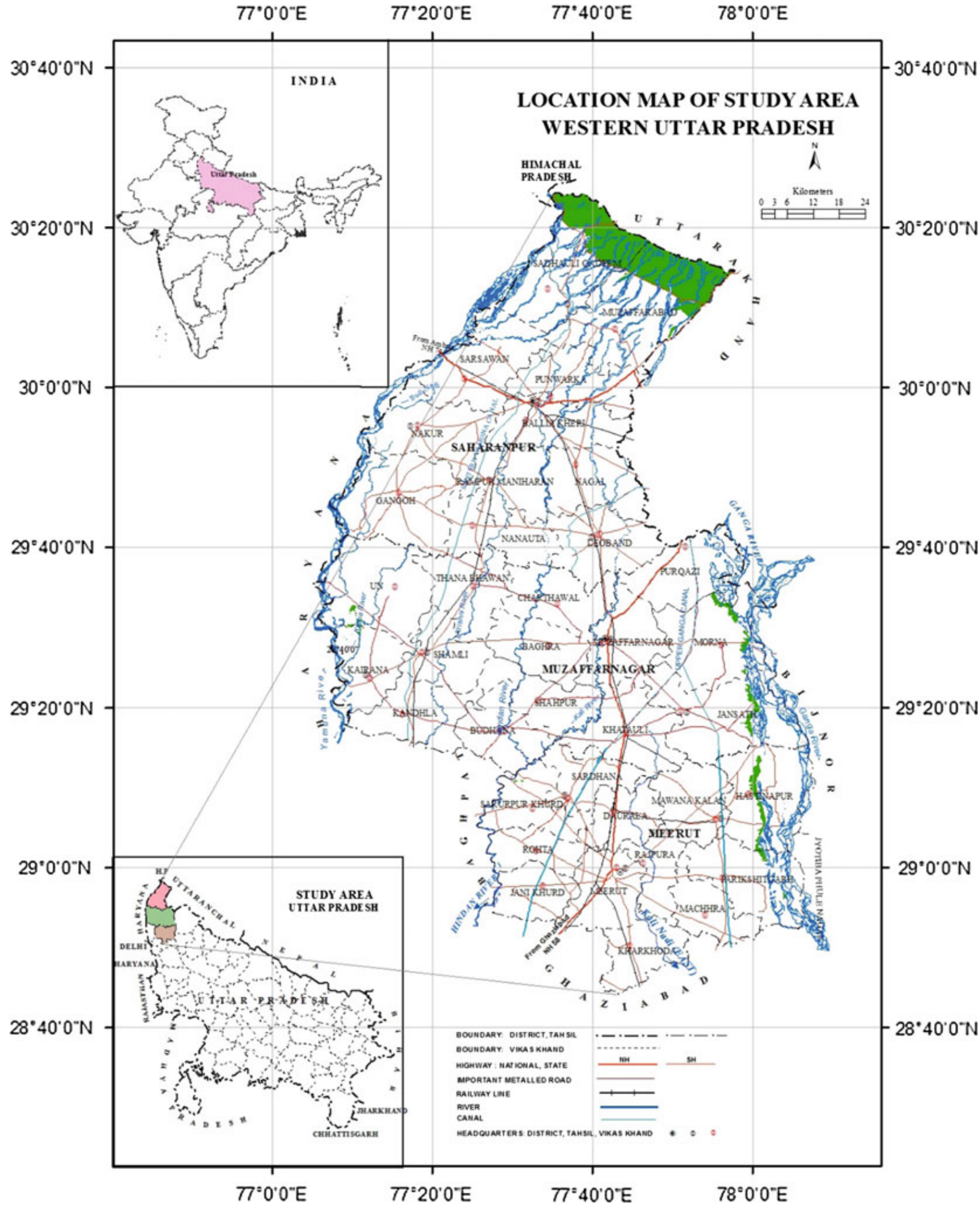

Fig. 13.1 Study area

Economics & Statistics Division (ESD) of the Planning Department, Uttar Pradesh. The QUEFTS (quantitative evaluation of the fertility of tropical soils) model is utilised to estimate the fertiliser input to bridge the crop yield gap.

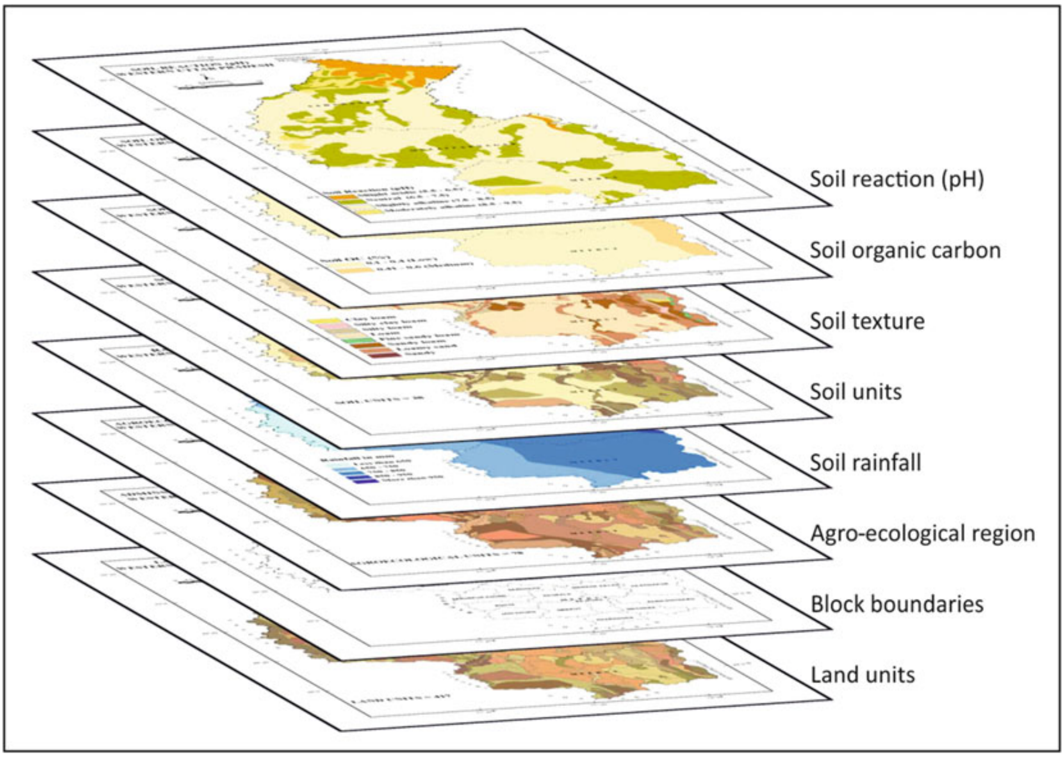

Fig. 13.2 Overlay analysis

13.4 Results and Analysis

13.4.1 Soil Unit and Agro-Ecological Unit

The maximum area (35.2%) in a soil unit has been identified with slightly alkaline (pH 7.5–8.5), low organic carbon content (0.1–0.4%) and being loam in texture. They are widely spread out in the central and western parts of Meerut district, the north-western and eastern parts of Muzaffarnagar district and the south-west part of Saharanpur district. The second highest soil unit covers 20.2% of TGA, its soil properties are neutral (6.5–7.5 in pH), low organic carbon (0.1–0.4%) and loam in texture. The third soil unit covers 14.9% of the area, located in the eastern part. Its soil properties are slightly alkaline pH, low organic carbon and loamy sand texture. The fourth soil unit is spread over 4.1% of TGA and its soil properties are slightly acidic (5.5–6.5 in pH), medium organic carbon content (0.4–0.6%) and loamy sand in texture. This unit is found in the northern part of Saharanpur and the north-east of Muzaffarnagar. Except for these four, the units cover an area less than 4.0% of TGA.

The area under each agro-ecological unit was computed. The agro unit that covers the highest area (17.6%) has soil properties of slightly alkaline pH (7.5–8.5), low organic carbon content (0.1–0.4%) and loam in texture; rainfall varies between >750 and ≤ 850 mm. It covers the central part of the area. In Meerut, it covers Daruala, Rajpura, the western part of Machhra, the southern part of Mawana and the north-eastern part of Meerut blocks. In

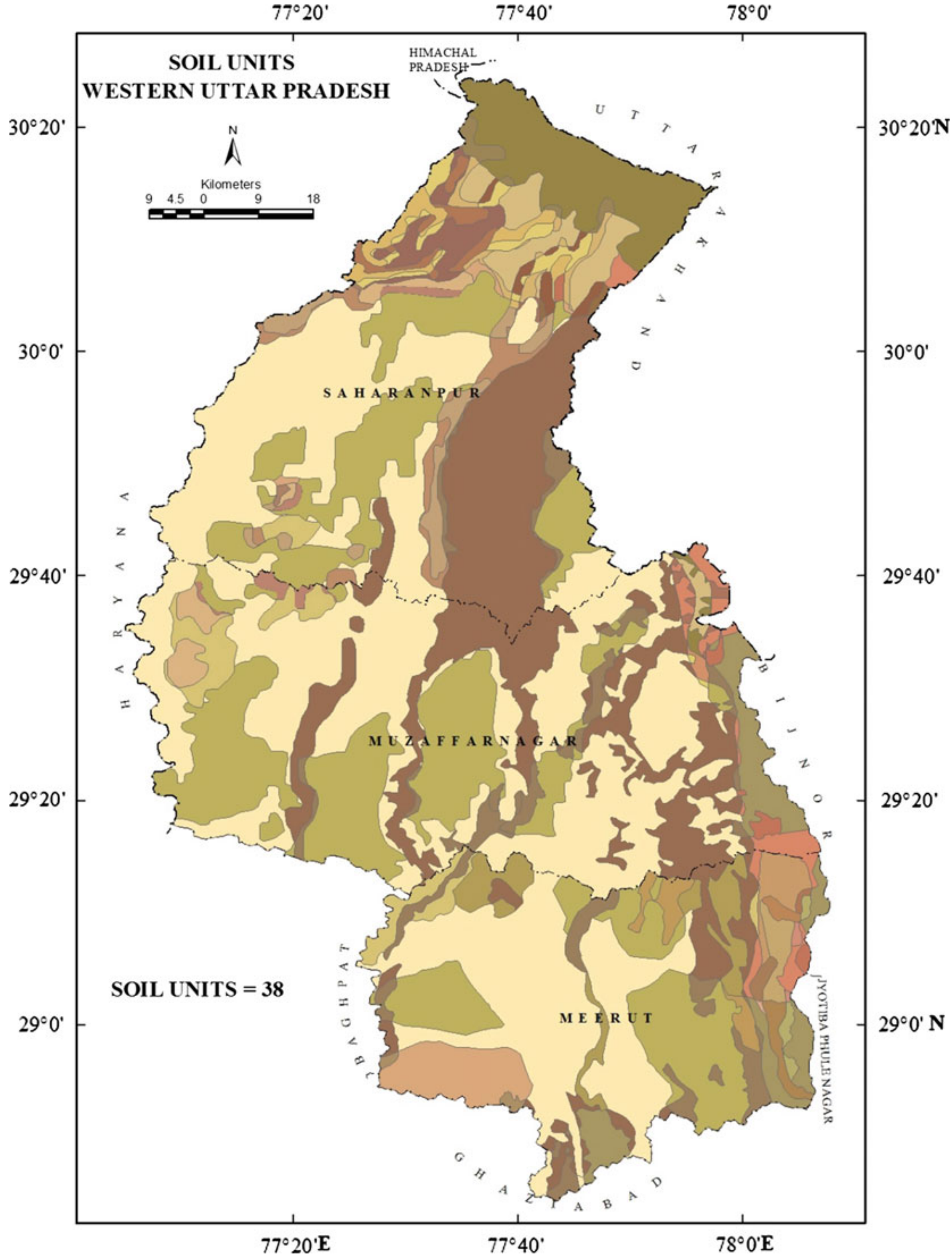

Fig. 13.3 Soil units

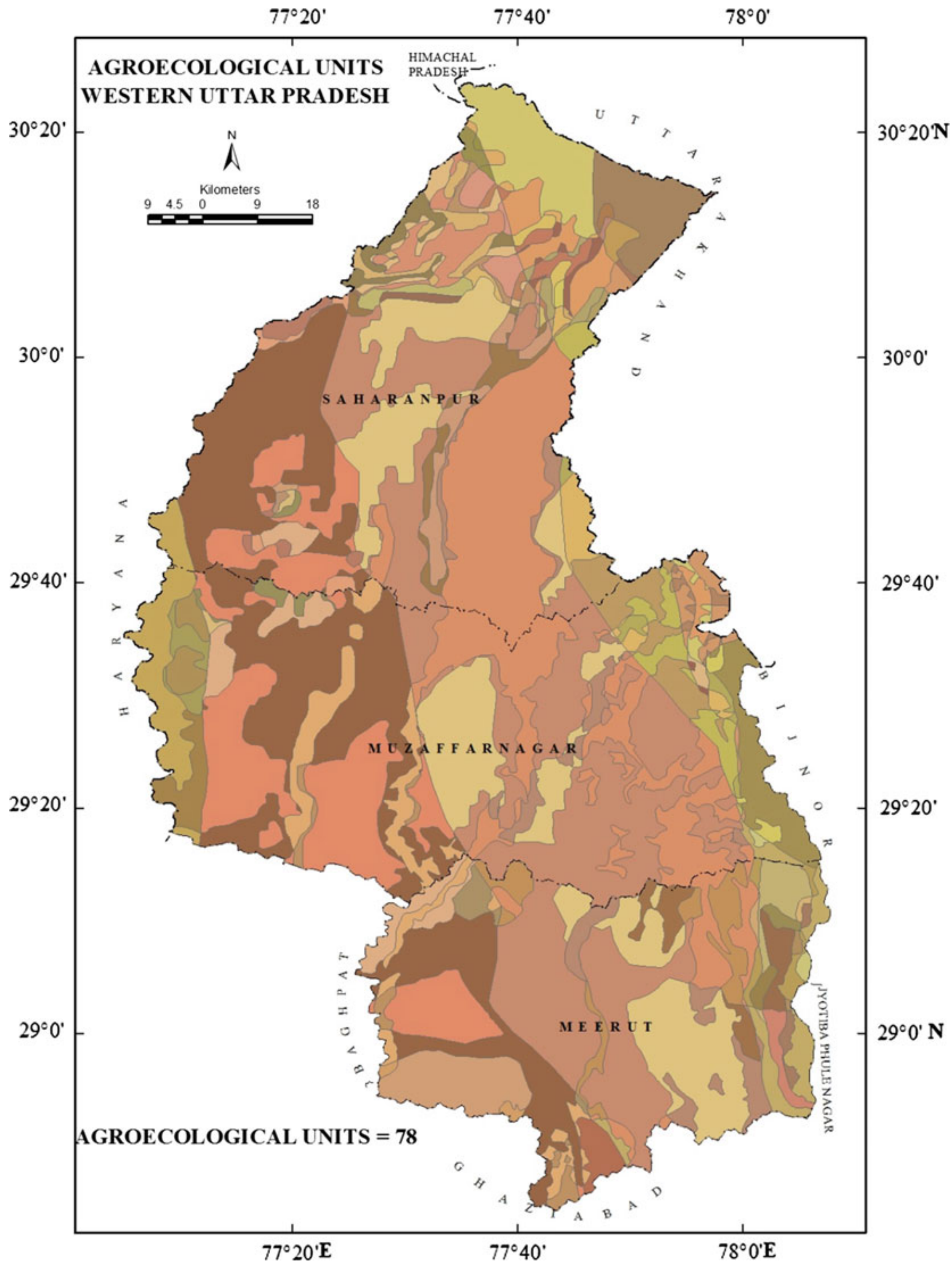

Fig. 13.4 Agro-ecological units

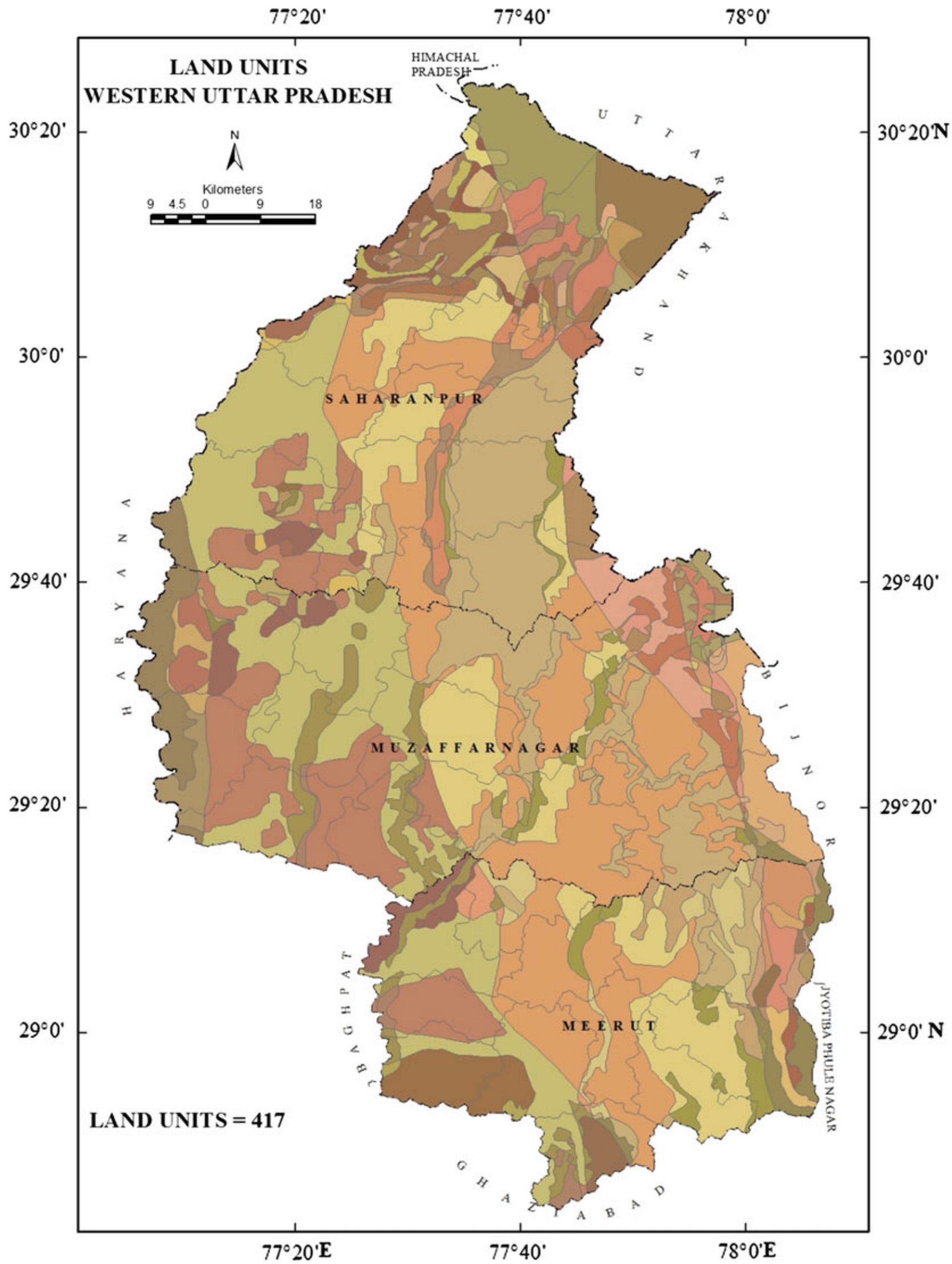

Fig. 13.5 Land units

The block wise crop production is converted into land unit wise by:

$$\text{land unit wise Production of crop} = \frac{\textit{Land Unit area in the block}}{\textit{Total Block Area}} \times \textit{Production of particular crop (like Rice) in the block}$$

Land unit area of each crop (Rabi crop is Wheat and Kharif crop is Rice, Sugarcane and Maize) is calculated by:

$$\text{Land unit area of Rice} = \frac{\textit{Percentage of Crop area (Rice)}}{100} \times \textit{Crop land of Kharif season} \text{ (satellite image, 2010)}$$

$$\text{Land unit area of Sugarcane} = \frac{\textit{Percentage of Crop area (Sugarcane)}}{100} \times \textit{Crop land of Kharif season}$$

$$\text{Land unit area of Maize} = \frac{\textit{Percentage of Crop area (Maize)}}{100} \times \textit{Crop land of Kharif season}$$

$$\text{Land unit area of Wheat} = \frac{\textit{Percentage of Crop area (Wheat)}}{100} \times \textit{Crop land of Rabi season}$$

Calculation of Yield of each crop in land unit wise by:

$$\text{land unit Yield of Rice/Sugarcane/Maize/Wheat} = \frac{\textit{Production of each unit wise Crop (Rice/Wheat)}}{\textit{Area of perticular unit}}$$

Fig. 13.6 Formula for block-wise land-unit conversion

Muzaffarnagar district, it lies in Khatauli, Muzaffarnagar and the western part of Jansath, Morna and Charthawal blocks. The Saharanpur district region covers the central part of Nanauta, Rampur Maniharan and Sarsawan, south-western part of Punwaraka blocks. The second largest agro-ecological unit covers 14.3% of the area. This has the same soil properties as the previous unit, but rainfall varies between ≥ 650 and ≤ 750 mm. This region covers the western part of the study area (the eastern part of Sarurpur Khurd, south-west of Sardhana, the western part of Meerut block in Meerut; most of the Thana Bhawan and Shamli blocks, the southern part of Kandhla and eastern part of Budhana block in Muzaffarnagar; the western part of Gangoh, Nakur and Sarsawan blocks in Saharanpur district).

The third largest agro-ecological unit is distributed over 12.1% of the area and soil properties are slightly alkaline (7.5–8.5 in pH), have low organic carbon content (0.1–0.4%) and are loamy sand in texture; rainfall varies between >750 and ≤ 850 mm. It covers the eastern part of the area. In Meerut, this unit forms the western part of Hastinapur and eastern part of Mawana Kalan. In Muzaffarnagar, it covers most of the Charthawal block, the western part of Jansath, Morna and Muzaffarnagar blocks. In Saharanpur district, this covers Deoband, Nagal, Ballia Kheri and the south-eastern part of Punwarka block. The maximum number of agro-ecological units is concentrated in the eastern part of Meerut and Muzaffarnagar districts, covering Hastinapur, Parikshitgarh and Morna blocks in Meerut and Purqazi, and Jansath blocks in Muzaffarnagar district. Similarly, the northern part of Saharanpur district has maximum units mostly covering Sadhauli Qudeem and Muzaffarabad blocks (Kaur 2014).

13.4.2 Irrigated Area, Crop Area and Crop Yield

Food-production capacity has been facing an ever-growing number of challenges, including a world population expected to grow to nearly 9 billion by 2050 and a declining man–land ratio. Some 20–40% of the world's potential crop production is lost annually because of the effects of weeds, pests and diseases. The productivity of cropping is measured by yields (production per unit of area). Productivity varies enormously and is highly sensitive to factors other than soil and water, for example the availability and affordability of technologies and inputs, access to markets and local financial returns.

At one extreme, dry farming systems produce sorghum or millet yields amounting to a few hundred kg per ha (wheat 4–5 tonnes/ha). At the other extreme, farmers in Europe achieve yields as large as 7–10 tonnes/ha for wheat (Molden 2007).

In the study region, the crop area under sugarcane is high in Muzaffarnagar district in comparison to Meerut and Saharanpur districts (Fig. 13.7). In the case of rice and maize, Saharanpur district has a higher crop area than other districts of the study area (Fig. 13.8). The area under wheat is higher in Muzaffarnagar district followed by Saharanpur and Meerut districts (Fig. 13.9). The analysis also reveals that there is an inverse relationship between crop areas of sugarcane and rice. The irrigated area for the entire crop – i.e. rice, wheat, sugarcane and maize – has been almost 100% (Fig. 13.10).

Block-wise analysis of rice production shows that Gangoh block of Saharanpur district is within a high category, followed by Punwarka block in the same district. In Muzaffarnagar, Un block has a higher rice production than Hastinapur block in Meerut district. All the blocks in Saharanpur district have a higher production of rice, followed by Muzaffarnagar and Meerut districts (Fig. 13.11). Block-wise crop production analysis also reveals that the production of sugarcane is higher in Kairana, Jansath, Khatauli and Morna blocks in Muzaffarnagar; Deoband, Gangoh and Nagal blocks in Saharanpur; and Parikshitgarh, Mawana Kalan and Hastinapur blocks in Meerut (Fig. 13.12). The production of wheat is very high in Un block of Muzaffarnagar followed by Nakur and Jansath blocks. Overall production of wheat is high in all the blocks in Muzaffarnagar followed by Saharanpur and Meerut districts (Fig. 13.13). The production of maize is extremely high in Muzaffarabad and Sadauli Qadeem blocks in Saharanpur district, followed by Kharkhoda and Sarurpur Khurd blocks in Meerut district. In Muzaffarnagar, the production of maize is very low due to the smaller size of the area under maize (Fig. 13.14). The data about the crop yield of the major crops vary during 1998–2010. In 1998 the yields of rice, wheat, sugarcane and maize in Meerut district were 2.5, 3.5, 67.6 and 1.5 tonnes/ha, respectively. But in 2010, the yields of these crops were 2.6, 3.7, 65.6 and 1.9 tonnes/ha, respectively. In Muzaffarnagar, the crop yields of rice, wheat, sugarcane and maize were 3.0, 3.3, 67.8 and 1.6 in 1998 but in 2010, they were 2.6, 3.4, 70.2 and 1.0 tonnes/ha, respectively.

In Saharanpur, crop yields of rice, wheat, sugarcane and maize were 2.7, 2.8, 66.3 and 1.3 during 1998 and they were 2.3, 3.0, 62.7 and 1.0 tonnes/ha in 2010, respectively. District-wise analysis reveals that the yield of sugarcane crop in Muzaffarnagar and Meerut is higher than Saharanpur. But the yields of wheat and maize crops are higher in Meerut district, followed by Muzaffarnagar and Saharanpur. The yield of rice, wheat, sugarcane and maize in the year 2010 is shown in Figs. 13.15, 13.16, 13.17 and 13.18.

13.4.3 Crop Modelling

Crop models assume that plants are systems and behave as an entire unit. Roots feed mineral substances and water to the leaves; leaves assimilate CO_2, and the stems provide the link and transport substances between the two so that when leaves grow, roots can grow as well. When water is absorbed by the roots, it is made available to the whole plant and carried through the above-ground parts. The structure of a system is the set of links and connections between its components. Depending upon the distance from which a system is looked at, the level of details can vary tremendously. Models attempt to describe the structure and the functioning of a system. Again, the word description can go from a simple verbal description to a mathematical description. When mathematical description is coded into a computer program, it will compute the evolution of the

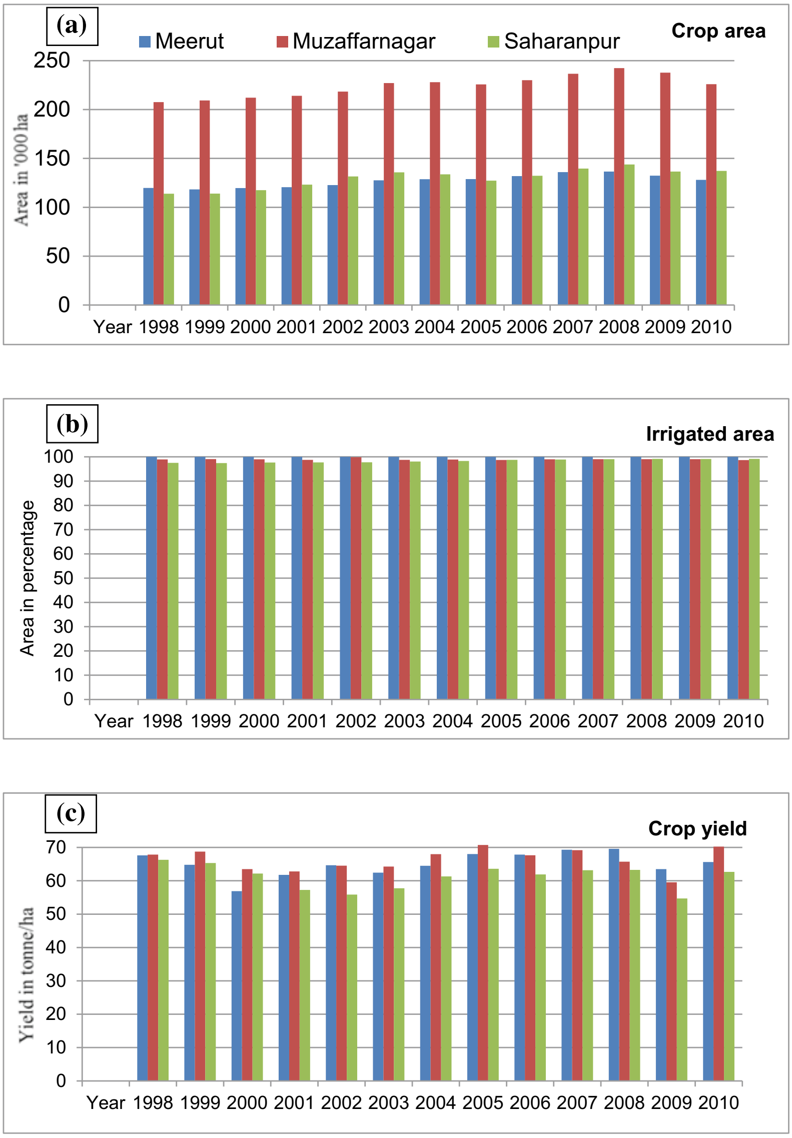

Fig. 13.7 **a** Crop area, **b** irrigated area and **c** crop yield of sugarcane (1998–2010)

numerical values attached to the model component. We talk of computer simulation, in which the machine mimics the behaviour of reality at a given resolution and with a given time step. A model attempts to simulate the way in which a crop responds to its environment.

Model outputs are usually value-added parameters that are more closely linked to crop yield than the inputs. For instance, crop soil moisture is more relevant to crop growth than is rainfall, as rainfall might run off without entering into the soil, particularly on hilly terrain. The outputs are empirically related to crop yield through standard regression techniques. This procedure is known as 'model calibration'. The result of the calibration is a mathematical expression – known as 'yield function' – that is used to calculate yield estimates based on model outputs. Crops require solar energy to develop and grow. However, exposure to the sun also

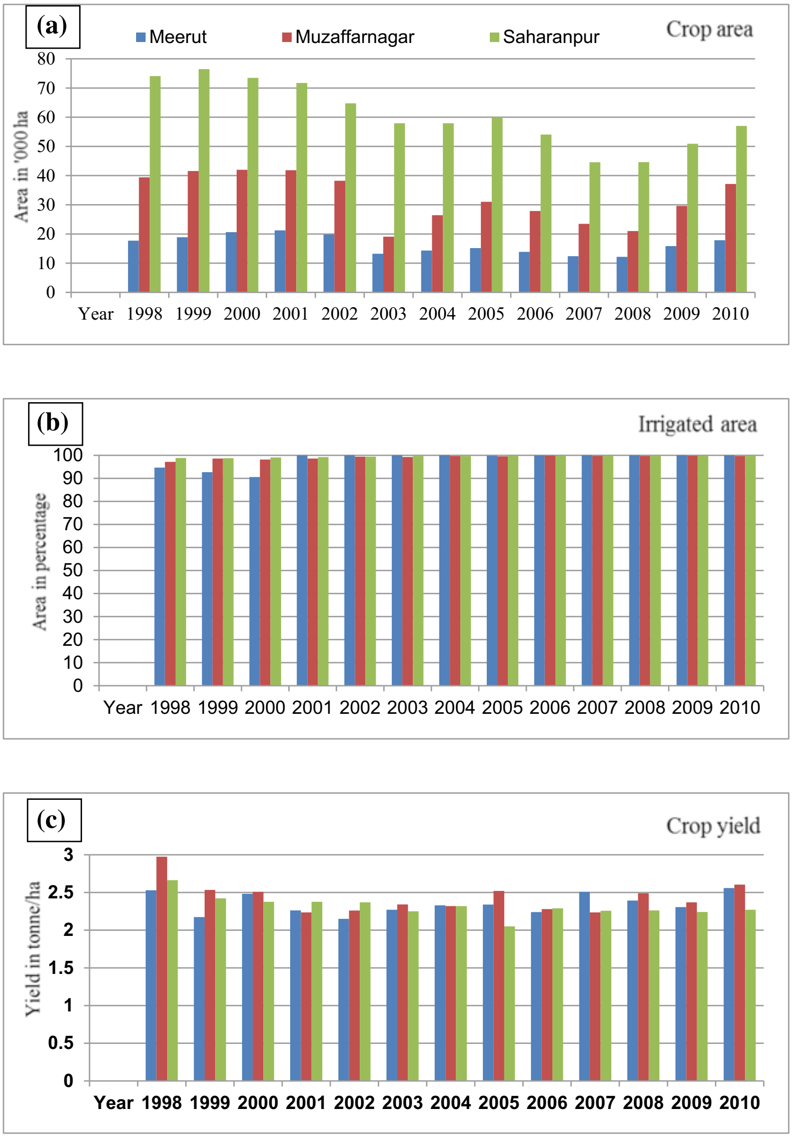

Fig. 13.8 **a** Crop area, **b** irrigated area and **c** crop yield of rice (1998–2010)

tends to increase the temperature of leaves, sometimes to such an extent that plants would die if they did not evaporate water to maintain their temperature at acceptable levels. In fact, the amount of solar energy that plants can accumulate is directly linked to the amount of water that can be evaporated. The main aim of the crop model and water budget described here is to estimate the amount of water consumed which, in turn, is very closely related to crop yield (Gommes et al. 1996). A model is a simplified representation of a system or a process. The modelling is based on the assumption that any given process can be expressed in a formal mathematical statement or set of statements. A crop model is a simple representation of a crop which helps in solving problems related to crop production.

Crop modelling can play a significant role in systems approaches by providing powerful

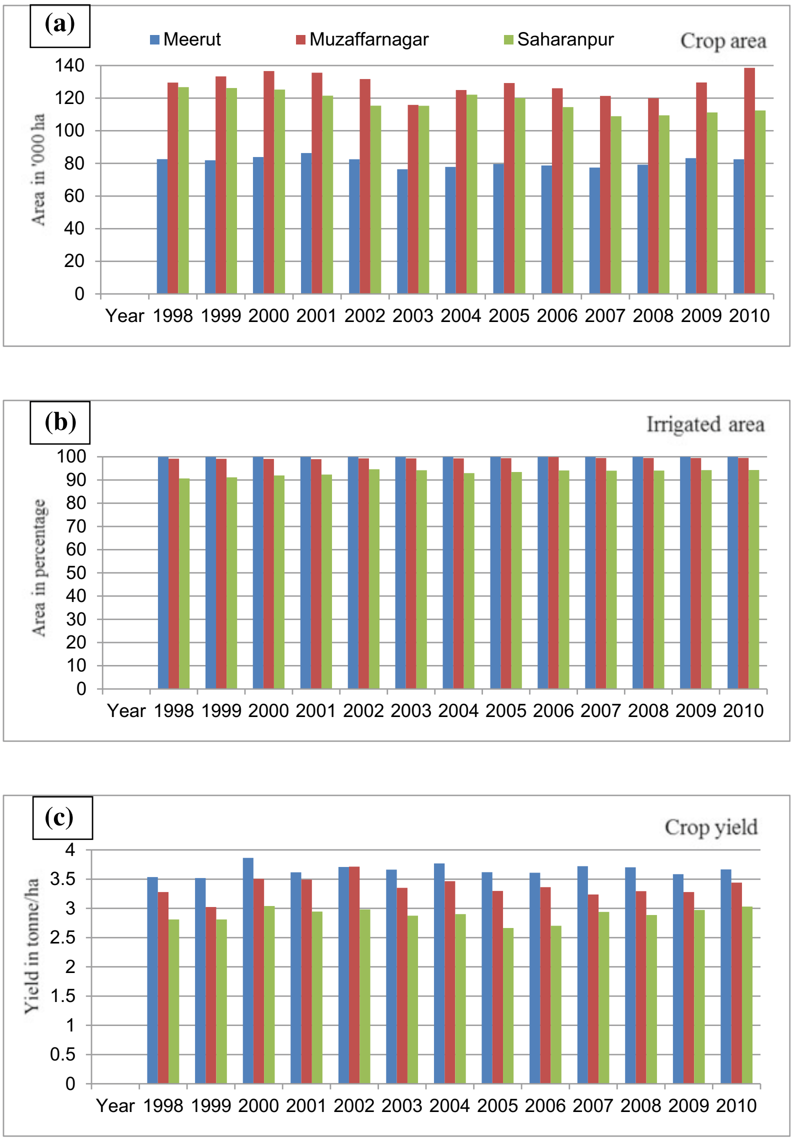

Fig. 13.9 **a** Crop area, **b** irrigated area and **c** crop yield of wheat (1998–2010)

scenario analysis. Crop modelling has developed extensively over the past 30 years and a diverse range of crop models are now available. It is argued, however, that the tendency to distinguish between and separate the so-called 'scientific' and 'engineering' challenges and approaches in crop modelling has constrained the maturation of modelling. It is argued that effective crop modelling must combine a scientific approach to enhance understanding with an applications-orientation to retain a focus on prediction and problem-solving. Greater use of crop simulation models has also been suggested to increase the efficiency of different trials. While simulation models successfully capture temporal variation, they use a lumped parameter approach that assumes no spatial variability of the soils, crops or climate. In the mid-1960s, crop simulation modelling began with the pioneering work of de Wit (1965).

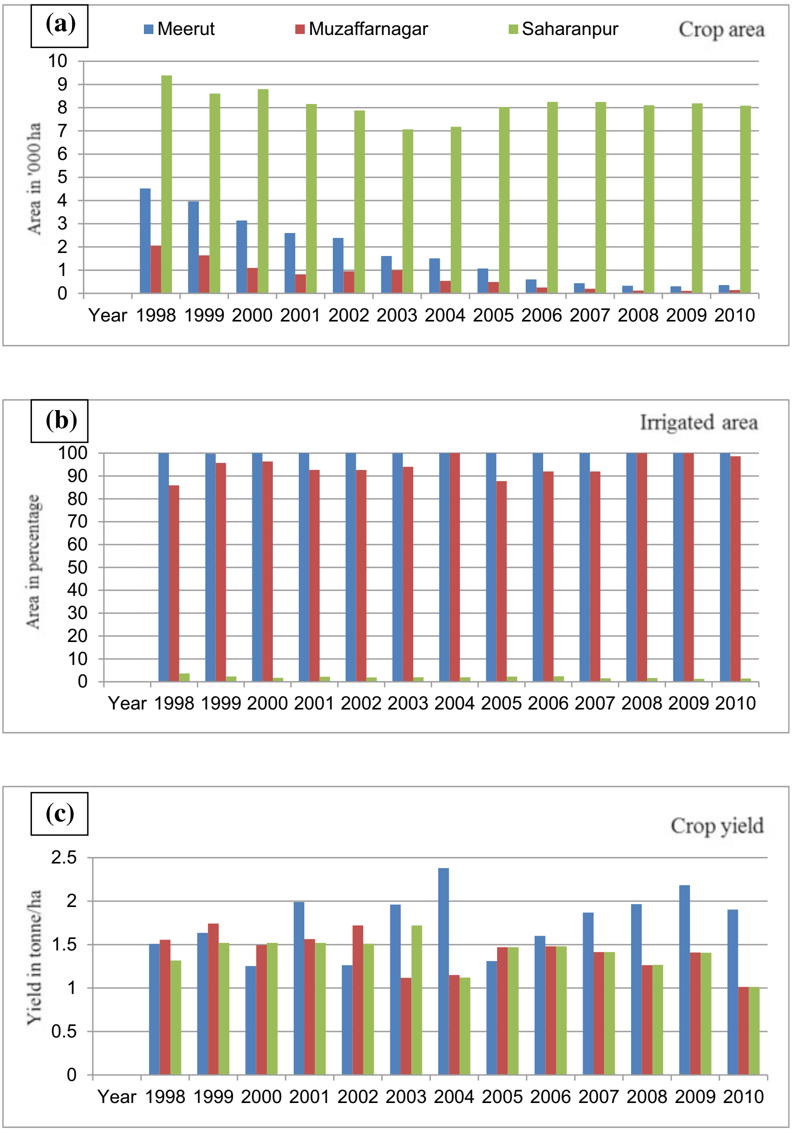

Fig. 13.10 **a** Crop area, **b** irrigated area and **c** crop yield of maize (1998–2010)

Crop simulation models can integrate knowledge of physiological processes and morphological traits to help explain yield formation in environments varying in physical, biological and agronomic factors. These simulations can be used to evaluate key interactions quickly and identify traits with the greatest impact on yield potential (Aggarwal et al. 1997) and for assessing the relationships between crop productivity and environmental factors. They have been shown to be efficient in determining the response of crop plants to changes in weather. Crop simulation models need to accurately reflect actual biological happenings under complex and rapidly changing conditions. Such models must be based on accurate and reliable information regarding the most fundamental of plant processes – photosynthesis (Boote and Loomis 1991).

InfoCrop InfoCrop is a decision-support system based on crop models that has been developed by

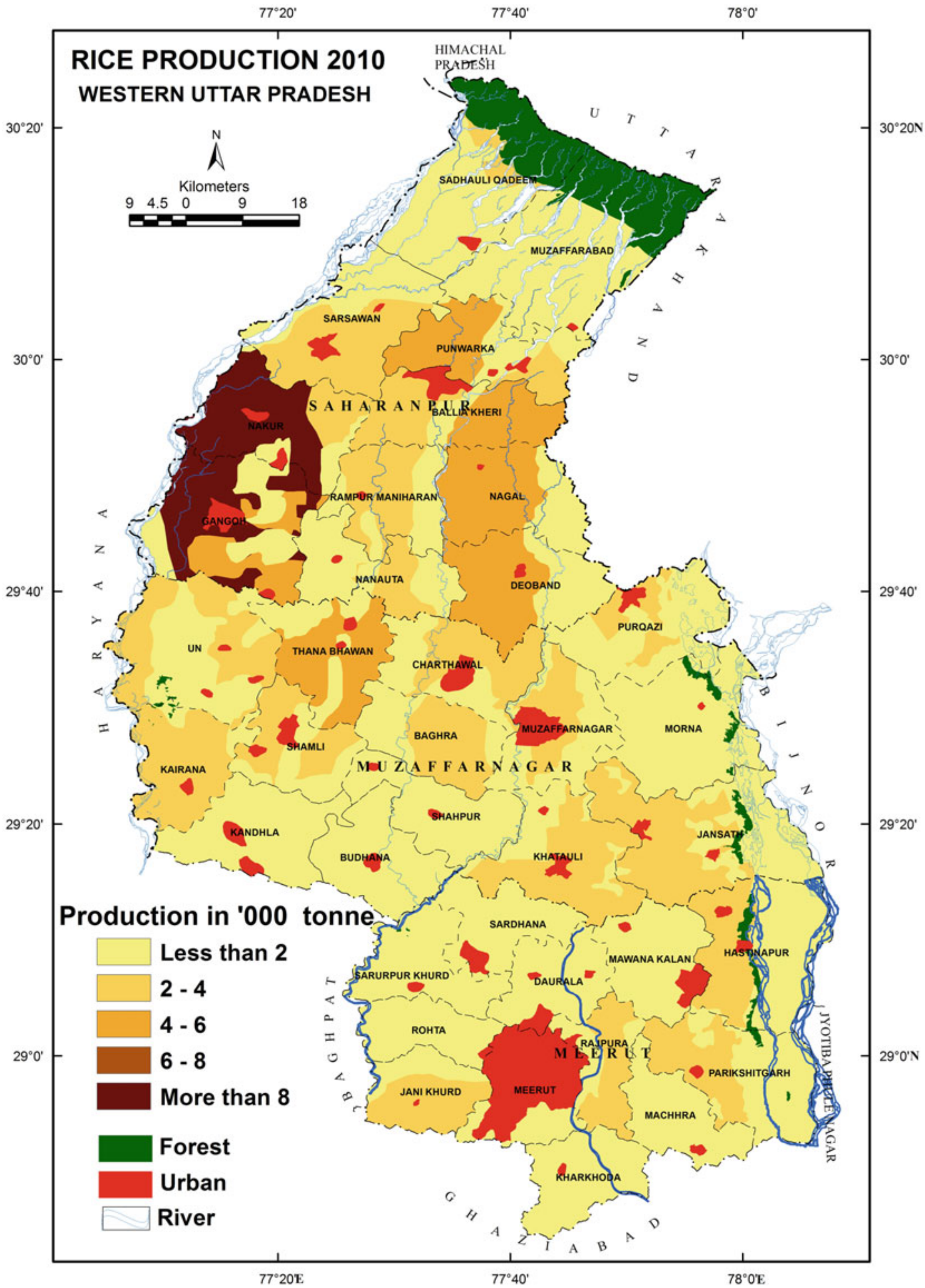

Fig. 13.11 Rice production (2010)

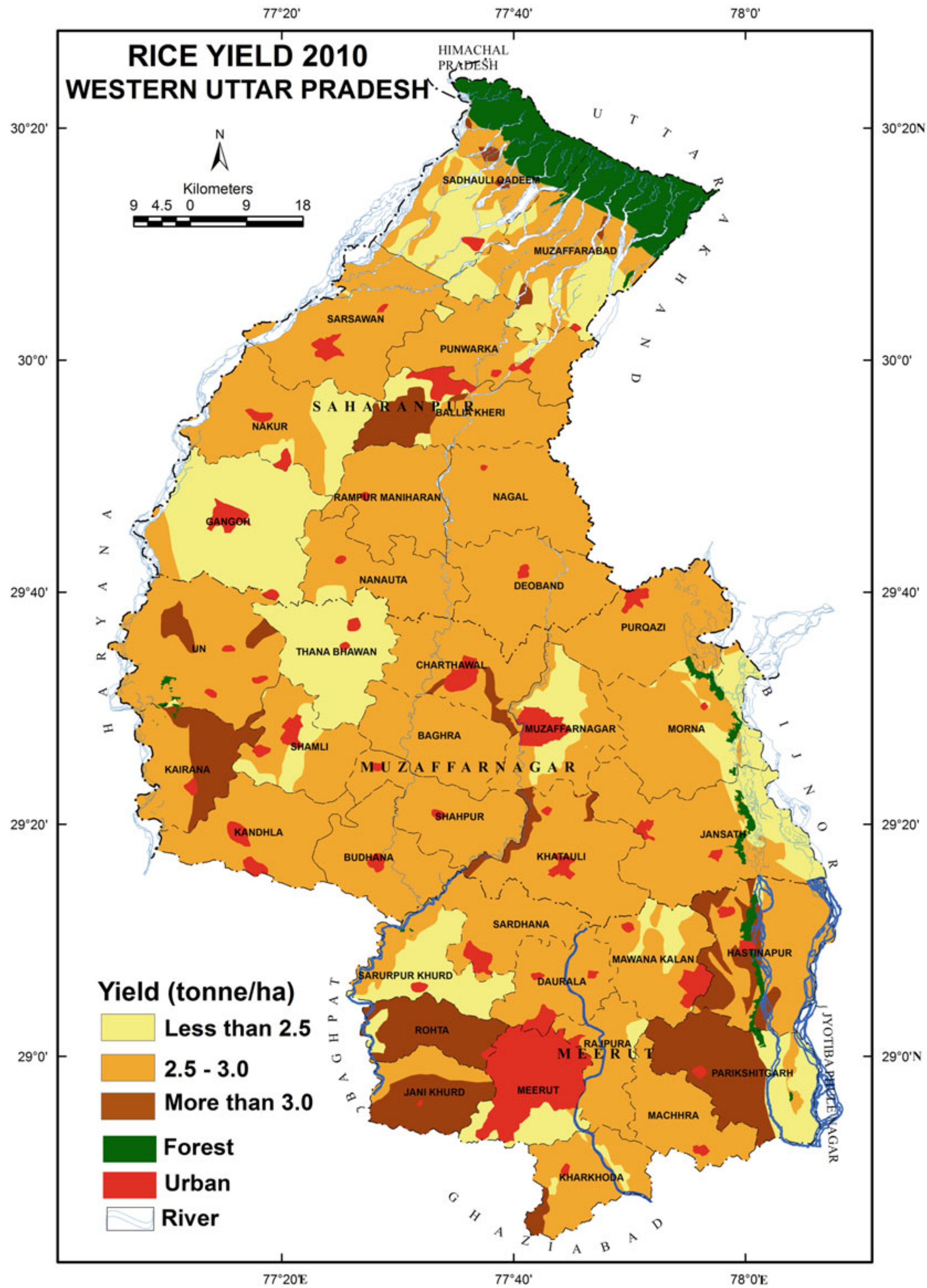

Fig. 13.12 Sugarcane production (2010)

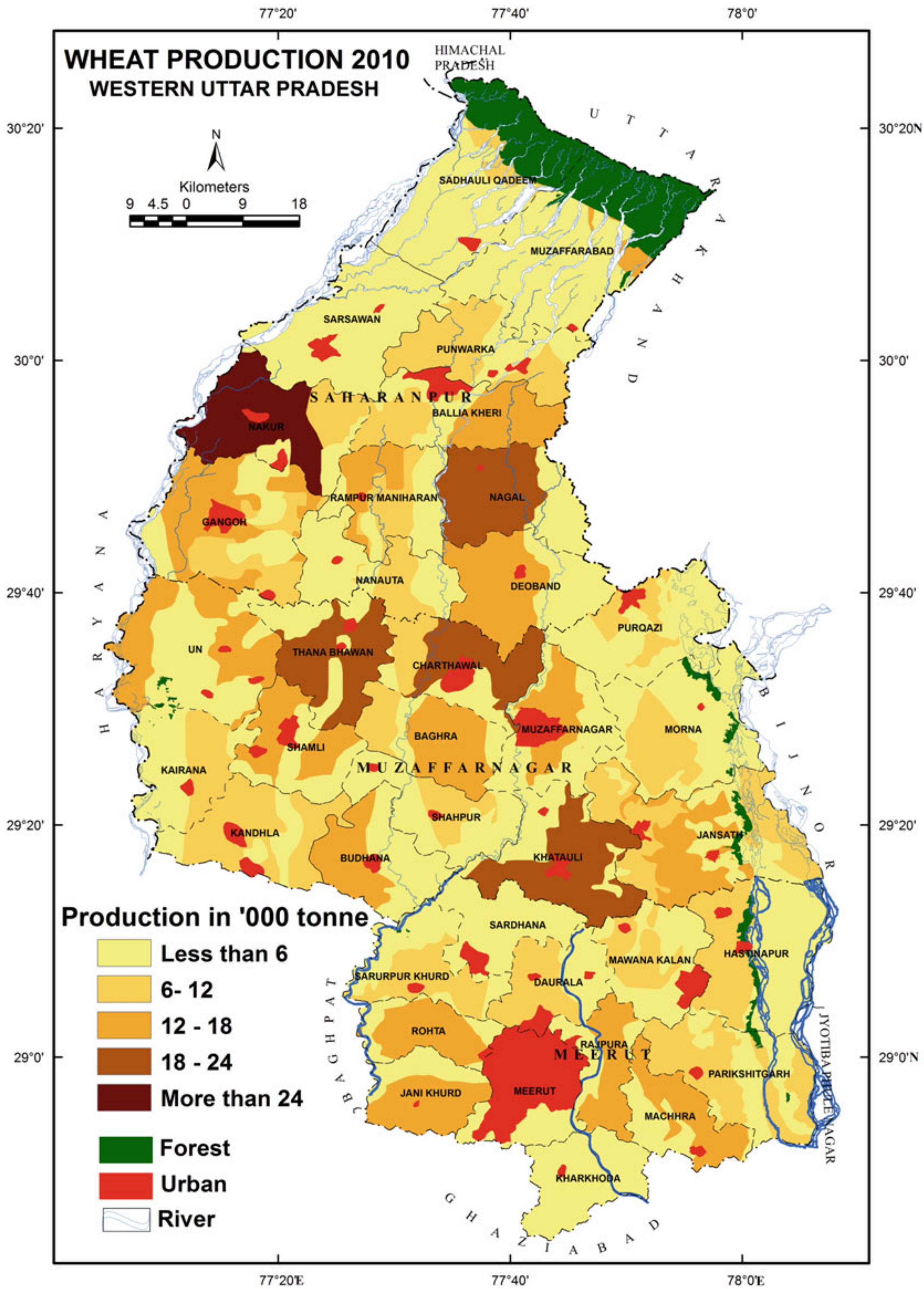

Fig. 13.13 Wheat production (2010)

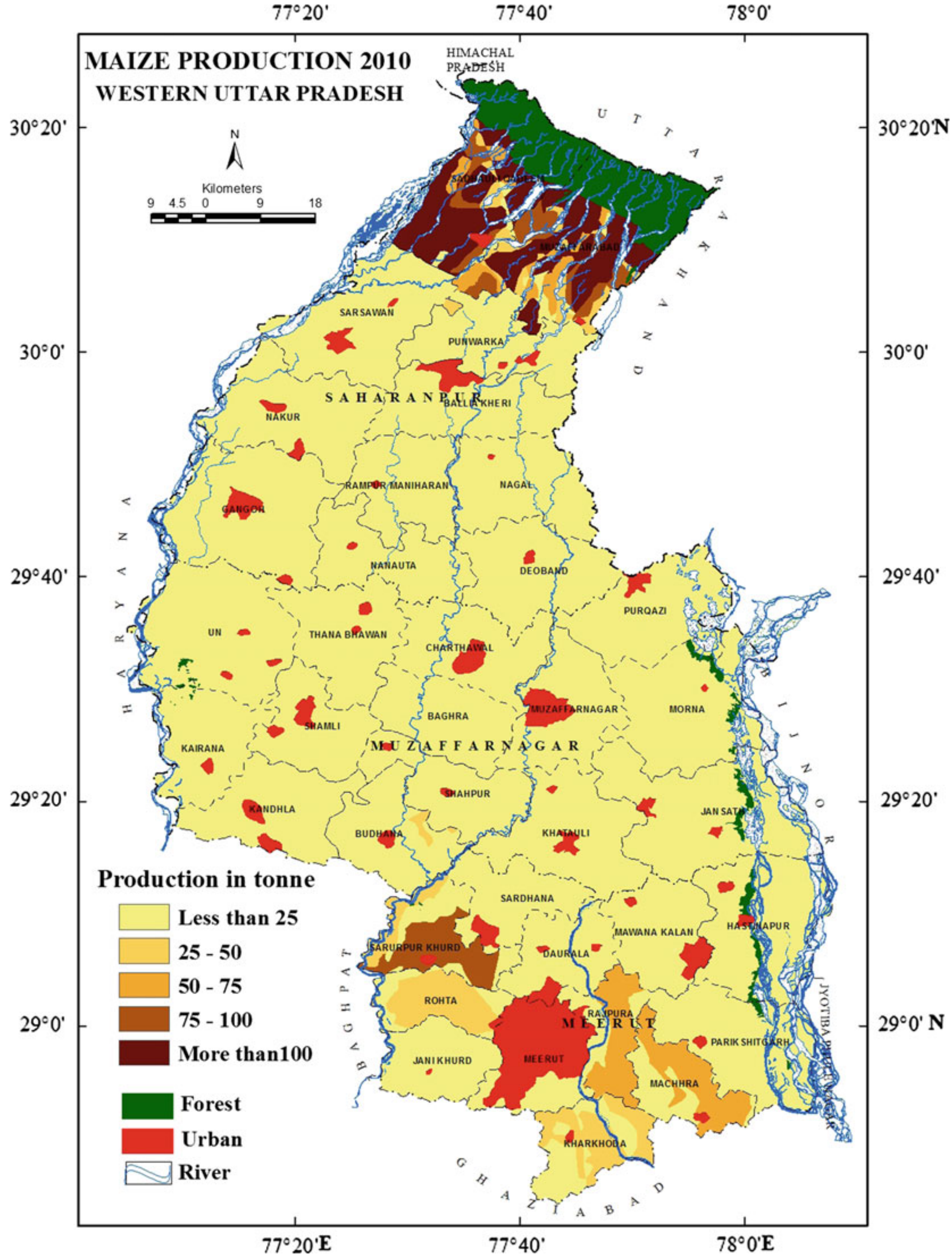

Fig. 13.14 Maize production (2010)

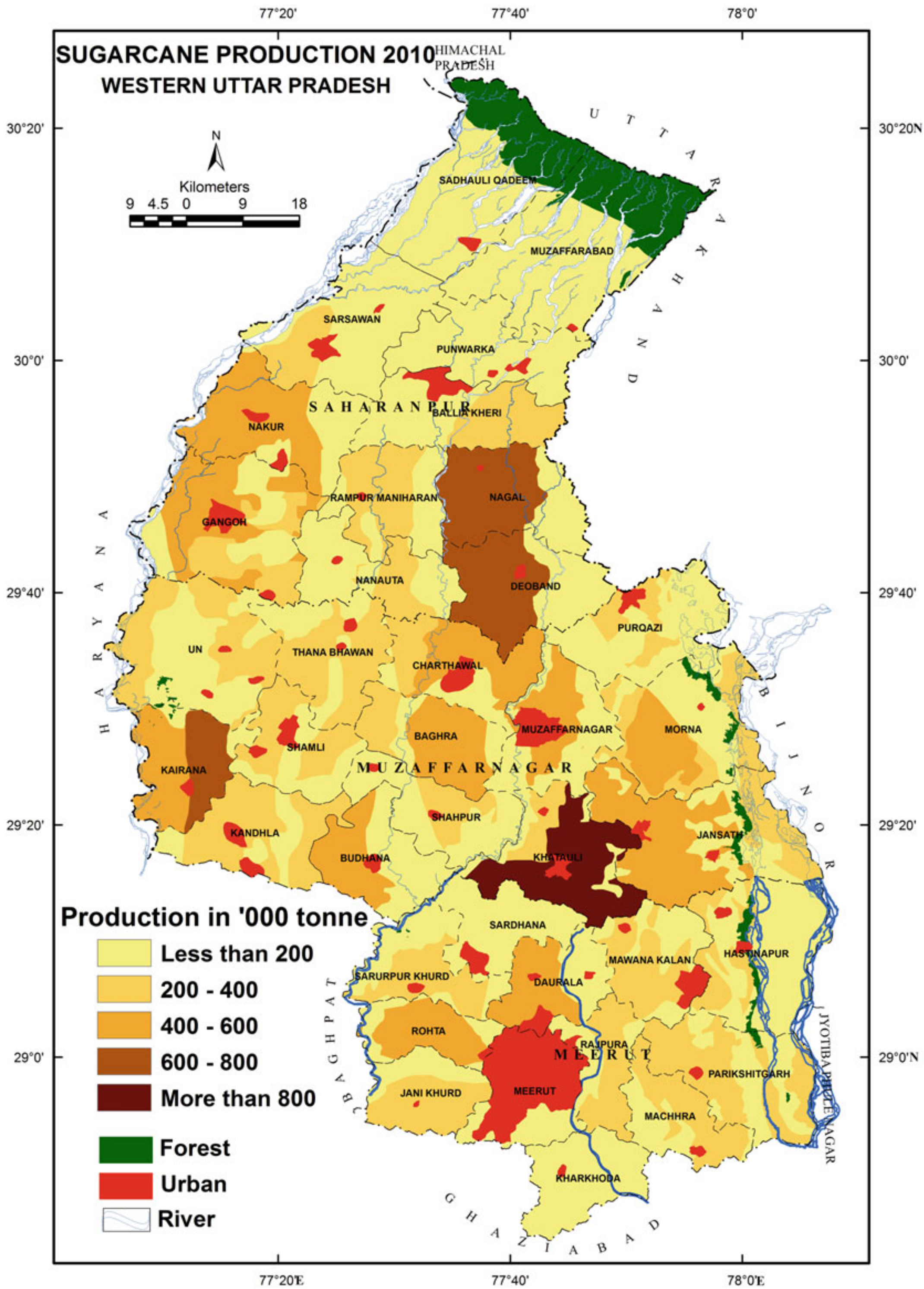

Fig. 13.15 Rice yield (2010)

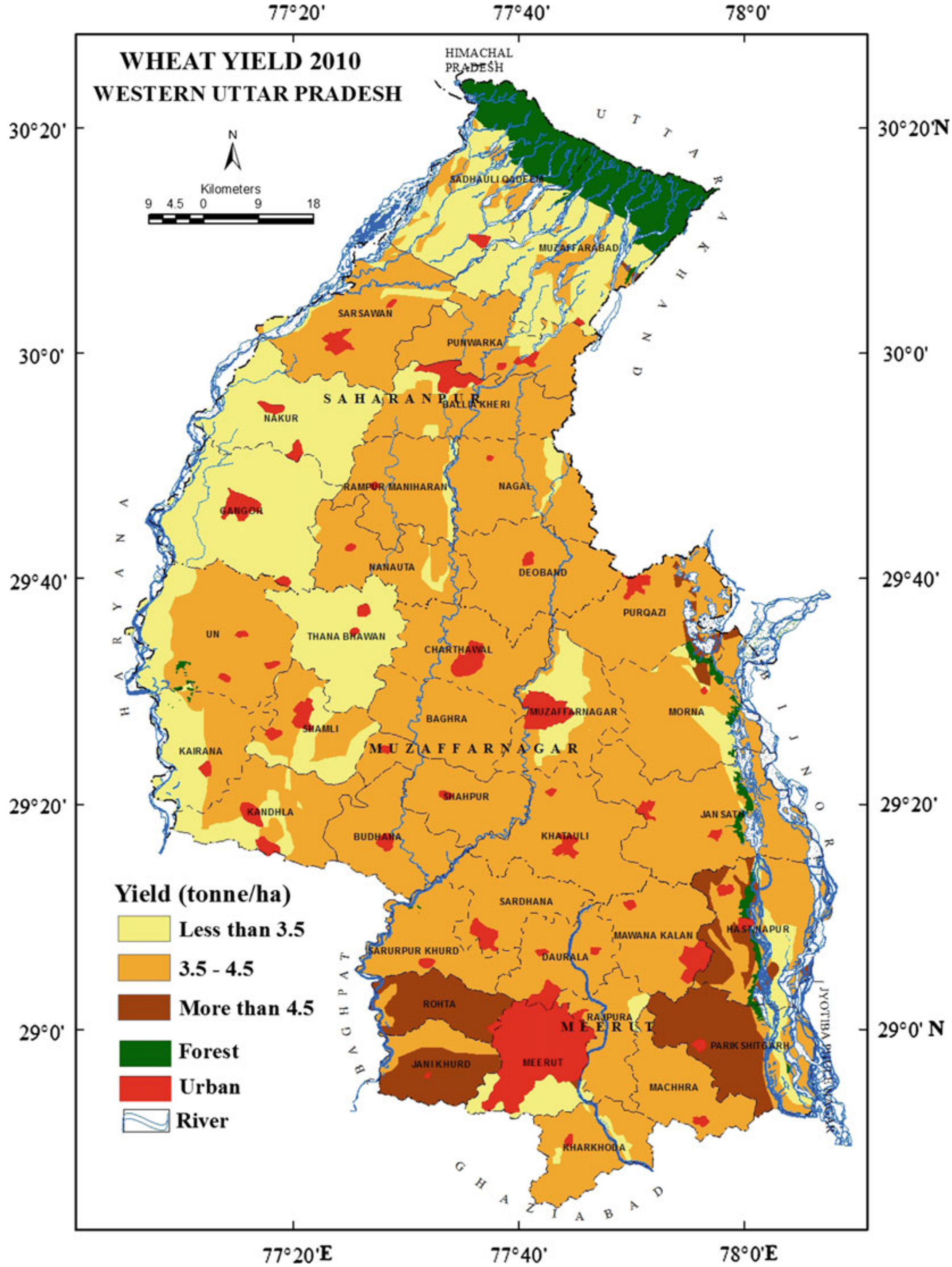

Fig. 13.16 Wheat yield (2010)

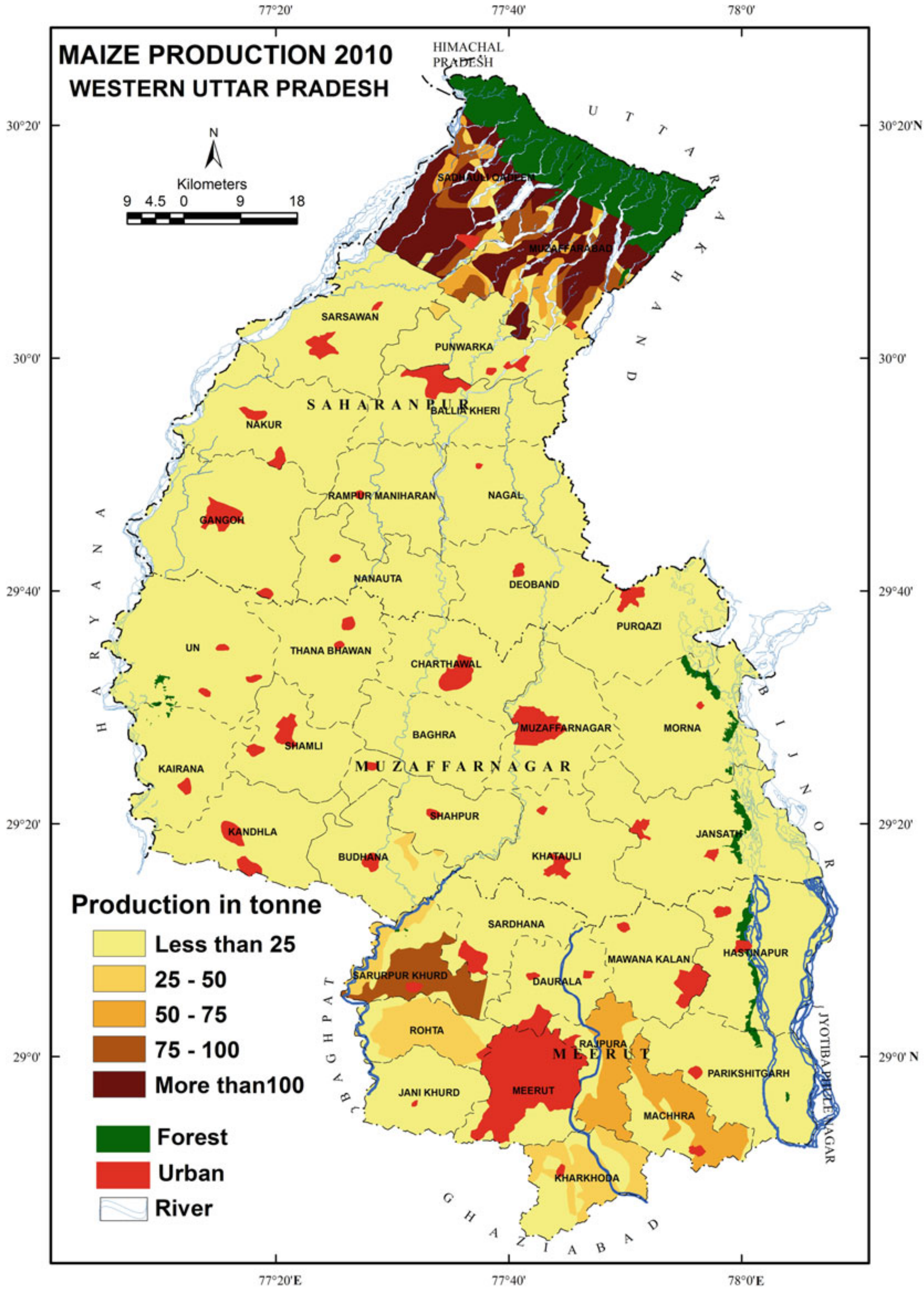

Fig. 13.17 Sugarcane yield (2010)

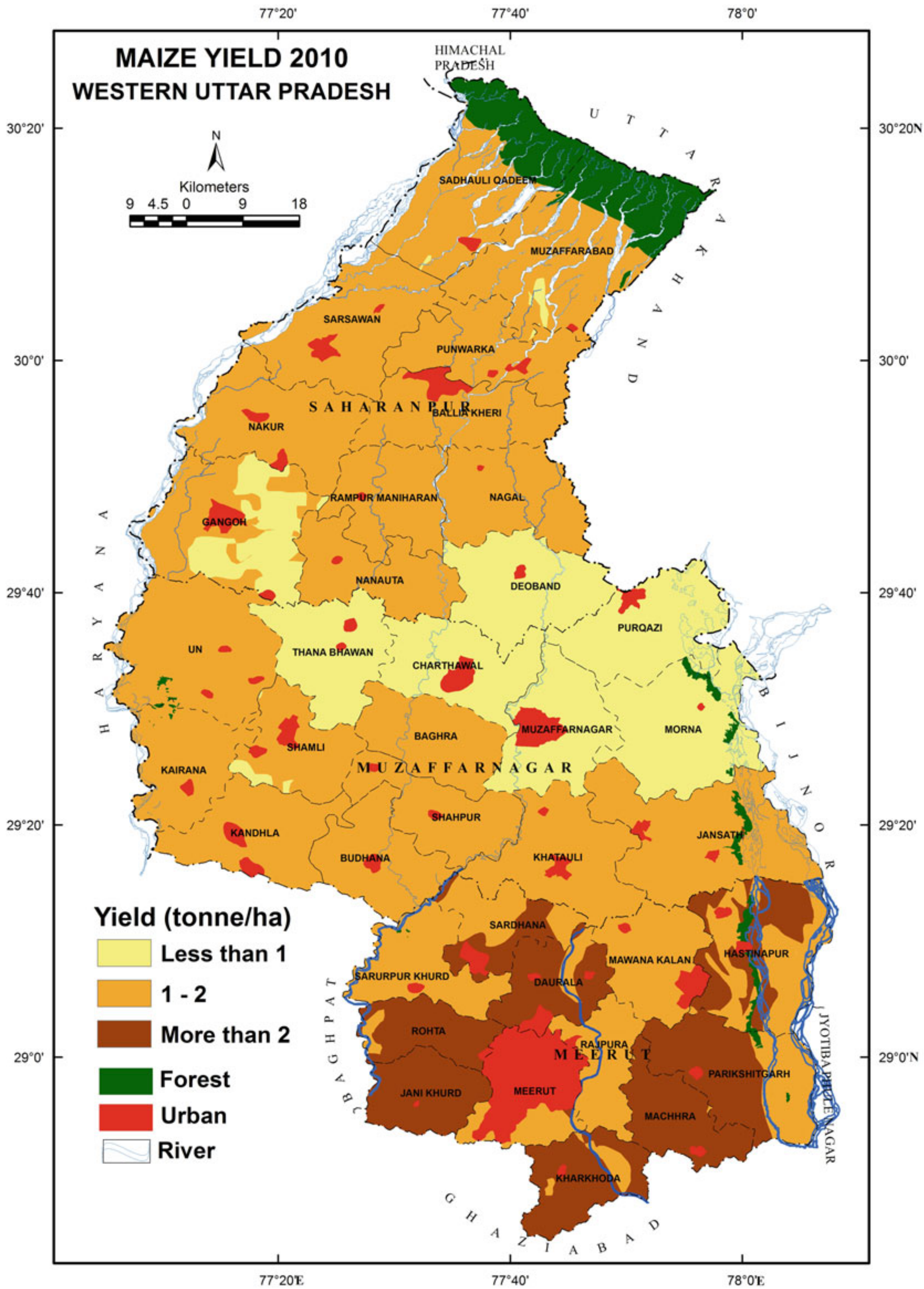

Fig. 13.18 Maize yield (2010)

a network of scientists to provide a platform for scientists and extension workers to build their applications around it and to meet the goals of stakeholders. These models are designed to simulate the effects of weather, soils, agronomic management, nitrogen, water and major pests on crop growth and yield, water and nitrogen management, and greenhouse gases emission. Its general structure is based on a large number of earlier models and the expertise of the scientists involved. In particular, it is based on the MACROS (Penning de Vries et al. 1989), SUCROS (Laar et al. 1997) and WTGROWS (Aggarwal et al. 1994) models. It (InfoCrop) is user-friendly, targeted to increase applications of crop models in research and development, and has simple and easily available input requirements.

The crop models have been developed by specialists in those crops and have been validated in major crop-specific environments in India. The decision-support system also includes databases of typical Indian soils, weather and varieties for applications. Models for rice, wheat, maize, sorghum, pearl millet, potato, sugarcane, cotton, pigeonpea, chickpea, groundnut, mustard and soybean are available in InfoCrop. The interface of InfoCrop was developed in the Microsoft.NET platform using Microsoft.NET technologies. This tool is designed keeping in mind the web revolution and increasing internet usage and has an enhanced and attractive web-based interface to give the user the experience of web-based looks and features, leaving behind the primitive and dull button-based interface used by most earlier applications (Aggarwal et al. 2004).

13.4.4 Estimation of Potential Yield and Yield Gap

A land evaluation scheme was proposed by the Food and Agriculture Organization (FAO), with respect to suitability of land for a range of alternate uses. In this approach, bio-physical environmental features such as climate, relief, soil, hydrology and vegetation could be used to assess land potentiality (FAO 1976), which offers a broad methodological approach. This has gone through subsequent modifications and, with the inclusion of management-related (or 'input') attributes, the land utilisation type (LUT) was defined as a specified production system within a socio-economic setting in which production is carried out. The development of GIS and availability of real-time data from satellite remote-sensing tools and the use of crop-growth simulation models have all created a computational-intensive land evaluation where the yield of crops can be estimated depending on the soil, climate and landform characteristics of each agro-ecological unit under various production environment scenarios. In our study, the FAO main framework was mainly followed with land-use systems adjusted to a specific technology level.

The potential crop production is the capacity of the land, under certain parameters, to achieve maximum production. The analysis about major crops (rice, wheat, sugarcane and maize) in the western Uttar Pradesh reveals that the potentiality of the land according to the InfoCrop model for rice is 8.37 tonnes/ha in Saharanpur and Muzaffarnagar and 8.89 tonnes/ha in Meerut district (Fig. 13.19). The potentiality of wheat in Saharanpur and Muzaffarnagar is 7.27 and 7.89 tonnes/ha in Meerut. The potential of sugarcane is 85 tonnes/ha in the entire study area. The potentiality of maize is 6.02 tonnes/ha in Saharanpur and Muzaffarnagar and 5.84 tonnes/ha in Meerut.

The study about the yield gap reveals that most of the study area has a gap between 5.5 and 6.5 tonnes/ha in rice crops except some regions such as Un, Kairana, Charthawal, Bagara, Khatauli and some parts of Jansath and Purqazi blocks in Muzaffarnagar, which have less than 5.5 tonnes/ha. In Saharanpur district, Punwarka, Ballia Kheri, the *terai* region of Sadauli Qadeem and Muzaffarabad block has a yield gap of less than 5.5 tonnes/ha. Some parts of Meerut district along the river Ganga in Parikshitgarh and south of Meerut city have more than 6.5 tonnes/ha (Fig. 13.19).

A yield gap of less than 3.5 of wheat crop is found in all the blocks of Muzaffarnagar district except Thana Bhawan, Shamli and Kandala block. In the Meerut district, the Rohta, Janikhurd, Rajpura and Parikshitgarh blocks also

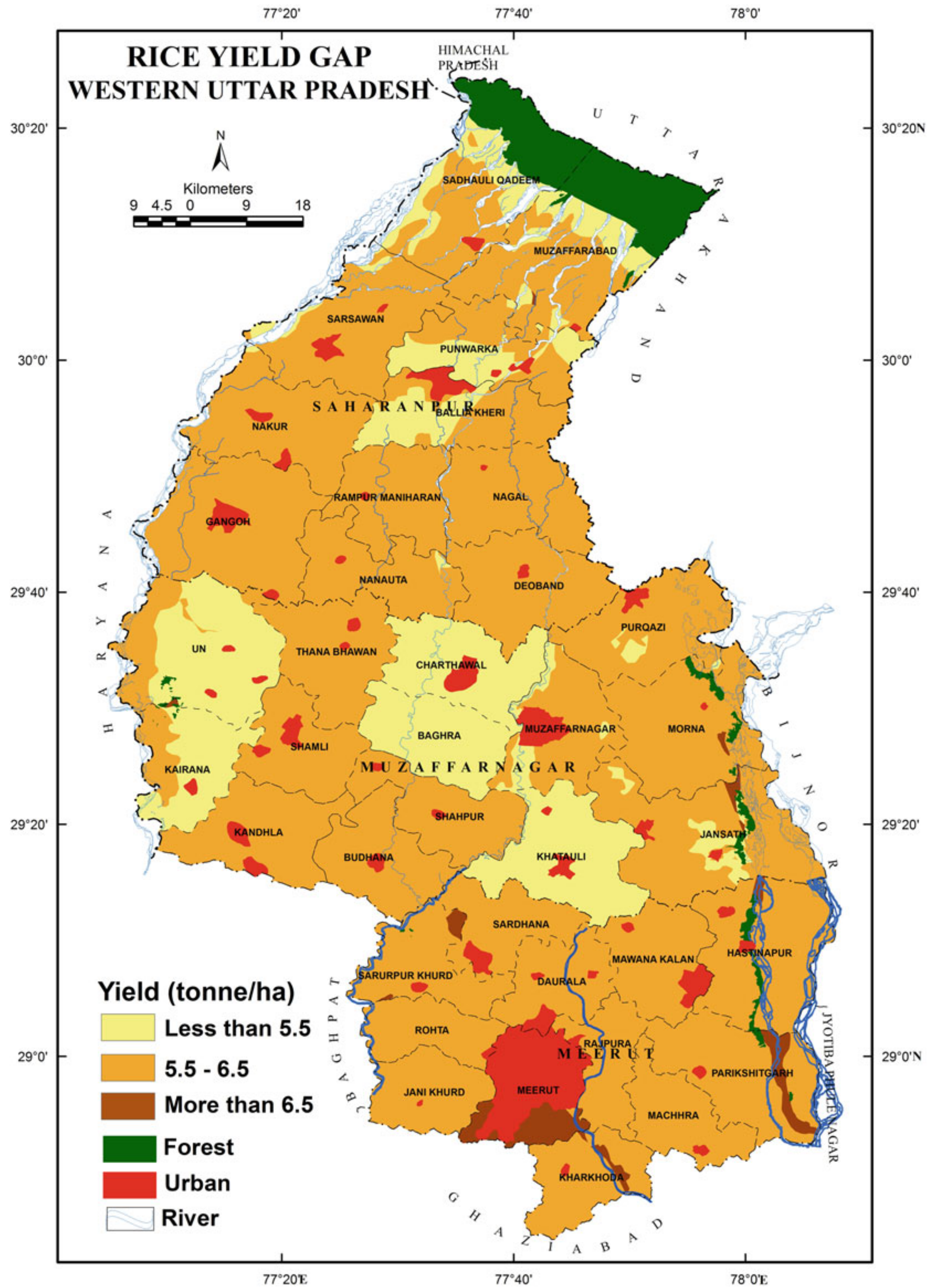

Fig. 13.19 Rice yield gap

have low yield gaps. In Saharapur district, the Ballia Kheri block has less than 3.5 tonnes/ha of yield gap of wheat. The highest yield gap has been found in the southern part of Meerut city and along the Ganga river in Hastinapur and Parikshitgarh block in the Meerut district and some parts of Saharanpur district (Fig. 13.20).

Study of the yield gap of sugarcane crop shows that there is very little scope for further increasing the yield except in the western part of the study area in Nakur, Gangoh in Saharanpur district; Thana Bhawan, Shamli, Kandhala and the western part of Muzaffarnagar block and eastern part along the river Ganga in Muzaffarnagar district; and Sarurpur Khurd, Mawana Kalan in Meerut district. Very few areas in the Gangoh block in Saharanpur district and south of Meerut city have more than 25 tonnes/ha of yield gap in the sugarcane crop (Fig. 13.21).

Maize is one of the major crops from rain-fed areas in the northern part of the Saharanpur district. The yield gap is very high in most of the blocks in Muzaffarnagar due to the area belonging to sugarcane crop. In Meerut district, all the blocks have a far smaller yield gap under maize crop (Fig. 13.22).

13.4.5 Bridging the Yield Gap

The yield gaps calculated are not fulfilled by current technology. The irrigation and fertiliser inputs are required to bridge the estimated yield gaps. The irrigation water and Nitrogen (N), Phosphorus (P) and Potash (K) fertiliser requirements were calculated for each land unit using the simulation model – QUEFTS (quantitative evaluation of the fertility of tropical soils) (Janssen et al. 1990). The gap can be minimised through the following five technology levels.

1. Current crop yield
2. 25% bridging potential crop yield gap
3. 50% bridging potential crop yield gap
4. 75% bridging potential crop yield gap
5. 100% bridging potential crop yield gap

At the same time, the amount of additional inputs required to achieve higher yields has led to environmental consequences like more extraction of groundwater, leaching of Nitrogen, greenhouse emissions etc.

These technology levels should be chosen as the best alternatives, but a balance between higher production and environmental security needs to be struck. The irrigation requirement corresponding to a particular crop was the same in all these land units. The irrigation water requirement in rice has to be increased from a current level of 860 mm to 1176 and 1492 mm at technology levels 2 and 3, respectively; thereafter, the irrigation requirement does not vary. In wheat, the irrigation water requirement was computed as 160 mm at current levels and 457 mm at potential yield levels, indicating a current gross loss of applied irrigation water. This calls for immediate attention to maximise the irrigation efficiency, so as to improve crop-water-use efficiency.

In general, fertiliser NPK use varied in accordance with the cropping system, farmer's land-holding size and available resources in western Uttar Pradesh. Of the total NPK use, N's share stands at 68–71%, indicating the fertiliser management practices of the region are highly imbalanced and may not sustain high productivity in the long run (Singh et al. 2012). The model suggests that the fertiliser requirement significantly varies in the study area. The fertiliser N requirement needs to be increased by 1.8, 2.6, 2.9 and 3.2× from its current dose in order to reach technology levels 2, 3, 4 and 5, respectively. The P fertiliser's dose of application has to be increased by 1.6, 2.1, 2.5 and 2.7× for levels 2, 3, 4 and 5, respectively. However, the dose of K fertiliser may remain the same up to technology level 3 and thereafter it may be increased by nearly 1.5× the amount of current levels for both rice and wheat (Kaur et al. 2013).

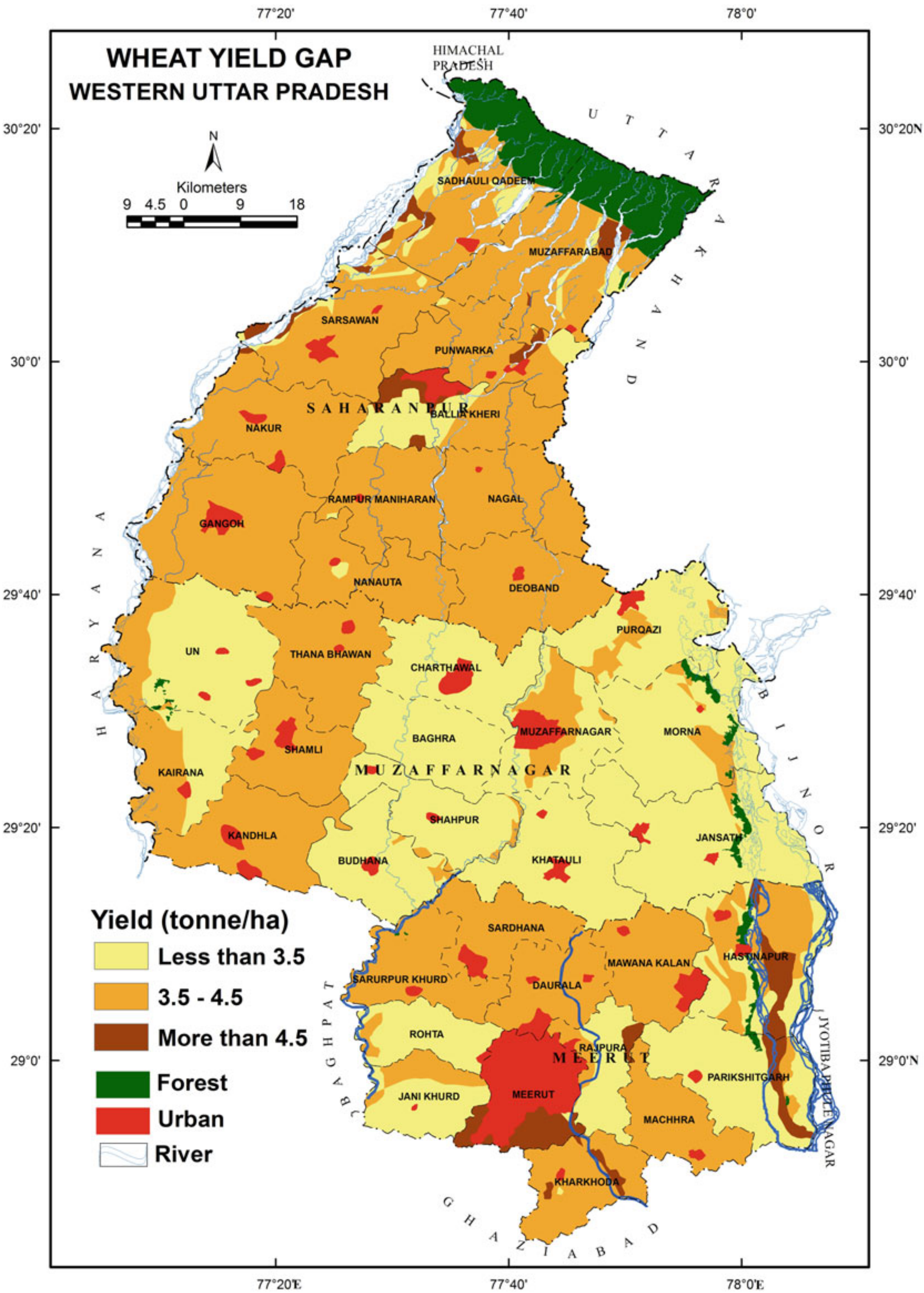

Fig. 13.20 Wheat yield gap

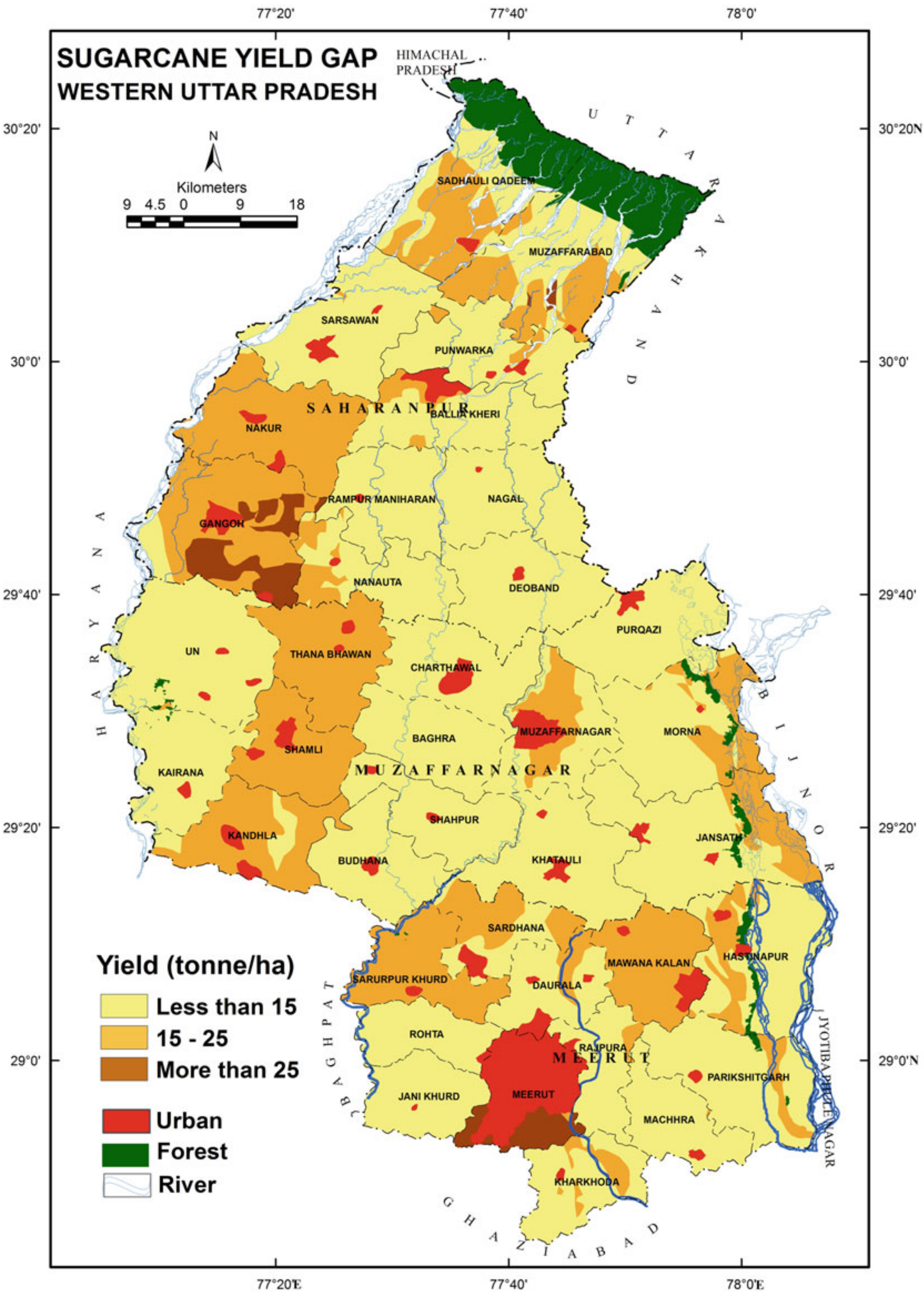

Fig. 13.21 Sugarcane yield gap

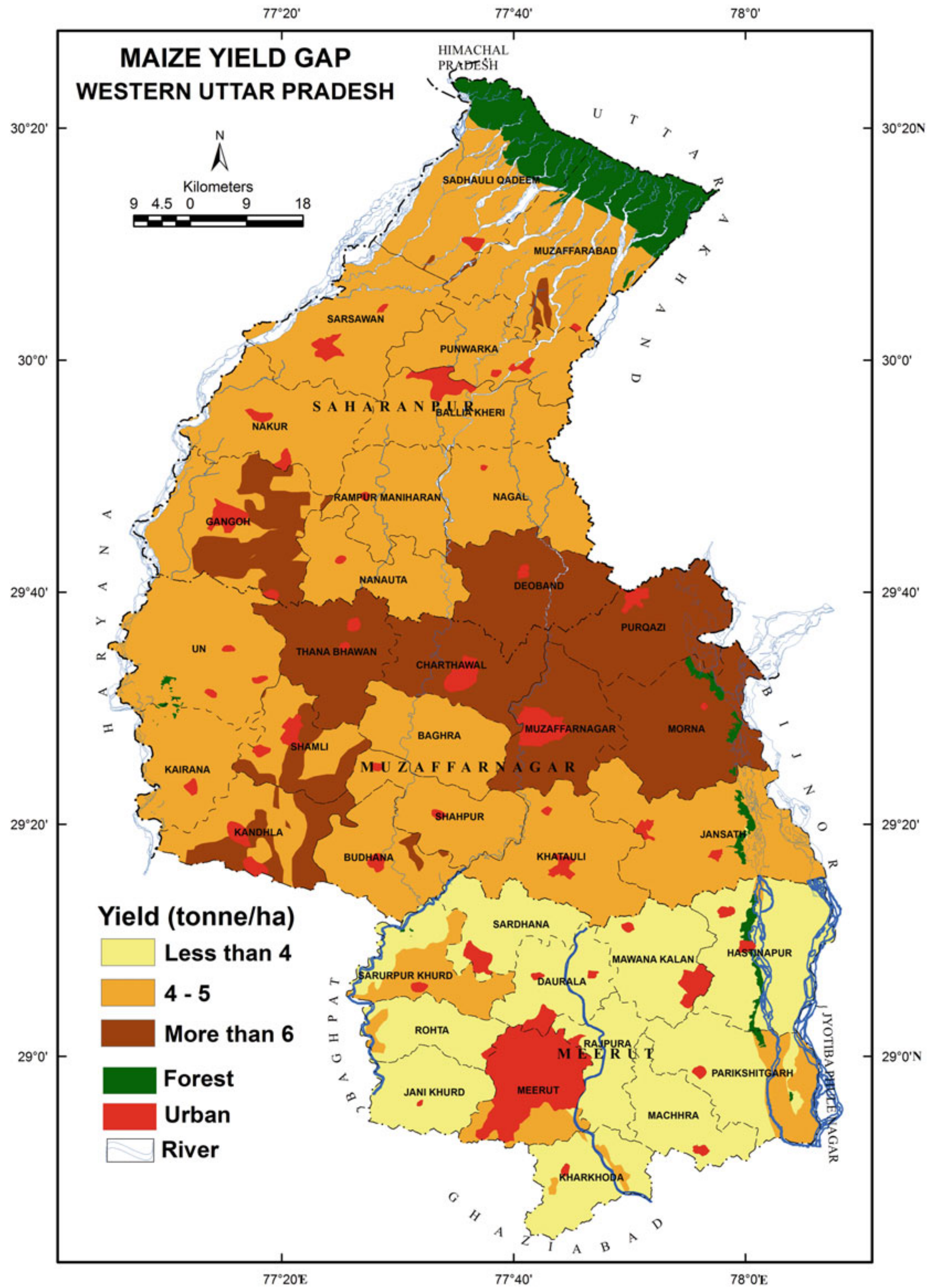

Fig. 13.22 Maize yield gap

13.5 Conclusion

The present study shows that there are possibilities to increase the productivity of the soil by utilising geospatial components such as remote sensing, GIS, GPS and simulation models like InfoCrop and QUEFTS in an integrated manner for planning, enhancing optimal productivity and exploring resource and input management options. The analysis reveals that the study area has 38 soil units, 78 agro-ecological units and 417 land units which have enormous potential for further development of resources for agricultural purposes. The data about the yield of rice, wheat, sugarcane and maize crops show that it is possible to increase the crop yield through proper management of the input of irrigation and organic and inorganic fertilisers. The present study will contribute to the required input for policymakers and other agencies for planning the best use of the available resources in order to improve the socio-economic and environmental conditions of the region as well as develop new policies and strategies for sustainable development.

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14 Spatial Information Technology Applications in Other SDGs

Abstract

Spatial information technology has wide applications for humankind. With the advent of the latest technology, spatial information technology has improved the capacity to resolve complex issues in digital environments and modelling for the future. There are 17 Sustainable Development Goals (SDGs) to be fulfilled by 2030. The present study highlights the role of spatial information technology in SDGs, such as: no poverty, zero hunger, good health and well-being, quality education, gender equality, clean water and sanitation, affordable and clean energy, decent work and economic growth, sustainable cities and communities, life below water, peace, justice and strong institutions and partnerships for the goals. This technology provides comprehensive digital database creation, analysis and mapping facilities of past and present scenarios as well as future modelling.

Keywords

Zero hunger · Inclusive and equitable education · Empowerment of women · Sustainable economic growth · Resilient infrastructure

14.1 Introduction

Spatial information technology has the capacity to create, analyse, model and develop the spatial applications and visualisation of geographical phenomena and features. The development of new databases and updation of existing databases in a timely manner is an important feature of the technology that enables us to create analysis activities such as: relationship between features, clustering, aggregation, statistics generation by using overlay, buffer and networking processes. The output of the geospatial database is depicted through visualisation techniques in the form of maps, charts and statistics in hard and soft copies. With the advantage of programming applications, interactive maps and web apps, new tools are developed for analysis and geo-visualisation. Thus, spatial information technology provides comprehensive mapping facilities of past, present and future scenarios to help achieve SDGs in a timely manner.

14.2 Goal 1: No Poverty: End Poverty in All Its Forms Everywhere by 2030

The SDG 1 target is to eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day. Poverty

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means 'the state of being extremely poor' or in other words, the state of being inferior in quality or insufficient in amount. Basically, it refers to the complete lack of basic needs for livelihood such as food, clothes and shelter. India accounted for the largest number of people living below the international poverty line in 2013 with 30% of its population under the $1.90 per-day poverty measure of the World Bank. Information about poverty and tracking progress toward this goal is very important to alleviate this issue. Here remote sensing and GIS play an important role to provide high-resolution satellite data, which is continuously mapping the Earth and providing socio-economic indicators of poverty and wealth such as poor and rich colonies (Fig. 14.1). The World Bank has also prepared a map showing the country-level poverty estimates used to generate the 2013 regional and global poverty estimates, which draw on data from more than two million randomly sampled households, representing 87% of the total population in 138 low-, middle- and high-income countries (www.worldbank.org) (Fig. 14.2). Target 1.2 is to reduce half of the

Fig. 14.1 Rich and poor neighbourhoods in parts of Delhi, India (*Source* https://www.google.co.in/maps/@28.568947,77.1736174,146m/data=!3m1!1e3?hl=en)

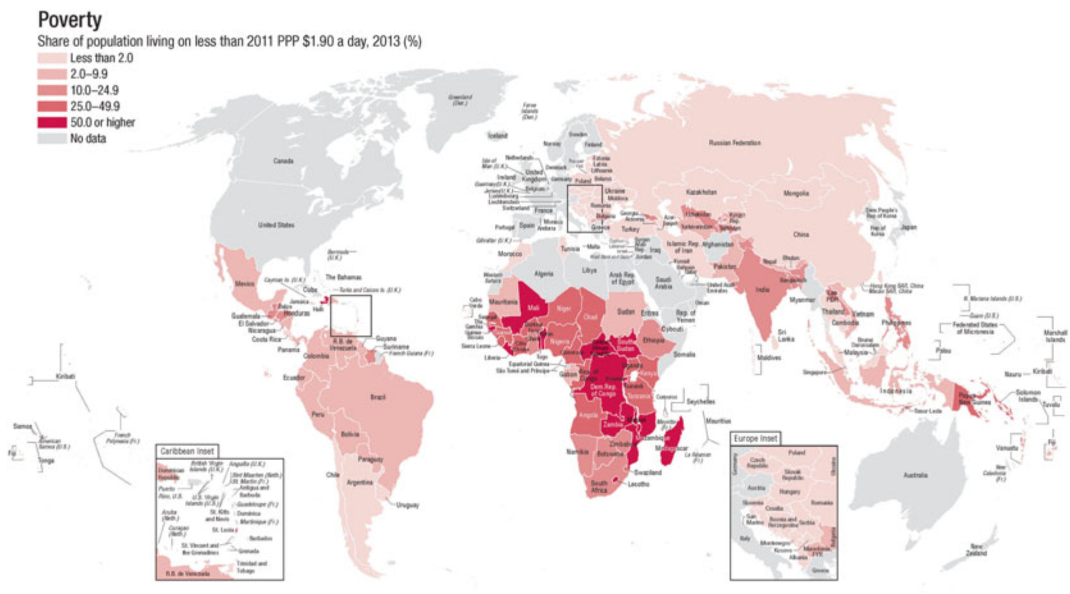

Fig. 14.2 Poverty map of the world (*source* www.worldbank.org)

proportion of men, women and children of all ages living in poverty by 2030. In this regard timely information about the proportion of the population living below the national poverty line by age and sex can be mapped to show regional and local disparity.

14.3 Goal 2: Zero Hunger: End Hunger, Achieve Food Security, Improve Nutrition and Promote Sustainable Agriculture

The target of SDG 2 is to end hunger and ensure access by all people – in particular the poor and people in vulnerable situations, including infants – to safe, nutritious and sufficient food by the year 2030. Spatial information technology is capable of providing information on sustainable agriculture and food security by the continuous monitoring and assessment of environmental conditions. FAO also produces a broad series of geospatial data and information from land-use/cover changes to map poverty for policy formulation at various levels and to meet the SDGs. This means ensuring sustainable food production systems, implementing resilient agricultural practices and increasing productivity and production that helps to maintain ecosystems that strengthen capacity for adaptation to climate change, extreme weather, droughts, flooding and other disasters and that progressively improve land and soil quality. A case study on ‘Crop Modelling for Sustaining Agriculture Productivity’ is discussed to demonstrate the role of spatial information technology (Fig. 14.3).

14.4 Goal 3: Good Health and Well-Being: Ensure Healthy Lives and Promote Well-Being for All at All Ages

The SDG 3 target is to reduce the global maternal mortality ratio to less than 70 per 100,000 lives. This means putting an end to preventable deaths of newborns and children under 5 years of age with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1000 live births, and under-5 mortality to at least as low as 25 per 1000 live births. Despite the gains achieved during the Millennium Development Goal (MDG) era, every day 16,000 children under the age of 5 still die. During 1990 to 2015, 236 million children died before reaching their fifth birthday (United

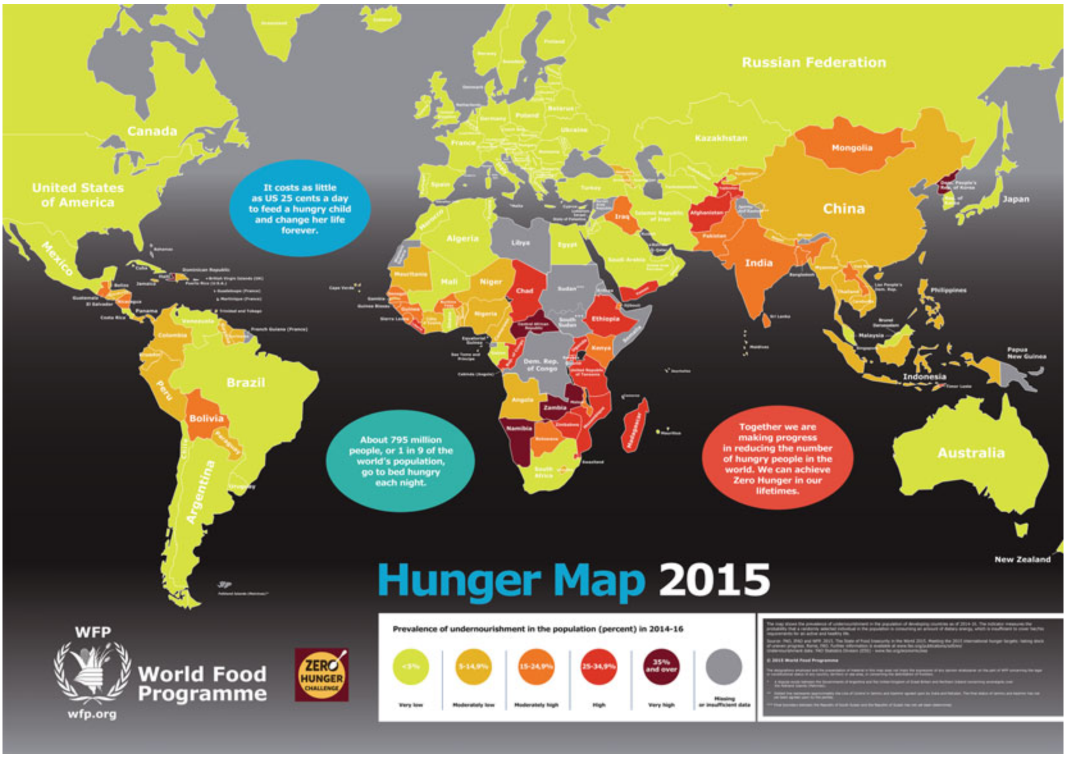

Fig. 14.3 Hunger map of the world 2015 (*source* http://documents.wfp.org/stellent/groups/public/documents/communications/wfp275057.pdf?_ga=2.31474430.1783817753.1514181170–910013392.1514181170)

Nations International Children's Emergency Fund [UNICEF]). According to United Nations Inter-agency Group for Child Mortality Estimation (UN IGME), Sub-Saharan Africa remains the region with the highest under-5 mortality rate in the world, and when including figures for South Asia this accounts for more than 80% of global under-5 deaths (Fig. 14.4). The spatio-temporal information about infant mortality rates of two time periods in India is shown in Fig. 14.5. United Nations International Children's Emergency Fund has also estimated the achievement of the SDG's target on child mortality by year and country (Fig. 14.6). By 2030, it forecasts the end of the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and the further combatting of hepatitis, waterborne diseases and other communicable diseases. Spatial information technology has been successfully implemented for over 50 years in examining the role of environmental factors in waterborne, airborne, soil-borne and vector-borne diseases. The World Health Organization (WHO) also recognises the capability of geospatial technology and applied it in the elimination of leprosy (http://www.who.int/lep/monitor/gis/en/index2.html). Location is the most important factor in health-related issues. It may be the location of a specific disease or of health facilities available.

14.5 Goal 4: Quality Education: Ensure Inclusive and Equitable Quality Education for All and Promote Lifelong Learning

Spatial information technology plays an important role in analysis, policy formulation and decision-making in the field of education systems. In order to achieve SDG 4, it is necessary to find up-to-date information about literacy rates,

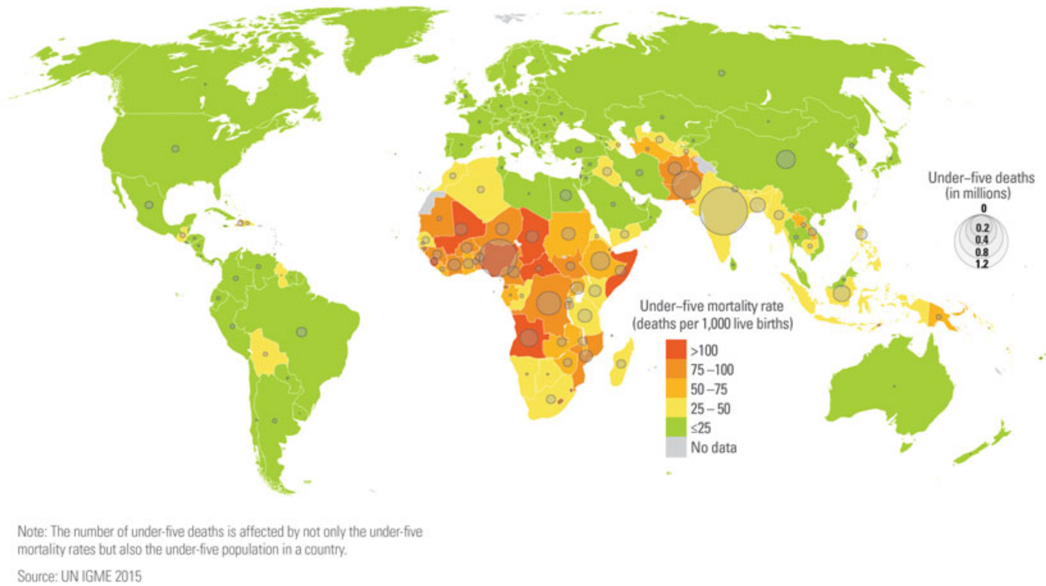

Fig. 14.4 Under-5 mortality rate and under-5 deaths by country, 2015 (*source* UN IGME, 2015)

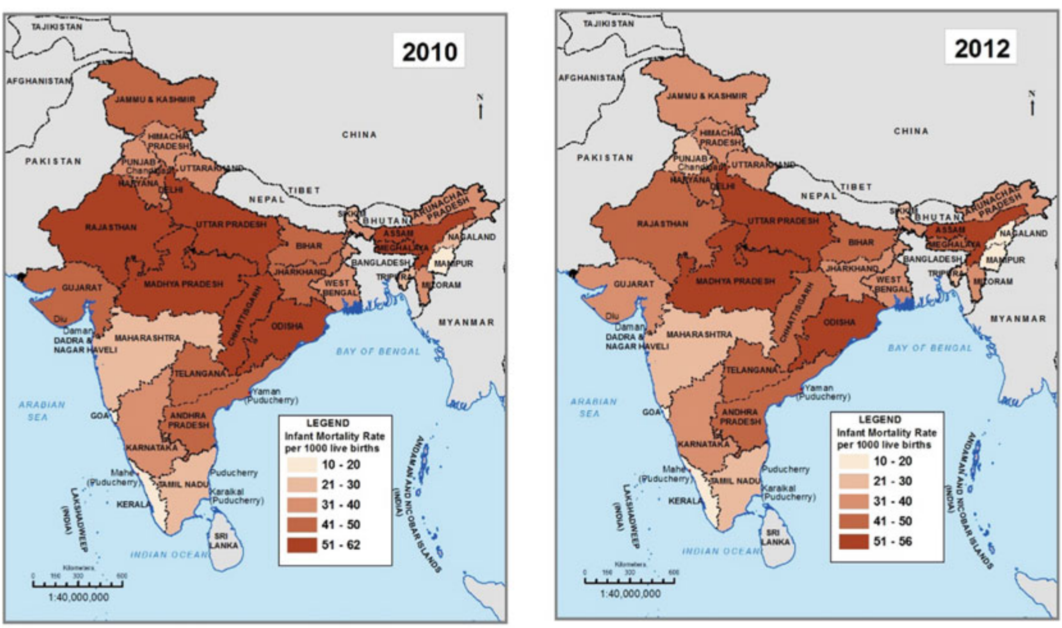

Fig. 14.5 Infant mortality rate in India (*source* Census of India)

education facilities, the number of educational institutes, the number of school-going boys and girls, student–teacher ratios, infrastructure available in schools etc. Information about literacy rates, primary schools, middle schools and adult literacy centres in Bhojpur district in Bihar, India is shown in Fig. 14.7. Such information is very important for making any decision for quality education for all (Fig. 14.7). According to UNICEF, more than half of countries and areas worldwide have achieved or nearly achieved universal primary education (Fig. 14.8).

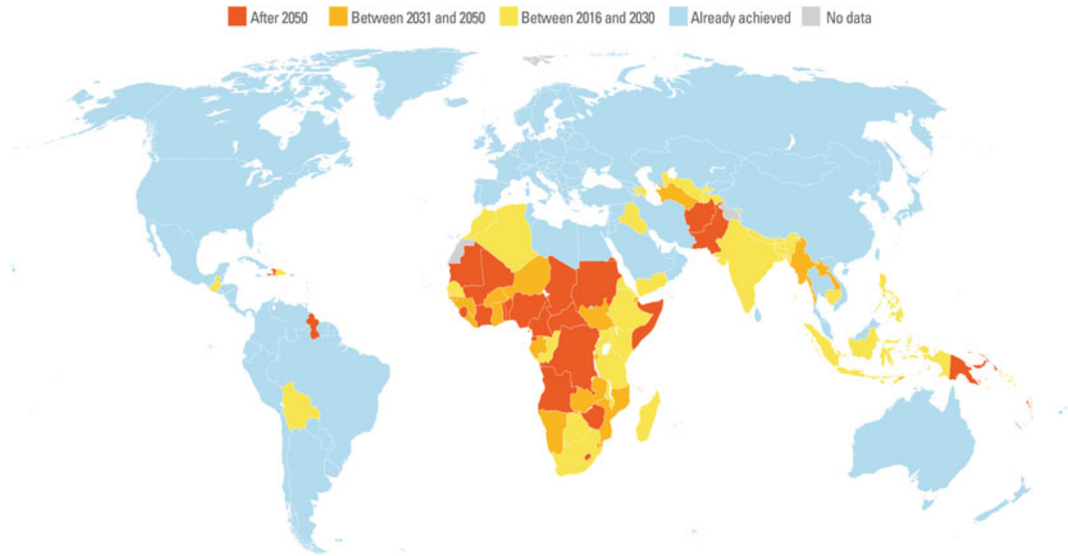

Fig. 14.6 Achievement of SDG targets on child mortality by year and country (*source* UNICEF analysis based on UN IGME, 2015)

The literacy rate among youth and adults is showing increasing trends because of the expansion of educational opportunities. Globally, the youth literacy rate increased from 83% to 91% during 1985 to 2013. The spatial distribution of youth literacy (Fig. 14.9) shows that countries in West and Central Africa have a very low literacy rate.

14.6 Goal 5: Gender Equality: Achieve Gender Equality and Empower All Women and Girls

The dictionary meaning of gender equality is the state in which access to rights or opportunities is unaffected by gender. According to UNICEF, this means that women and men, and boys and girls, enjoy the same rights, resources, opportunities and protection. Gender equality refers to the equal rights, responsibilities and opportunities of women and men and girls and boys. Equality does not mean that women and men will become the same but that women's and men's rights, responsibilities and opportunities will not depend on whether they are born male or female. Gender equality implies that the interests, needs and priorities of both women and men are taken into consideration, recognising the diversity of different groups of women and men. Gender equality is not a women's issue but should concern and fully engage men as well as women. Equality between women and men is seen both as a human rights issue and as a precondition for, and indicator of, sustainable people-centred development (http://www.un.org/womenwatch/osagi/gendermainstreaming.htm). The SDGs offer a historic opportunity to pursue transformational measures to ensure equality for every woman and girl. Investing in women's economic empowerment sets a direct path towards gender equality, poverty eradication and inclusive economic growth. The inclusion of women and girls in the economy and the provision of safe working and public spaces must be accompanied by measures to prevent violence against women and girls, and enable them to participate fully in society and contribute to the health and prosperity of their communities. In India, Haryana State ranked at the bottom in terms of sex ratio at birth, with 857 girls for every 1000 boys in 2012.

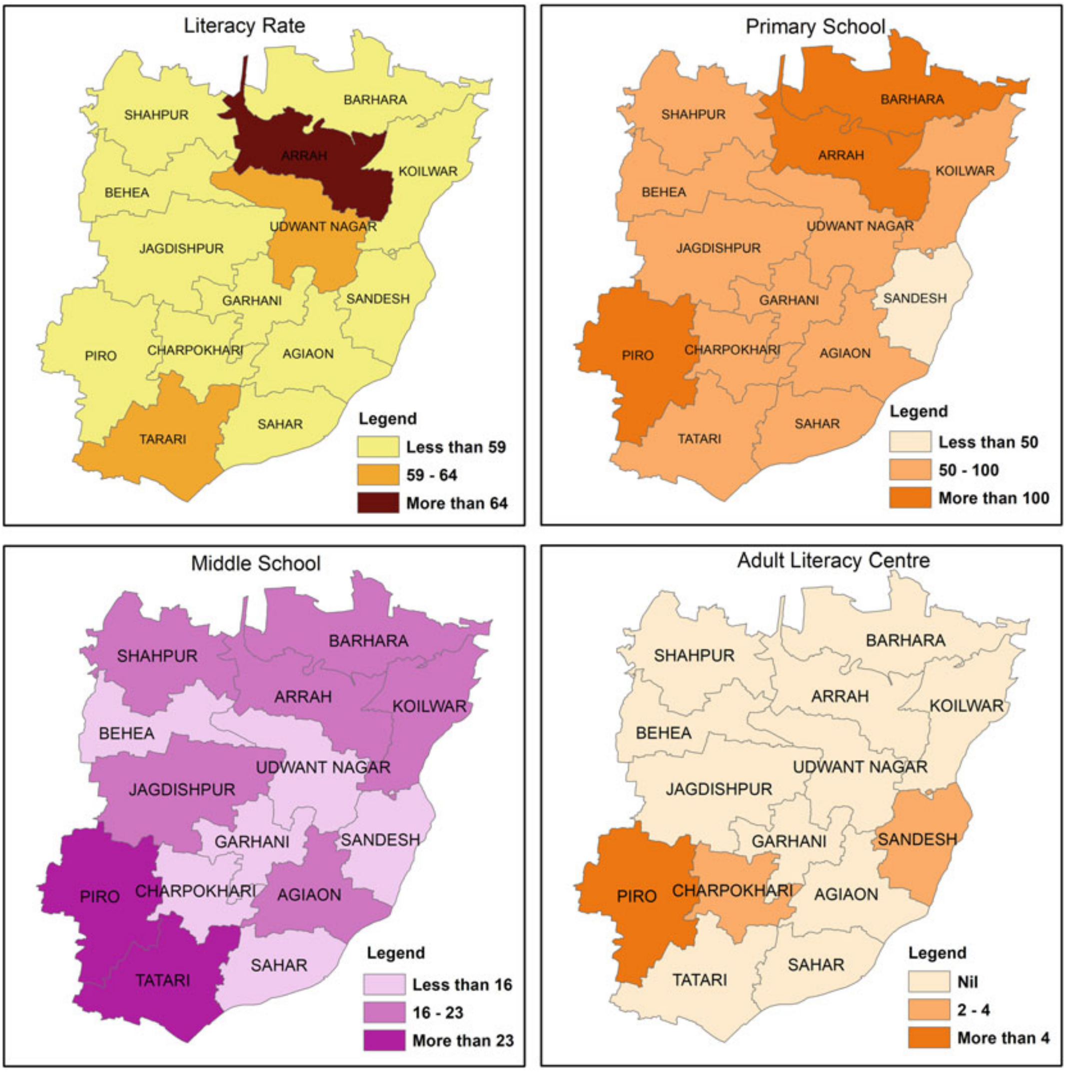

Fig. 14.7 Information about education such as literacy rates, distribution of primary, middle schools and adult literacy centres in Bhojpur district, Bihar, India

This number was 868 in 2013, 871 in 2014 and 876 in 2015. Because of the government's signature *Beti Bachao, Beti Padhao* campaign to save and educate the girl child, Haryana's daughters have a new spirit of life and empowerment (http://paper.hindustantimes.com/epaper/viewer.aspx, dated 21 December 2017) (Fig. 14.10). So the spatial distribution of the sex ratio is very useful for the formulation of plans for the development of women (Fig. 14.11).

The Woman Stats Project is a team of students dedicated to the continual expansion of the WomanStats Database, as well as the pursuit of a research agenda assessing the relationship between the situation and security of women with the aid of maps available on its website (www.womanstats.org). Various issues related to women are mapped, such as child marriage for girls, practice and laws, maternal mortality rate, birth rate, life expectancy of women etc. (Fig. 14.12). Various government initiatives aim

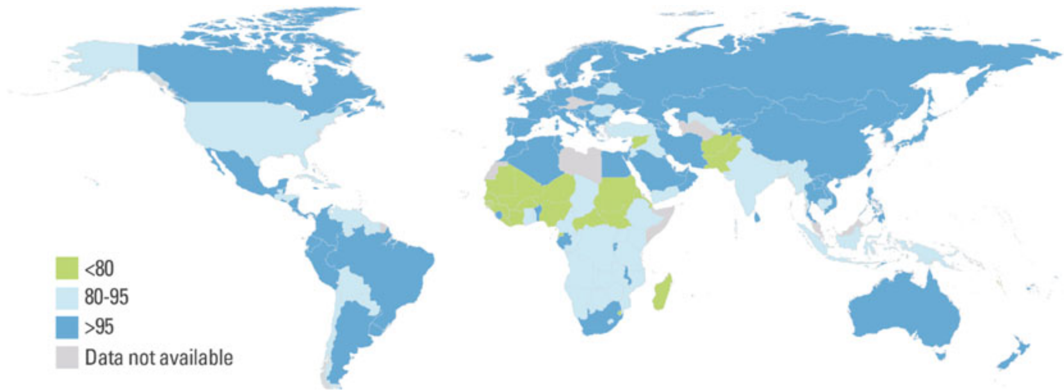

Fig. 14.8 Primary school net enrolment rate or net attendance rate (percentage), 2015

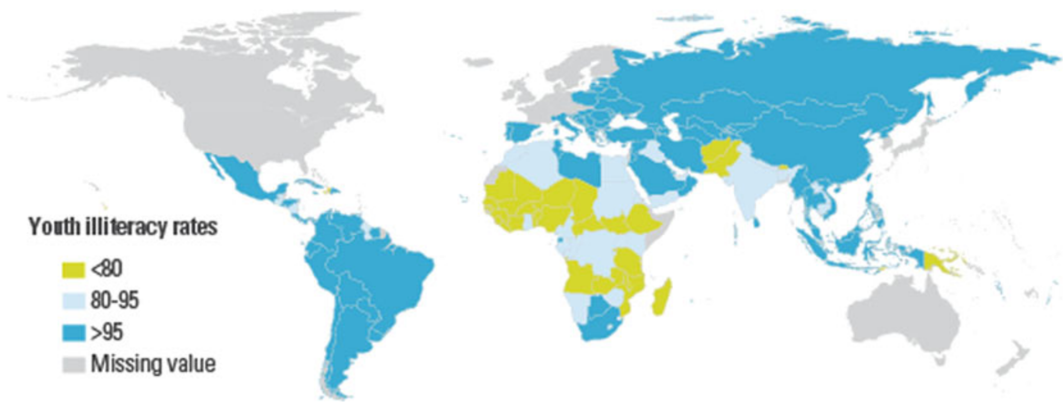

Fig. 14.9 Youth illiteracy rates, 2014

at improving women's physical and societal well-being.

14.7 Goal 6: Clean Water and Sanitation: Ensure Access to Water and Sanitation for All

Geospatial technology is widely applied to provide spatial information on clean water and sanitation. Achieving universal and equitable access to safe and affordable drinking water for all is one of the targets of this goal (Singh and Kumar 2014). Huge disparities lie in access to drinking water (Mathur et al. 2005). Developed countries have achieved the goal but less-developed countries are still miles away, particularly those in Saharan Africa where less than 50% of the population have access to basic drinking water (Fig. 14.13).

The figure shows that between 91% and 100% of the population has access to basic drinking water, except in Africa and South Asia. Besides this global data, there is a large disparity within countries (see Chap. 12, Fig. 12.3). Target 6.2 is to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations. WHO/UNICEF JMP is monitoring the data on drinking water, sanitation and hygiene (WASH). Simultaneously, they are providing their services through various forms of visualisation techniques (Fig. 14.14).

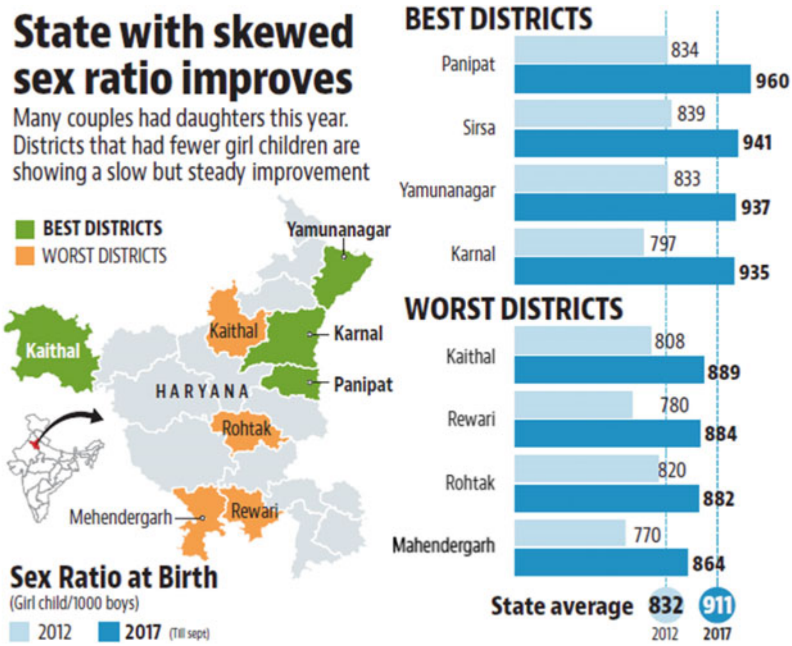

Fig. 14.10 Improved sex ratio in Haryana, India

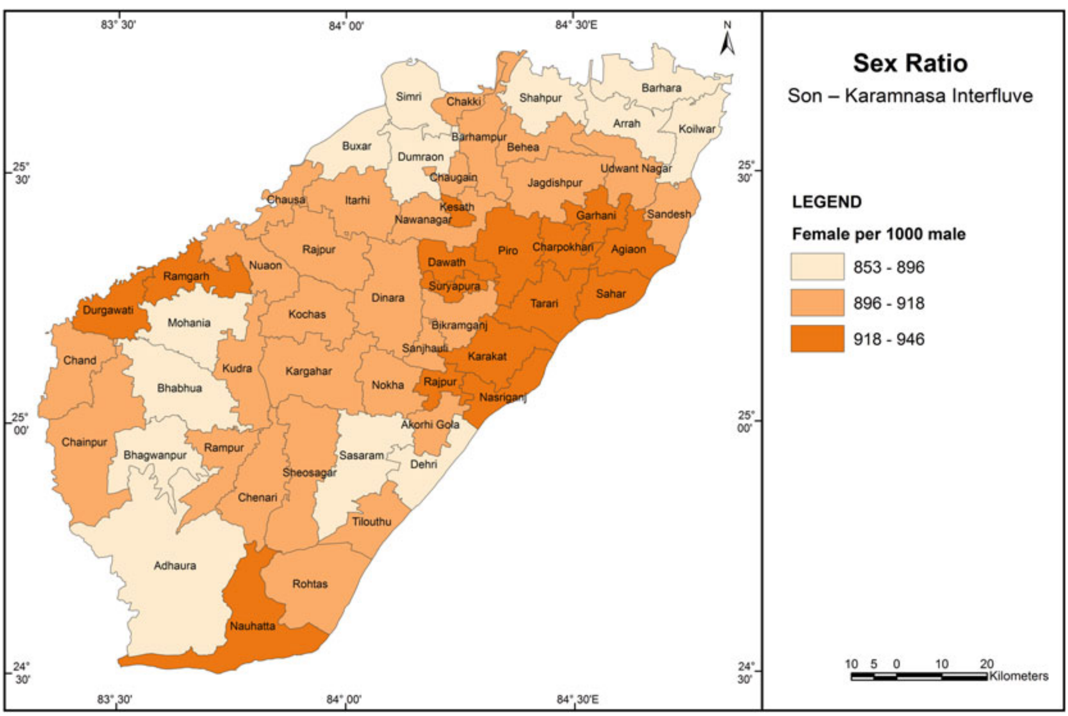

Fig. 14.11 Spatial distribution of sex ratio in parts of Bihar, India

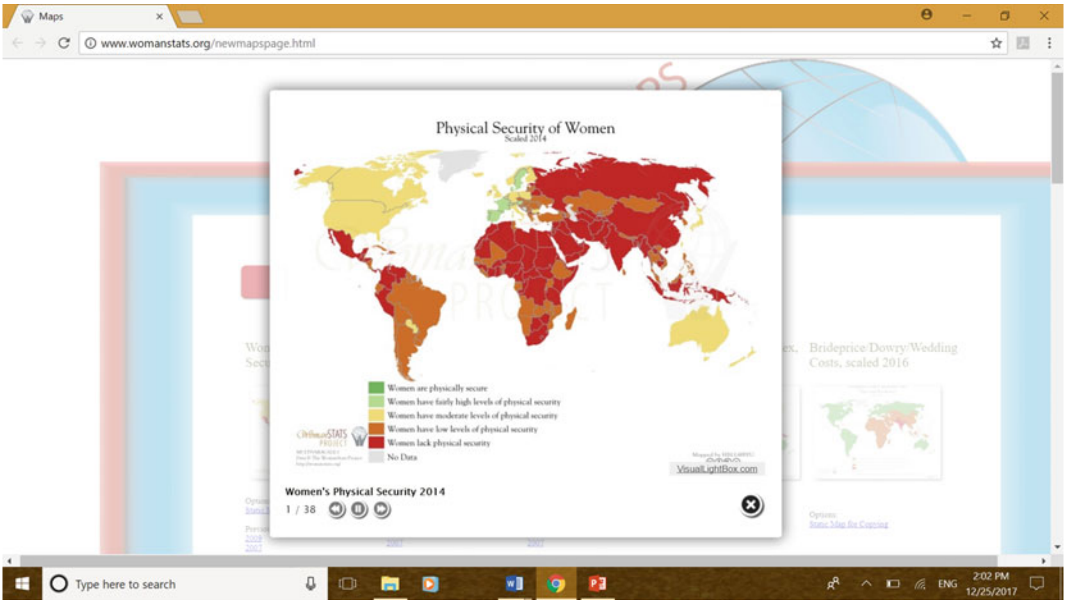

Fig. 14.12 Map on website for visualisation of women-related issues

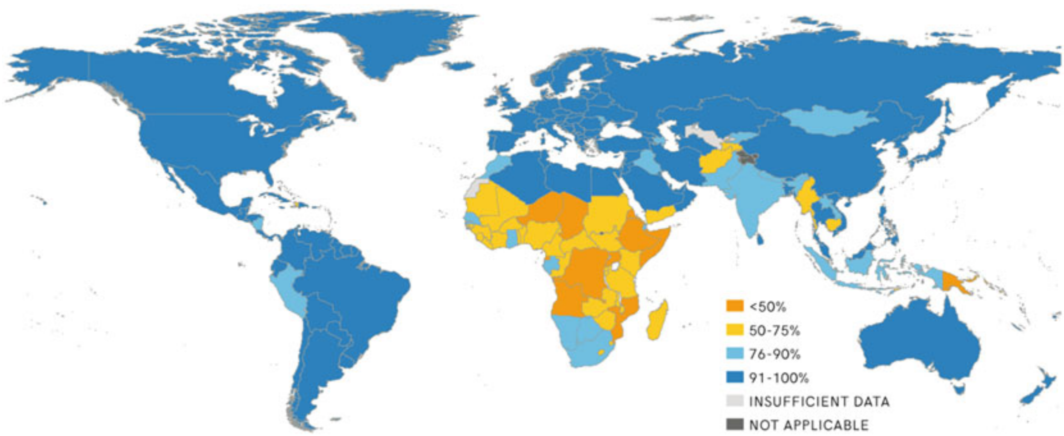

Fig. 14.13 Proportion of the population using basic drinking water services in 2015

Fig. 14.14 Web-based visualisation of drinking water, sanitation and hygiene

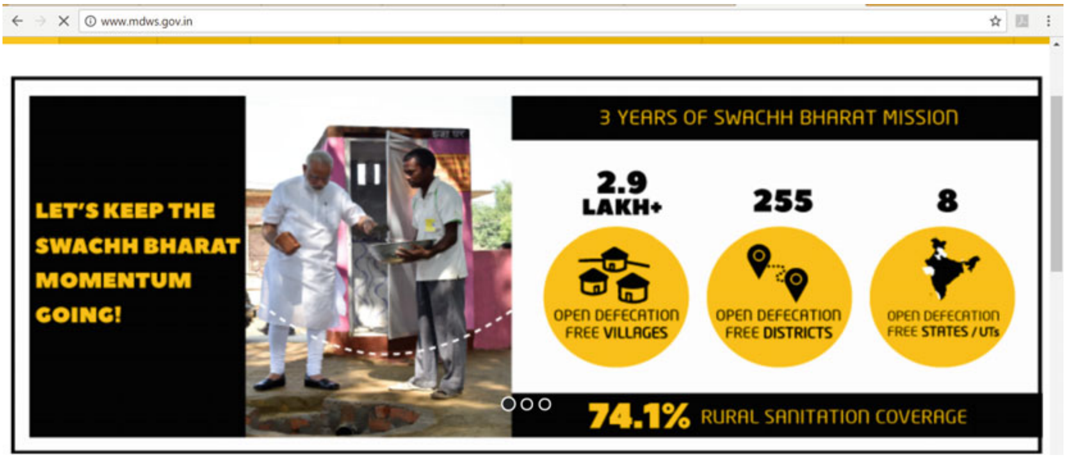

Fig. 14.15 'Swachh Bharat Mission in India' initiated by Hon'ble Prime Minister Shri Narendra Modi

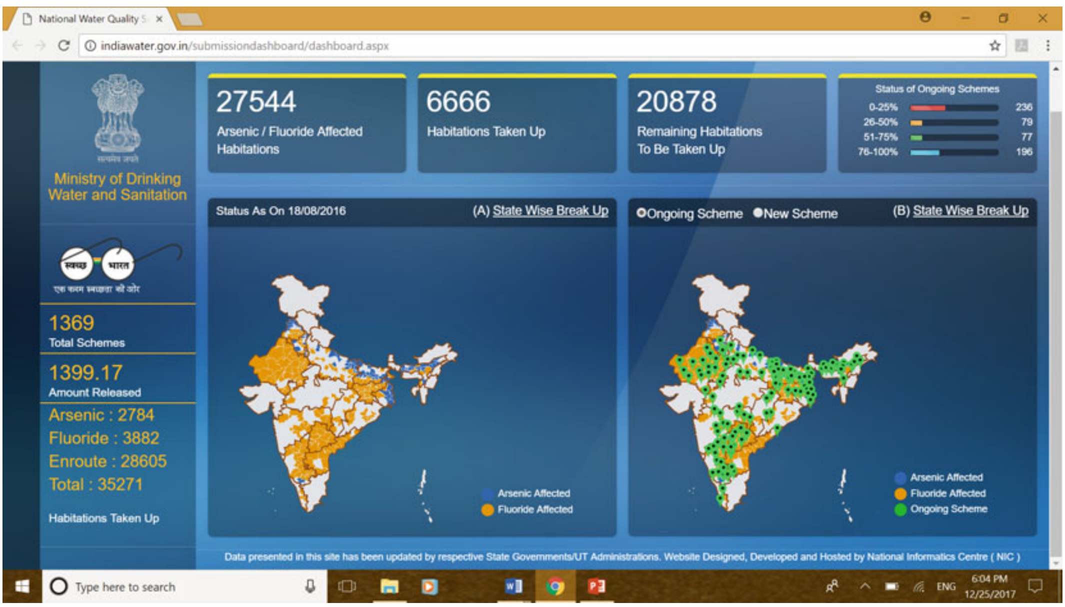

Fig. 14.16 Ministry of Drinking Water and Sanitation web portal for spatial characteristics of water-related problems (*source* https://indiawater.gov.in)

The Ministry of Drinking Water and Sanitation, the government of India, has a web portal (indiawater.gov.in) to provide information on such issues (Figs. 14.15, 14.16 and 14.17). The government of India has also initiated Swachh Bharat Abhiyan (Clean India Mission) and undertaken the task of mass toilet construction. Household toilet availability has improved from 41.93% in 2014 to 63.98% in 2017, and Himachal Pradesh, Sikkim and Kerala have all achieved 100% open defecation-free status.

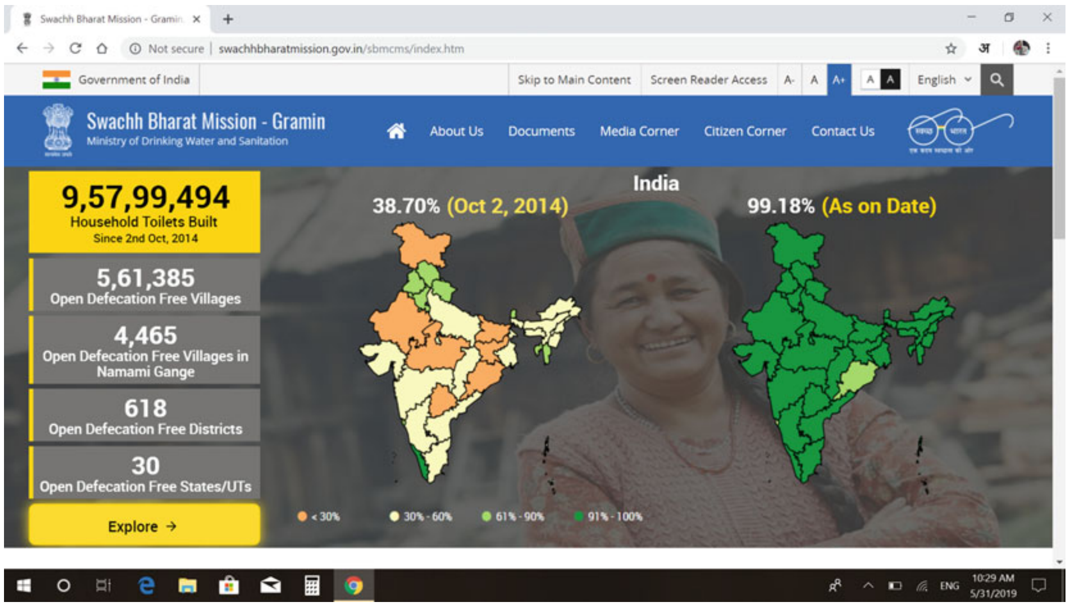

Fig. 14.17 Web portal of Swachhata Darpan

14.8 Goal 7: Affordable and Clean Energy: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All

The main targets are to ensure universal access to affordable, reliable and modern energy services, increase the share of renewable energy and double the improvement in energy efficiency. Meaningful improvements will require higher levels of financing and bolder policy commitments, together with the willingness of countries to embrace new technologies on a much wider scale. The World Bank, International Energy Agency and the Energy Sector Management Assistance Program jointly prepared the Global Tracking Framework related to electricity through maps (Fig. 14.18). India has a vast potential for solar power generation with about 58% of the total land area receiving above 5 KWh/m^2/day annual average global insolation. It is a viable alternative for power generation among the available clean energy sources (www.ibef.org). Deendayal Upadhayaya Gram Jyoti Yojana is a Scheme of the Government of India for Rural Electrification (Fig. 14.19). The (*Sahaj Bijli Har Ghar Yojna Saubhagya*) is a web portal designed and launched to monitor the progress of household electrification in India using solar power as a good example of spatial information technology application to meet SDG targets (Fig. 14.20). The government of India has also initiated Prime Minister Ujjawala Yojana (PMUY), which aims to safeguard the health of women and children by providing free LPG gas connection to 'below the poverty line' (BPL) households. This is a clean fuel as opposed to firewood, coal, dung-cakes etc. (http://www.pmujjwalayojana.com/released-connections.html).

14.9 Goal 8: Decent Work and Economic Growth: Promote Inclusive and Sustainable Economic Growth, Employment and Decent Work for All

Sustaining per capita economic growth in accordance with national circumstances and at least 7% gross domestic product (GDP) growth per annum in the least developed countries is

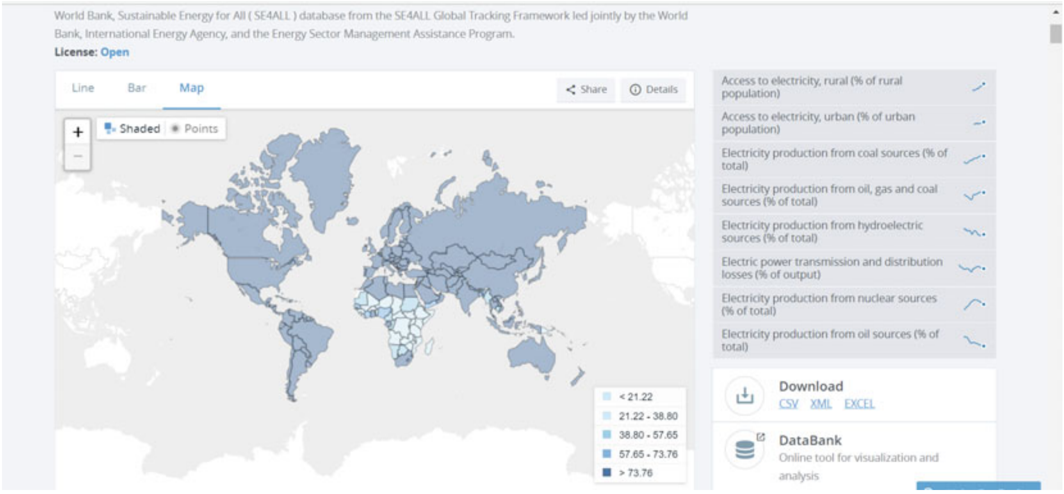

Fig. 14.18 Access to electricity (percentage of population)

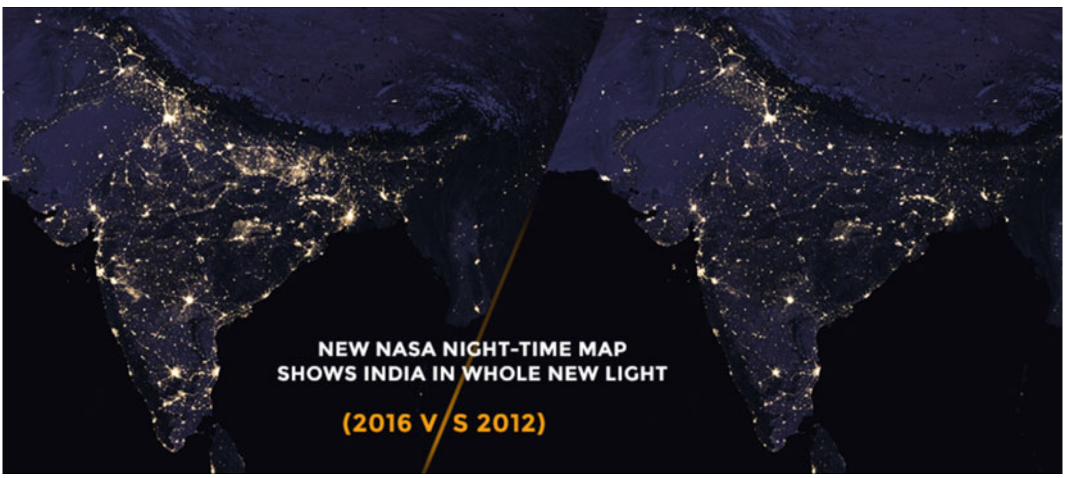

Fig. 14.19 Electricity development in India during 2012–2016 (*source* http://powermin.nic.in/)

one of the targets of SDG 8. Information about economic growth by map can show the status of the country (Fig. 14.21). Tourism is one of the world's fastest-growing industries and an important source of foreign exchange and employment for many developing countries. SDG target 8.9 is to devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products. The travel and tourism sector in the global economy continues to be very robust and seamlessly increasing. In 2017, the contribution of travel and tourism to the world GDP rose to 10.2%. Worldwide, this sector provides employment to 1 in every 10 people (Fig. 14.22).

Fig. 14.20 Saubhagya web portal (*source* www.saubhagya.gov.in)

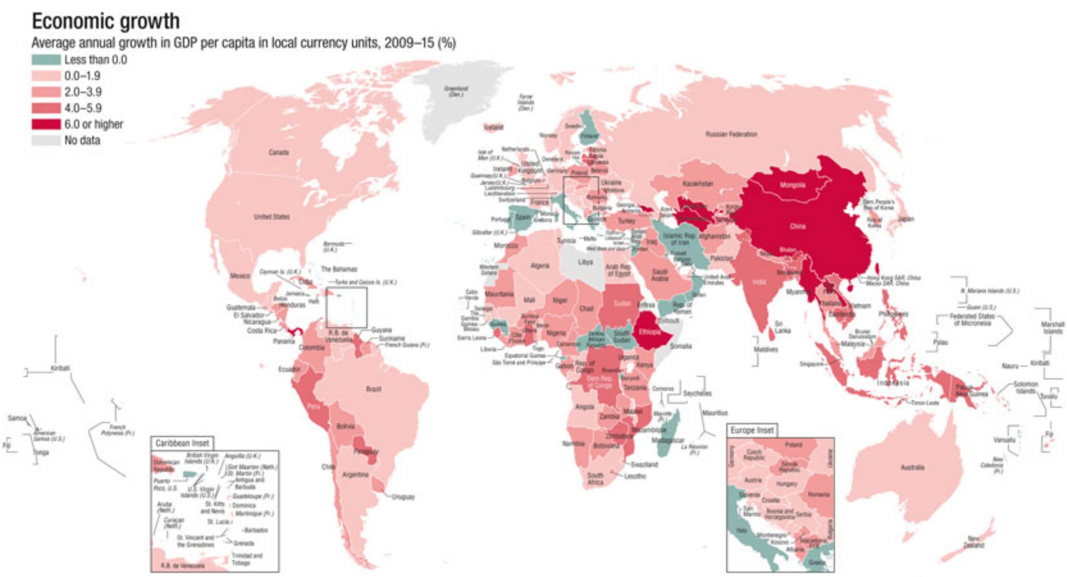

Fig. 14.21 Economic growth (*source* World Bank)

Fig. 14.22 Growth of travel and tourism industry in 2017 (*source* World Travel & Tourism Council)

14.10 Goal 9: Industry, Innovation and Infrastructure: Build Resilient Infrastructure, Promote Sustainable Industrialisation and Foster Innovation

The target of SDG 9 is to develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure to support economic development and human well-being with a focus on affordable and equitable access for all. Spatial information technology plays an important role in the development of infrastructure. The Great London Authority has developed an infrastructure map tool to explore current and future development and infrastructure projects in London (Fig. 14.23).

14.11 Goal 11: Sustainable Cities and Communities: Make Cities Inclusive, Safe, Resilient and Sustainable

The main target of SDG 11 is to ensure access for all to adequate, safe and affordable housing and basic services and to upgrade slums. This goal also targets providing people access to safe, affordable, accessible and sustainable transportation systems and improving road safety (notably by expanding public transport), with special attention to the needs of those in vulnerable situations – women, children, persons with disabilities and older persons. The Smart Cities Mission of the Government of India is a bold initiative in sustainable and inclusive development in India. The purpose of this mission is to drive economic growth and improve the quality of life of the people by enabling local area development and harnessing technology. Area-based development will transform existing areas (retrofit and redevelop), including slums, thereby improving the liveability of the whole city. New areas (greenfield) will be developed around cities in order to accommodate the expanding population of urban areas. Application of smart solutions will enable cities to use technology, information and data to improve infrastructure and services. Comprehensive development in this way will improve the quality of life, create employment and enhance incomes for all, especially the poor and the disadvantaged, leading to inclusive cities (Fig. 14.24).

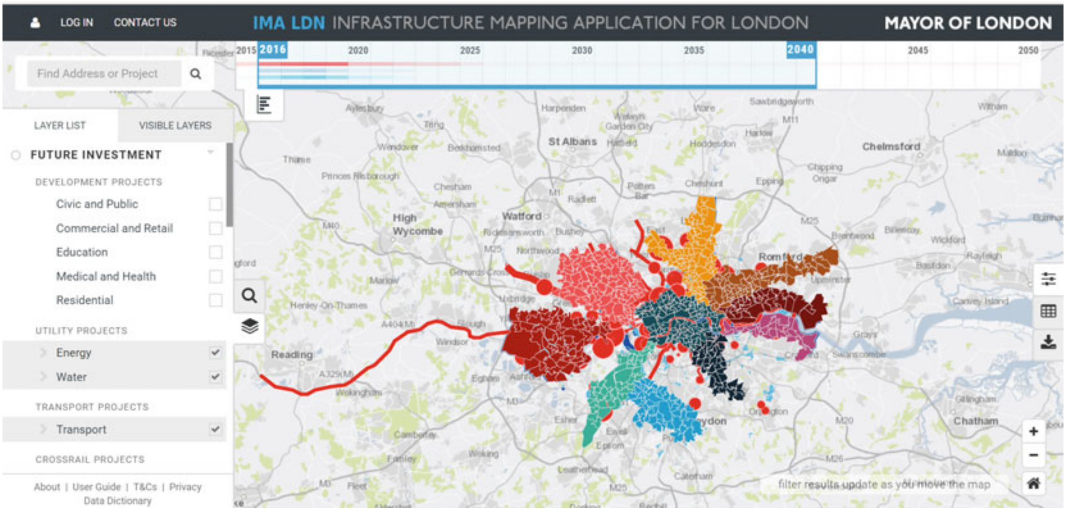

Fig. 14.23 London infrastructure mapping tool (*source* maps.london.gov.uk)

14.12 Goal 14: Life Below Water: Conserve and Sustainably Use the Oceans, Seas and Marine Resources

The target of SDG 14 is to prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution. Spatial information is always required for preventing and reducing marine pollution (Fig. 14.25). The map shows the five levels of risk from coastal eutrophication and the very high risks found in the Bay of Bengal, East China Sea, Gulf of Mexico, North Brazil Shelf and South China Sea (https://unstats.un.org).

In India, the Earth System Science Organisation-Indian National Centre for Ocean Information Services (ESSO-INCOIS) is an

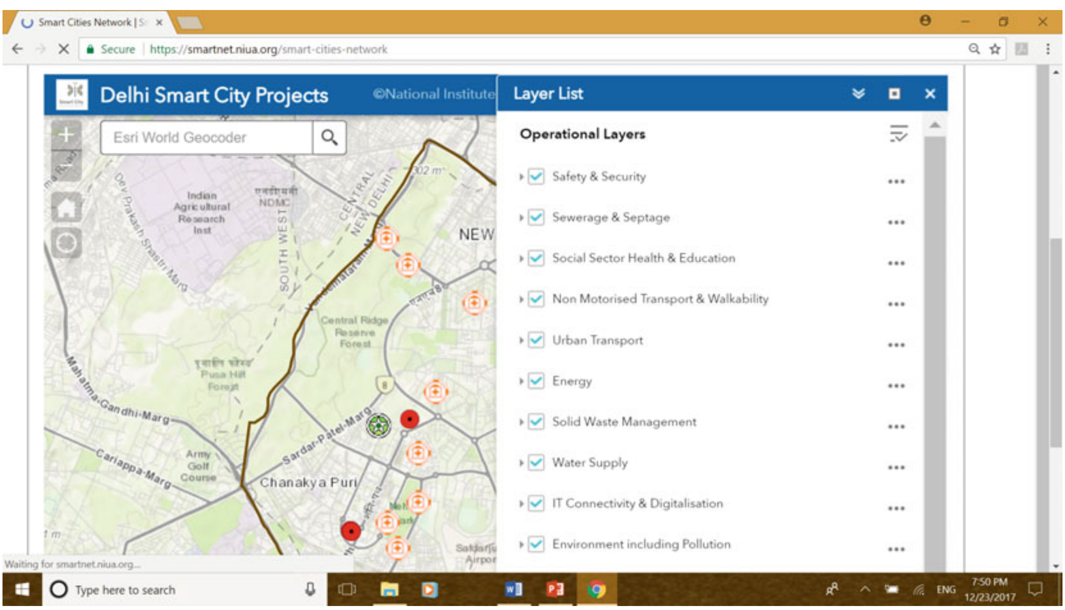

Fig. 14.24 Web portal for urban mapping (*source* https://smartnet.niua.org/smart-cities-network)

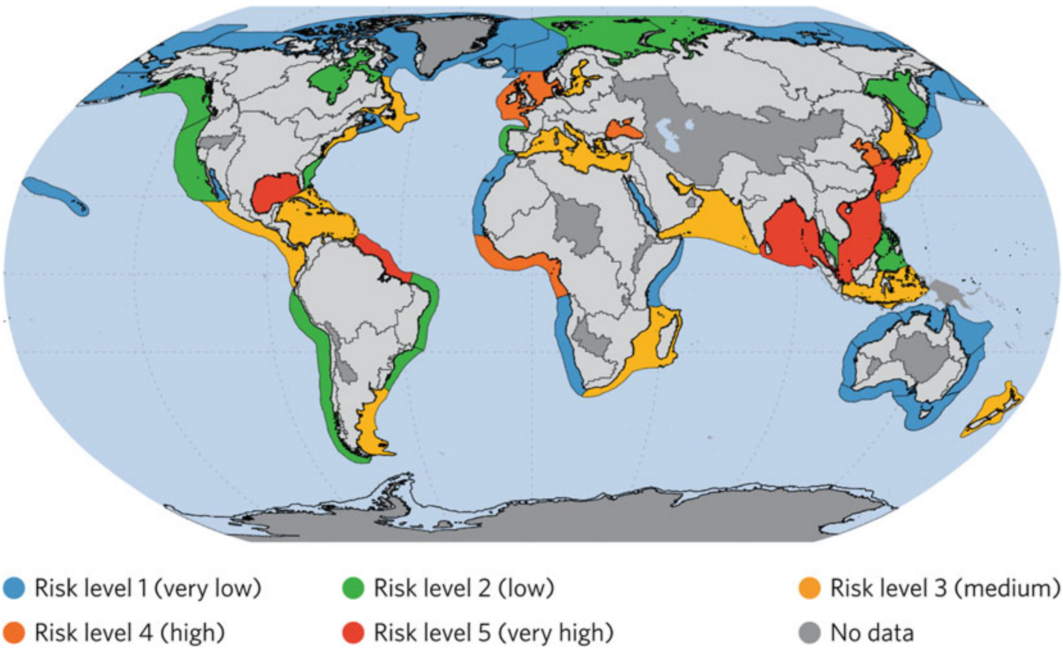

Fig. 14.25 Nutrient risk indicator categories of large marine ecosystems (*source* https://unstats.un.org)

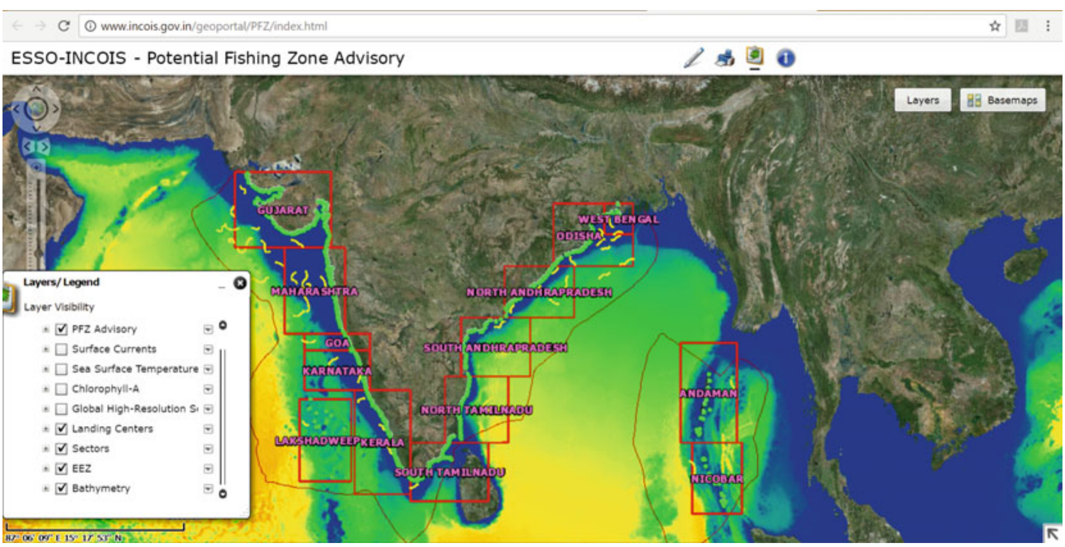

Fig. 14.26 ESSO-INCOIS web portal for ocean information (*source* www.incois.gov.in)

autonomous body under the Ministry of Earth Sciences, Government of India, that aims to provide the best possible ocean information and advice to society, industry, government agencies and the scientific community through sustained ocean observations (Fig. 14.26).

14.13 Goal 16: Peace, Justice and Strong Institutions: Promote Justice, and Peaceful and Inclusive Societies

The target of SDG 16 is to reduce all forms of violence and related death rates, end abuse, exploitation, trafficking and the torture of children. Estimates by the World Economic Forum show that 45.8 million people are enslaved worldwide. Where 4.37% of North Korea is enslaved, with the highest incidence of modern slavery, it is followed by Uzbekistan at 3.97% and Cambodia at 1.65% (Fig. 14.27). In terms of absolute numbers, India has more people in slavery than any other country, estimated at 18.3 million.

The spatial distribution of terrorism index can also be mapped to understand the impact of terrorism. The figure shows that the top five most affected countries in 2014 were Iraq, Afghanistan, Nigeria, Pakistan and Syria (Fig. 14.28).

14.14 Goal 17: Partnerships for the Goal: Revitalise the Global Partnership for Sustainable Development

The target of SDG 17 is to enhance international support for implementing effective and targeted capacity building in developing countries to support national plans to implement all the SDGs, including through North–South, South–South and triangular cooperation. For the sustainable development of the country, the Government of India has adopted a new information technology regime, its ‘Digital India’ programme to support good governance. Geospatial technology has proven to be an effective enabler to meet these challenges by developing technical capacity at the individual

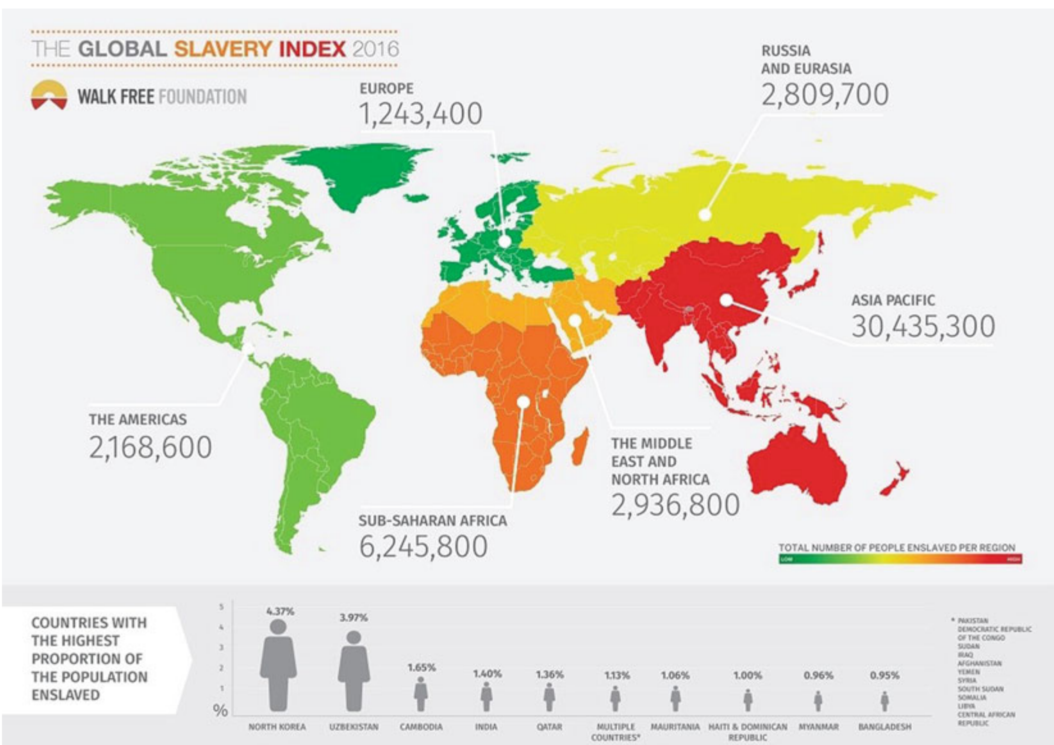

Fig. 14.27 Global Slavery Index 2016 (*source* World Economic Forum)

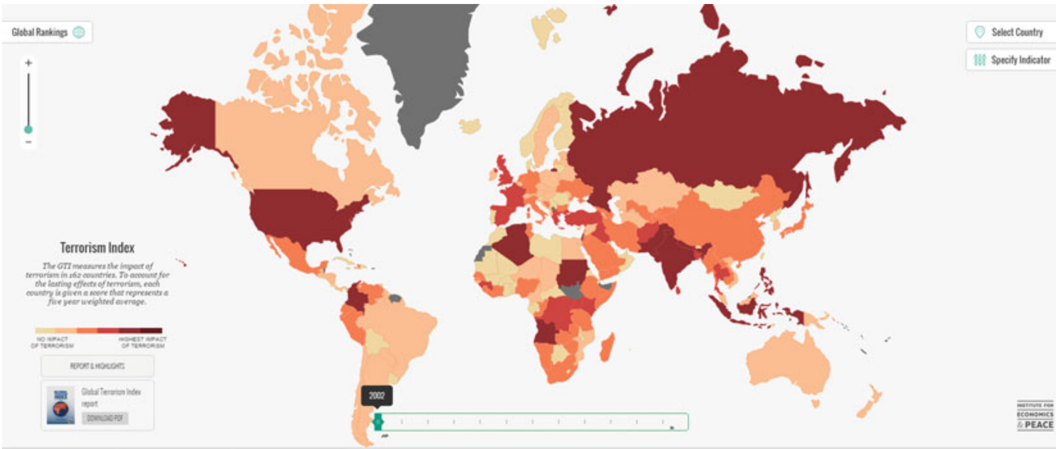

Fig. 14.28 Terrorism index, 2014 (*source* www.weforum.org)

level. Capacity building is an ongoing process and involves changing attitudes, imparting technical knowledge and developing skills while maximising the benefits of participation, knowledge exchange and ownerships. The Natural Resources Data Management System (NRDMS) programme is a multidisciplinary and multi-institutional research and development programme of the Department of Sciences and Technology, Government of India, to develop technology for integrated resource management and capacity building at the micro- to macro-levels in a spatio-temporal context.

14.15 Conclusion

Spatial information technology not only provides spatio-temporal information but is also one of the best techniques for communicating information to the general public. It has the capacity to show the spatial relationships among the features of the Earth's surface. With the help of various techniques of map visualisation, the information is made more memorable by the use of different colours and shapes of display. So we can say that a map can speak a thousand words. With modern technology, the huge amount of databases can easily store, retrieve and manage various types of spatial analysis for humankind.

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15 Conclusion: Spatial Information Technology for Sustainable Development Goals

Abstract

Remote sensing, GPS and GIS play an important role in achieving SDGs through mapping, monitoring, measurement and modelling of the Earth's resources. Global communities are widely applying this technology for improving our understanding. There were global initiatives toward mapping technology launched in 1996 to prepare eight basic layers of information: boundaries, drainage, transportation, population centres, elevation, land use, land cover and vegetation. The World Geodetic System 84 (WGS 84) was developed for the uniform datum of global mapping. The United Nations Geospatial Information Section has also developed global multi-scale data sets named 'UNmap'. Similarly, India has initiated advanced GIS and satellite-based technologies for the application of natural resources. Various organisations such as Rastriya Krishi Vikas Yojana (RKVY), Niti Ayog, Department of Sciences and Technology, National Platform for Disaster Risk Reduction (NPDRR0) and many NGOs are utilising spatial information technology for development planning and management.

Keywords

Geospatial information authority · Human resources · Decision-making · Global maps Science and technology

15.1 Introduction

Spatial information technology is applied worldwide in the mapping, monitoring, measurement and modelling of natural and human resources and phenomena for decision-making processes. It includes GIS, remote sensing, GPS and other information technology such as computer systems and mobile technology for planning and management. Global academic communities are applying this technology for their planning and development of resources in an integrated manner.

15.2 Global Initiatives

The International Steering Committee for Global Mapping (ISCGM) and Geospatial Information Authority of Japan (GSI) launched its 'Global Mapping Project' in 1996. It is an international cooperation initiative through voluntary participation of national mapping organisations around the world. The aims of the project are to develop a digital geo-information framework, ensuring spatial resolution at 1 km, with standardised specifications, available to everyone at marginal cost. Global map data sets consist of eight basic layers: boundaries, drainage, transportation, population centres, elevation, land use, land cover and vegetation for 71 countries and 4 regions,

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collectively covering 60% of the whole land area. Global maps for elevation, land cover and vegetation (percentage of tree cover) layers wholly cover the land area of the globe. The US National Geospatial-Intelligence Agency (NGA) develops, maintains and enhances the World Geodetic System 84 (WGS 84) for a reference frame for the Earth. India is also converting all map references to WGS 84 for uniform datum for global mapping. This datum is widely used in cartography, geodesy and navigation as well as in GPS.

The United Nations Geospatial Information Section (UNGIS), formerly United Nations Cartographic Section (UNCS), has developed global multi-scale geospatial data sets named 'UNmap' for rapid map production and web mapping in support of the Security Council and the Secretariat, including UN field missions on the scale of 1:1 million, 1:5 million and 1:10 million. The purpose of UNmap is to develop and maintain a spatial data infrastructure for UN needs that will provide a single homogeneous data set of global geospatial features of the world for any mapping purpose. UNmap is a series of geo-databases for core mapping layers such as international and administrative boundaries, coastlines, drainage, water bodies, roads, railways, airports, populated places and urban areas on various scales enabling users to store, query, manipulate and exchange geospatial information. UNGIS is developing a GIS-based UN International Boundary Information System (UNIBIS) that provides a knowledge base of international boundary issues with treaties, relevant documents, maps and satellite imagery as well as status of disputed boundaries in support of the Security Council and the Secretariat as well as the Member States. The objective of this knowledge base is to prevent potential conflicts, resolve border disputes and support border demarcation as well as cross-border cooperation. UNIBIS allows the research of data related to the status of international boundaries, including analysis and interpretation of the satellite imagery, treaty maps and other relevant material. Updates and maintenance of international boundary geo-databases is carried out in order to build the capacity for rapid response to the growing demand of Member States, especially in conflict areas, and for assistance in international boundaries delineation and demarcation.

The Second Administrative Level Boundaries (SALB) data set project was launched in 2001, for the collection, management, visualisation and sharing of data/information down to the second administrative level. The administrative boundaries are the fundamental component of any national spatial data infrastructure and constitute vital basic data for the work of many decision-makers, managers, planners and other users in a variety of sectors: census, health, education, regional development, water, agriculture, energy and environmental resources etc., to name a few. The project has been developed under the leadership of WHO. Coordination and policy issues have been taken care of by UNSD, and technical aspects have been undertaken by UNGIS. UNGIS is also developing a global place-name database and search engine to find place-name locations worldwide by searching with a place name's phonetic spelling (how it sounds) and searching through a database that contains over 8 million entries. A search for a location may not return a result even though a different spelling is in the database. The database of place names will be incorporated into the UNmap geo-database for additional utilisation as well.

The Geo-Portal provides the full range of GEOSS data and information for decision-makers, managers and other users of Earth observations. It is run by the European Space Agency (ESA) and the Food and Agriculture Organization (FAO) of the United Nations. It provides a web-based interface for searching and accessing data, information, imagery, services and applications. OneGeology is another international initiative of the geological surveys of the world launched in 2007. The aim is to create dynamic digital geological map data for the world and make it accessible via its portal (OneGeology Portal). ReliefWeb is the humanitarian information service managed by OCHA, and has produced a series of location maps for use by the UN and the wider humanitarian community. These maps can be embedded into documents, reports, briefing notes and websites as needed. The ReliefWeb

Location Map is a map that highlights a country, its capital and the surrounding region. These 200 country location maps are now available and can be downloaded at http://reliefweb.int/location-maps. The United Nations initiative on Global Geospatial Information Management (UN-GGIM) was established in July 2011 to draw together national capabilities for global geospatial information development and promotion so that the benefits of geospatial information can be available to national policymakers and for key global challenges. The UN expert committee on UN-GGIM decided to prepare a document of the thoughts of leaders in the geospatial world on the future of this industry over the next five to ten years. In Europe, a preparatory committee has provided guidance on the process of establishing a regional committee.

15.3 National Perspective – India

In India, *Niti Ayog* focuses on advanced GIS and satellite based technologies for identification, distribution and utilisation of natural resources. Rashtriya Krishi Vikas Yojana (RKVY) is the government of India's XIIth Five Year Plan (2012–2017) to ensure holistic development of agriculture and allied sectors. One of the major objectives is to ensure the preparation of agriculture plans for the districts and states based on agro-climatic conditions, availability of technology and natural resources. It further mentions that, 'to the extent possible, assets created by this scheme should be captured digitally and be mapped on a GIS platform for future integration onto a National-GIS system'. The Department of Agriculture and Cooperation (DAC) has set up a Mahalanobis National Crop Forecasting Centre with ISRO collaboration to augment present crop forecasts and assessment with regular remote-sensing, GIS and GPS data. Land is the prime natural resource of which 140 million ha is net-sown area, which is still decreasing, and land is degrading in mechanical, chemical and biological terms. Over 120 million ha has been declared degraded or problem soils. Conservation agriculture, integrated nutrient management, carbon sequestration, erosion control, saline and alkaline soil management, legislation for soil protection, development of remote-sensing and GPS-based decision-support systems and amelioration of polluted soil are all required to rejuvenate deteriorated soils. Sustainable agriculture development and reliable and timely availability of forecasts of agricultural crops are prerequisite, especially for food grain and estimates of agricultural production losses due to pests, diseases, floods and drought. The available estimates generated through sample surveys suffer from organisational and operational problems introducing inconsistency in these surveys. Here, remote-sensing techniques with GPS and GIS tools help to develop reliable estimated areas of agricultural crops, land-use planning and precision farming.

The Department of Science and Technology of the Government of India started an ambitious programme on State Spatial Data Infrastructure (SSDI) for data development and management in different states such as management of spatial data assets of Uttarakhand (UK) State in India. A Geo-Portal database has been an important requirement. Guideline documents are required in management of the Uttarakhand Geo-Portal—the first is on the Administrative, the second on the Department-wise Data Management Plan; the third on the Uttarakhand Data Sharing Policy. Preparation of a road map for the Uttarakhand State Geospatial Data Asset Management was considered a prerequisite for continuous updation and management of geospatial data. It was thus recommended that a data management (updation/maintenance/sharing) plan be developed and implemented by UCOST and State Line Departments. Regular workshops at state and district levels are needed for reviewing the progress of the data management plan on a sustained basis. The Uttarakhand Geo-Portal database needs to be continuously improved with not only data updation but with high-resolution data additions for its updation depending on GIS applications for different projects.

The National Platform for Disaster Risk Reduction (NPDRR) is constituted in India for the assessment and spatial representation of hazard-risk, vulnerability and capacities associated with disasters and their management, using spatial information technology-enabled systems of mapping, and for the promotion of disaster-related database management systems to mitigate disasters and preparedness. State disaster databases, disaster reporting systems and India Disaster Response Network (IDRN) are the most important initiatives by the government of India for better disaster risk management.

15.4 Spatial Information Technology and SDGs

The indicators of the SDGs need accessible, timely and reliable disaggregated data. It is a challenge to all countries to create databases for the global indicators. Spatial information technology includes all forms of information technology that enable us to deal with geo-referenced spatial databases. Broadly, these includes remote sensing, GIS and GPS. Remote sensing provides reliable, unbiased and near real-time spatial data, while GPS provides coordinate information about features and phenomena on the Earth's surface. GIS includes all its components such as computer hardware, software, databases, procedures and trained people for the decision-making process by data capturing, managing, analysing and displaying geo-referenced databases to final mapping, and provides complete map visualisation to achieve UN SDGs. These technologies are complementary to each other in dealing with complex databases in a holistic manner to achieve the SDGs. The United Nations Global Geospatial Information Management (UN-GGIM) is an international-level committee led by the UN which has a vision to make accurate, authoritative and reliable spatial information readily available to support national, regional and global development. UN-GGIM also seeks to guide the making of joint decisions and set directions for the production and use of geospatial information within national and global policy frameworks. Chapters 1 to 8 deal with conceptual and methodological frameworks of spatial information technology in the above contexts.

15.5 Case Studies and SDGs

There are five case studies discussed in this book to address SDGs 1, 2, 3, 4, 6, 7, 9, 10, 12, 13 and 15. Ultimately, all the case studies directly or indirectly help to achieve SDG 1, to end poverty in all its forms everywhere over the next 15 years.

The case study on 'crop modelling for sustainable agricultural productivity', discussed in Chap. 13, will seek to help to overcome the problem of starvation and to achieve food security and improved nutrition and promote sustainable agriculture. SDG 2 urges access to sufficient nutritious food for everyone by doubling agricultural productivity, increasing investment and sustaining properly functioning food markets. The case study presents an idea to utilise spatial information technology in an integrated manner for crop simulation modelling to ensure optimum productivity. The bio-physical environments like soil, climate and landform characteristics are used to assess the potentiality of the land. According to InfoCrop modelling, the potentiality of study area for rice production will be around 8.5 tonne/ha, potentiality of wheat will be 7.5 tonne/ha, potentiality of sugarcane will be 85 tonne/ha and potentiality of maize will be 6 tonne/ha. These potentialities of the crops show that it is possible to increase crop yield through proper management of the input of irrigation, and the use of organic and inorganic fertilisers to eradicate the problem of starvation and achieve food security.

SDG 15 focuses on the protection, restoration and promotion of sustainable use of terrestrial ecosystems, sustainable management of forests, combatting of desertification, halting and reversing of land degradation and halting of biodiversity loss. The case study on land-use modelling for micro-level planning can meet SDG 15 by using the technology of spatial information. On the basis of the geo-environmental conditions of a study area, alternate land use is suggested in three categories: management of agricultural lands, management of wasteland and management of forest land. Afforestation, agro-forestry, agro-horticulture, double crops, fishery, fodder and fuel plantation, forest plantation, gully-plugging measurement and silvipasture are all suggested for alternate land use to conserve and protect land resources. The land-use model is prepared in such a way that no land should be kept as wasteland, and no use or monetary returns made, or other environmental aspects under the prevailing geo-environmental conditions violated that would prevent the livelihood and preservation of the eco-system for future generations.

Infrastructure is the backbone of any nation for attaining prosperity and one of the major indicators for sustainable development. Likewise, information about infrastructure is also required to understand the distribution pattern of available facilities. The aim of SDG 9 focuses on the promotion of infrastructure development, industrialisation, innovation and access to information and communication technology. Therefore, information about infrastructure and services like education, health, availability of drinking water, transport, communication, post, telegraph and telephone, irrigation and electricity facilities plays an important role in sustainable development. Spatial information technology also plays a vital role in providing information about infrastructure spatially. The case study on 'Infrastructure Assessment for Sustainable Development' (Chap. 12) broadly provides an example for the achievement of SDG 9 as well as SDGs 3, 4, 6 and 7. The case study reveals that the development of infrastructure is high in the eastern part of the study area.

The case study on 'Monitoring and Assessment of Flood-Inundated Areas' (Chap. 11) represents one of the major issues in natural disasters. SDG 13 addresses how we must combat climate change and its impacts. It is also estimated that due to the rise in temperature of the Earth, most of the islands and low-lying areas will submerge and unpredicted spontaneous rainfall will lead to flood inundation along major rivers in the world. In India, monsoon floods are common in major rivers, which affects not only natural resources but also human life and livestock. An attempt is made to monitor, assess and manage flooded areas in Son-Karamnasa Interfluve in Bihar, India. The assessment is based on the multi-temporal Indian Remote Sensing Satellite-P6 (IRS-P6). The analysis reveals that low-lying areas along the river Ganga and Karamnasa are flooded during September to November, during monsoon and post-monsoon periods that affect not only the *kharif* crops but also the *rabi* crops. Preventive measures and preparedness are required in this area for sustainable development.

SDG 6 seeks to ensure the availability and sustainable management of water and sanitation for all. The sustainable development of water resources requires assessment in their natural boundaries, such as watersheds, and can be managed in natural conditions. The case study about watershed characterisation (Chap. 10) and priority for land and water resource management focuses on the development of these resources in watersheds, a hydrological unit, considered a more efficient and appropriate unit for soil and water resources. It is also important to determine the morphometric characteristics such as linear, areal and relief aspects of the watershed that control the flow of water resources, groundwater recharging and soil erosion. In this regard the research is done on the Son-Karamnasa interfluve for the prioritisation of watersheds on the basis of morphometric parameters for further management of soil and water resources to meet SDG 6.

As discussed above, spatial information technology plays an important role in providing unbiased information on the Earth's features within a very short time for the rational management of resources and environmental phenomena for human use in order to contribute towards SDGs. The UN SDGs seek to improve the social, economic, environmental, institutional and governmental aspects of society. Spatial information technology provides a helping hand in decision-making processes through mapping, monitoring, measuring and modelling of the different phenomena of the world in order to contribute towards SDGs.

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Appendix: How to Obtain Satellite Data from Bhuvan

Bhuvan is an Indian Geo-platform (http://bhuvan.nrsc.gov.in) developed by the National Remote Sensing Centre (NRSC), Indian Space Research Organisation (ISRO). This portal allows the users to select and download the geospatial data free of cost based on various data search mechanisms like bounding box, tiles ($1^\circ \times 1^\circ$ and $15' \times 15'$), interactive drawing and Survey of India mapsheet number on 1:250,000 for AWiFS Ortho and CartoDEM and 1:50,000 for LISS-III Ortho scale for India only. Users can download Elevation data of CartoDEM-1arc second, Resourcesat-1:AWiFs data(56 m) and LISS-III(24 m) of Indian region from Indian Remote sensing Satellite (IRS). normalized difference vegetation index (NDVI) global coverage, CartoDem version 3R1 available for South Asian Association for Regional Cooperation (SAARC) countries and climate product for the North Indian Ocean.

Steps to download data

- Select the category, i.e. Satellite, Theme or Project, and then desired type of data, e.g. CartoDEM-1 arc second.
- Select the tiles on the map using available search mechanisms, i.e. Bounding Box, Tiles, Mapsheet and Interactive Drawing.
- Press 'Next' button to get selected tile list.
- Use 'View' button to view the particular tile on the map and 'Remove' (after View is pressed) button to remove it from the map. In case of AWiFS and LISS-III data, you can only view the thumbnail of the tile.
- Click on 'Metadata' button for metadata of the corresponding tile.
- Click on 'Download' button to download the tiles. Login is required for downloading the tiles.
- Number of tiles for download has been fixed to 10 tiles/day for Cartosat-DEM, AWiFs data and 16 tiles/day for LISS-III data. Other tiles can be saved in backlog list for future reference.

United States Geological Survey (USGS) has two portals to search and download various geospatial database at no cost. USGS Earth-Explorer (EE) (http://earthexplorer.usgs.gov/) is a complete search and order tool for aerial photos, elevation data and satellite products distributed by the USGS. USGS Global Visualization Viewer (GloVis) (https://glovis.usgs.gov/) is another portal that provides all Landsat 8 OLI/TIRS, Landsat 7 ETM+, Landsat 4/5 TM, Landsat 1–5 MSS, EO-1 ALI, EO-1 Hyperion, Sentinel-2, and Global Land Survey (GLS) data sets; LP DAAC ASTER and selected MODIS data holdings are also available. These are browse-based for enhanced visualization (https://lta.cr.usgs.gov/get_data/).

ESA's Sentinel online has a free full and open data policy adopted for the Copernicus programme that foresees access available to all users for the Sentinel data products via Copernicus Open Access Hub. EOLi (Earth Observation Link) is the European Space Agency's client for Earth Observation Catalogue Service providing services to browse metadata and preview images of Earth Observation data acquired by the satellites ERS and Envisat and download the products of various processing levels.

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The Japan Aerospace Exploration Agency (JAXA) released ALOS World 3D-30 m, the global Digital Surface Model (DSM) data set with a horizontal resolution of approximately 30 m. In order to obtain this highly accurate DSM data set, users must register online at http://www.eorc.jaxa.jp/ALOS/en/aw3d30/registration.htm.

The Global Land Cover Facility (GLCF) provides earth science data and products to help everyone to better understand global environmental systems. In particular, the GLCF develops and distributes remotely sensed satellite data and products that explain land cover from the local to global scales. Primary data and products available at the GLCF are free to anyone via FTP. Online data sets may be accessed through http://landcover.org.

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