Chapter 5
Remote Sensing Application in Water Resources Planning

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Abstract Remote sensing-based satellite data and processing tools as part of geographic information system (GIS) have been utilized in many disciplines in earth sciences, water resources management in particular. Retrieving spatial data and processing technology require a systematic knowledge and experience for an effective use that is the main motivation of this chapter. Field work in large areas and installing gauges have been painstaking and costly. Even the developed countries began to remove gauges measuring eddy-covariance and other meteorological variables due to the high maintaining cost. Instead, they invest on satellite technologies and radar systems. Today, most field works and conventional point data collection have given its place to processing synoptic satellite images using open source GIS tools. The use of spectral indicators and remote sensing technologies to control and monitor the water quality and quantity of rivers, reservoirs and groundwater has been very cost-effective. Different variables that can be remotely measured in water quality are salinity, suspended sediment, water color, extent of oil spill and eutrophication, growing phytoplankton and algal bloom. Also, estimation of land cover and land use, actual evapotranspiration, land surface temperature, runoff, preparation of flood maps, determination of snow cover and depth changes may benefit from remote sensing-based satellite data and GIS technology. To do operations in physical sciences, basic knowledge in remote sensing and geographic information systems (GIS) is necessary as they depend each other. First, basic data is collected and then processed by sensors of remote sensing satellites using different color spectra or recorded thermal properties. This leads to the creation of raw databases that are processed in GIS to enhance data and utilize information management and

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store layer composition. Modeling, production of output maps and spatial analysis are very fast and accurate with GIS tools such as gdal, pyproj, pymodis libraries in Python language and 3D data storage in common data format (netCDF). GIS is a very powerful management tool for planners and designers to adopt appropriate land and water management strategies. Since remote sensing and GIS are deep and extensive source, studying the principles and methods require a structured summary of basics and relevant applications in the field of water management and engineering.

Keywords Satellite images · Radar systems · GIS · Spectral indicators · Spatial analysis

5.1 Introduction

Human eyes have always been one of the most important tool to describe, identify environmental issues. When a person uses their sense of sight to observe the environment, he or she receive color and spatial information in an instant with the help of the joint function of the eye and the brain and then It is sent to different parts of the brain. So that the types of colors and spatial information felt simultaneously coincide. Although the brain and eye perception systems have achieved the ultimate evolution, there is still a great deal of information on the Earth's surface that the eyes of humans cannot observe, understand, or process. While human rational perception is able to make and use many advanced tools and equipment that can receive more useful information from Earth's surface objects in addition to the sun's visible light, using other spectral ranges of electromagnetic waves. Remote sensing (RS) is a method of data collection in which there is no direct physical contact with the measured objects. There are many definitions of remote sensing in the literature. We will list only some of the most common ones as below.

Based on Colwell et al. (1983), remote sensing science and technology is the acquisition of information about an object, region, or phenomenon by processing and analyzing data obtained by a device (without direct contact with the object, region, or phenomenon being studied). Sabins (1997) defines remote sensing as the science of processing and interpreting images that are the result of the interaction of electromagnetic energy and objects. Chandra and Ghosh (2002) defines remote sensing as the process or method of obtaining information about an object, area, or phenomenon through data obtained by a device without direct contact with them.

In addition to usual photography, this industry's potential applications were also noted, and the first image of a balloon was taken in 1859 near Paris. The most important evolution in remote sensing was created in 1909 by the invention of the airplane by the Wright brothers. The aircraft was more stable than the balloon and also had more controllability, so balloon imaging quickly gave way to the airplane. The first extensive use of aerial photographs was in World War I (1918) when about 56,000 aerial photographs were taken to identify enemies' locations and equipment. The period between the two world wars was an opportunity to develop and growth the applications of aerial photography in civilian purpose including geology, forest and rangeland surveying, and map preparation. World War II not only led to develop and interpret aerial photography, but also the emergence of special systems for detecting objects such as infrared and radar at the same time.

This continued in Iraq and Afghanistan wars to identify crucial targets using high resolution and not publicly available satellite data from IKONOS. Figure 5.1 illustrates the oil facility of Rumalia, Iraq Retrieved from IKONOS satellite.

Infrared photography, which was known to be useful for identification operations, now used to study a variety of plant coverings, and multi-band imaging has gradually established itself among experts in the field.

With the production of computer-generated maps, many new tools for spatial data and maps were developed. The data processing operation requires a set of powerful tools for collecting, storing, retrieving, converting, and displaying real-world spatial data for a variety of purposes. There are several definitions of GIS as follows:

Burrough (2000) describe geographic information as a powerful tool for collecting, storing, retrieving, and displaying real-world locations. Clarke (2001)

Fig. 5.1 The map of Rumalia oil facility in Iraq. (https://www.satimagingcorp.com/gallery/ikonos/ikonos-rumaliafield-lg/)

defines geographic information as a computer-aided system for controlling, storing, retrieving, analyzing, and displaying locations in a specific organization.

The 1960s were crucial in the history of remote sensing and GIS, as human endeavors to access space came to fruition, the culminating of that is travel humans to the moon. After that, for the first time in the United States, work began on the GIS started. Some of the first satellites launched into space presented as follows.

In 1957, the world's first satellite was launched by the former Soviet Union, Sputnik-1, surprising the world. In 1964, the first meteorological maps of the Earth's surface were prepared by the Nimbus satellite, which had a meteorological application in war.

In 1972, the first satellite of natural resources was launched, which was first called ERTS-A, then renamed Landsat, and this year rapid advances in digital image processing was saw. In 1977, the first European meteorological satellite, Meteosat, was launched with the aim of providing visible and infrared images day and night.

Due to the high efficiency of remote sensing techniques, GIS and their interdisciplinary nature (defense, reclamation and earth sciences), their widespread applications are observed in various sciences e.g. illegal housing, drugs, mining, and deforestation. Applications of remote sensing and GIS in water resources science including estimation of potential and true evaporation and transpiration, determination of plant coefficient, determination of flood ranger of the river, estimation of evaporation from free water level, estimation of precipitation in a zone, determination of salinity and humidity. There are numerous articles and research on estimating soil moisture, determining the drought index, estimating the volume of snow and its equivalent water, analysis of erosion and sedimentation rates, groundwater analysis (Ganapuram et al. 2009; Guzinski et al. 2013; Nijzink et al. 2018; Stisen et al. 2011). The literature review on the use of remote sensing in water resources engineering and management is summarized below.

Ahmad et al. (2005) investigated a new technique for estimating net groundwater utilization within irrigated lands by combining remote sensing approaches. This case study was conducted in Pakistan. This technique is a combination of remote sensing methods and water balance concepts. They concluded that the harvest values were 0.8 to 1.6 mm per day, which averaged 82 mm per year.

Alparslan et al. (2007) investigated water quality in the reservoir of Ömerli Dam using remote sensing techniques. This case study was conducted in Turkey. They concluded that remote sensing methods were reliable and inexpensive, and that satellite imagery could be used to detect changes in water quality, sources of pollution and its effects. Stisen et al. (2008) investigated the potential of applying remote sensing-based input data in hydrological model for Senegal River basin in West Africa. Yilmaz et al. (2008) test the relationship between vegetation water content (VWC) and equivalent water thickness (EWT) for three different vegetation types. EWT and VWC estimated by data from SMEX05 and SMEX02.

Ghazanfari Moghaddam et al. (2011) compared the precipitation data obtained from the PERSIANN model, co-kriging interpolation method and inverse distance weighting. This case study was conducted in Iran. The results of this study illustrate that the use of precipitation estimation models, based on satellite images that have high temporal and spatial resolution, and can be a good alternative to interpolation methods. Vinukollu et al. (2011) developed and inter-compare three process-based evapotranspiration products over lands, based on sensors on the NASA Aqua satellite platform. Stisen et al. (2011) analyzed the spatial pattern of remotely sensed variations in surface temperature to improve a physical based hydrological model. Guzinski et al. (2013) presented modifications for the dual temperature difference model that enable applications using thermal observations from polar orbiting satellites.

McCabe et al. (2017) explored innovative and smart observation approaches and highlight new remote sensing platforms including small cube satellites, drones and LIDAR.

Demirel et al. (2018) determined the appropriate spatial model parametrizations and objective functions to evaluate distributed hydrologic model outputs. In addition, they incorporated spatial pattern of satellite based on actual evapotranspiration data in the model calibration and validation.

Miao et al. (2019) investigated the water quality of urban rivers in China using remote sensing. The study used Landsat-8 satellite data, the vegetation index (NDVI) and the Canadian water quality index. They concluded that the results of the collected ground samples and the data obtained from the remote sensing have a good fit showing the accuracy and proper performance of this approach.

Kalhor and Emaminejad (2019) investigated the relationship between groundwater level and urbanization using remote sensing data to sustainably develop cities. The case study was conducted in the Atlanta metro area of Georgia, USA. The study used remote sensing data from GRACE, MODIS, TRMM, IRIS and GLDAS. They concluded that limited urban development has taken place in the region since 2001–2013, but is projected to increase by 2050, which requires careful and comprehensive planning for sustainable urban development in the region.

Lyazidi et al. (2019) investigated the management of water resources in semi-arid regions by GIS. This case-by-case study of the Gareb-Bouaregin Morocco. In this research, MODFLOW and Arc GIS software have been used. They concluded that the development of this model is very useful for controlling, planning and managing groundwater levels when the water level rises and causes significant damage to agricultural fields.

Ahmadi et al. (2019) investigated the effectiveness of water consumption and improving land drought by remote sensing. This case study was conducted across the United States. In this study, MODIS measurement data and quality flags were used. Dembélé et al. (2020) used spatial pattern information from multiple sources of satellite remote sensing (SRS) data to constrain the model and improve the spatial representation of hydrological processes.

5.2 Definition and Terms

In this section, a brief description of the definitions and terms required to learn remote sensing science and the GIS is presented.

5.2.1 Remote Sensing

Remote sensing is the science of extracting information from objects indirectly and by using of a sensor. In other words, remote sensing is the science and art of obtaining information from an object under study by a tool which it is not physically in contact.

5.2.2 Geographic Information System (GIS)

GIS is an information system that produces, processes, analyzes, and manages geographic information, and also it is able to collect, store, analyze, and display geographic information. Processing includes changing raster pixel size via upscaling and downscaling methods (resampling), merging image tiles (mosaic), trimming the borders of the domain. The ultimate goal of a GIS is to support decisions based on geographic data, and its basic function is to obtain information that obtained by combining different layers of data in different ways and with different perspectives. The most commonly used GIS tools are ArcGIS, Quantum GIS (QGIS), SAGA, GDAL, PostGIS and GRASS.

5.2.3 Electromagnetic Spectrum

The frequency range of electromagnetic radiation is called the electromagnetic spectrum.

5.2.4 Absorption and Transfer

Part of the electromagnetic energy is absorbed by various molecules, such as ozone, water vapor, and carbon dioxide, as it passes through the atmosphere. Therefore, during different wavelengths, the amount of absorption by different molecules is different, which causes the identification and selection of different bands to perform different tasks.

5.2.5 Atmospheric Distribution

Particles or gas molecules in the atmosphere, cause the distribution of electromagnetic energy from their initial path when electromagnetic energy collides with them. Atmospheric distribution depends on different factors such as wavelength of the radiation, number of particles and radiated distance.

5.2.6 Pixel and Pixel Data (Raster)

Images in remote sensing are of a raster nature and consist of a matrix of components called pixels (grids). The dimensions of each pixel are the smallest unit identified by the meter or degree-decimal based on the earth projection that shows the ground level. 1 degree at Earth's equator is approximately 111 km. A second of arc, 1/60 of a sea mile (1,852 meters), is about 30 meters (98 feet).

A raster consists of a set of points or cells that cover the effects of the earth in a regular network and are addressed using row and column numbers. The smallest constituent of a raster is called a pixel or cell, the value of each of which represents the spectral or descriptive information of the terrestrial complication. Scanning data and satellite imagery have a raster structure. In addition, the unit of measured pixel data from the satellite and distributed models can be different. For instance, actual ET estimated based on RS data is watt/m^2 (energy balance equations) whereas it is a flux in hydrologic models with the unit of mm/day (Demirel et al. 2018; Guzinski et al. 2013). That's why we need bias-insensitive metrics like SPAEF and SPEM (Dembélé et al. 2020; Koch et al. 2018) to evaluate variables with different units.

5.2.7 Vector Data

In two-dimensional spaces, data are formed by combining geometric shapes such as dots, dashes, triangles, and other polygons, and in three-dimensional spaces, they are made by cylinders, spheres, cubes, and other multifaceted objects. In this model, the position of each point is precisely represented by a pair of coordinates in a given coordinate system. This means that its coordinates and one of the modes of representation [point (well, urban and rural points), lines (road, river and rail lines) and levels (lake and zoning) determine the position of each object or phenomenon.

5.2.8 Band

A range of electromagnetic spectra with a specified wavelength is called a band. Its value is different in each sensor and is a criterion for dividing and classifying meters.

5.2.9 Sensors

Any device that collects electromagnetic radiation reflected from various phenomena or other emitted energies (such as thermal infrared) and provides a suitable way to obtain information from the environment is called a sensor. Assessors are divided based on energy source (active and inactive) or information efficiency (visual and non-visual). Video information efficiency is divided into two groups: visual and numerical. It should be noted that each sensor is only sensitive to a range of electromagnetic spectra.

5.2.10 Multi Spectral Sensor

A sensor with a bandwidth of less than 50 bands is called a multi-spectrum sensor. The smaller the number of bands in an image, the greater the bandwidth of each band in the electromagnetic spectrum, which in turn reduces the spectral power.

5.2.11 Active Sensors

These sensors generate electromagnetic energy and already send energy to the desired phenomenon and collect and record their reflection.

5.2.12 Passive Sensors

These sensors do not generate electromagnetic energy and collect energy reflected from various phenomena on the Earth's surface to which the sun's electromagnetic radiation is emitted.

5.2.13 Pictorial Sensors

The information efficiency of these sensors can be converted to photos.

5.2.14 Non-imaging Sensors

The information efficiency of these meters is in the form of tables and diagrams and cannot be converted to photos.

5.2.15 Numerical Sensors

The information efficiency of these sensors is digital and they are converted to photos and used after certain steps.

5.2.16 Platform

Carriers of telemetry meters are called platforms and have different types such as satellite, airplane and balloon, etc. Radio-controlled aircraft and balloons are used for remote sensing at lower altitudes and satellites are used for remote sensing at higher altitudes. The height of the platform is a very important factor in choosing a platform because it depends on determining the resolution of the earth and the field of view of the moment being measured.

5.2.17 Projection

One of the most important basics of cartography and geodesy is how to transfer the spherical surface of the earth to a plane that called map projection. It is like peeling of the orange to a plane surface. Turning the geographical atlas shows that the orbits and meridians are not the same shape on all planes. On some pages, circuits are depicted as straight lines and in others as curves or even concentric circles. This deformation in the grid is the result of the transferring the spherical surface of the earth to the plane of the paper (map). One of the most common projection systems is Universal Transverse Mercator (UTM) coordinate system.

5.2.18 UTM

UTM is a coordinate system that assign coordinate to locations on the surface of the earth. UTM coordinate system process is like traditional methods of longitude and latitude. It means UTM represent locations of the map in a horizontal position. In other words, UTM ignore altitudes and treats the earth like a perfect ellipsoid. UTM is based on Gauss-Kruger projection system and in terms of longitude, the earth is divided into 60 zones of six degrees, numbered from west to east (from one to 60). Its scope does not include the North and South Poles: latitudes above 84° N and below 80° S have been removed.

5.2.19 World Geodetic System

The world Geodetic System (WGS) is a standard system used in navigation. WGS consists of, a reference for coordinates, a center of mass for the Earth, and a similar circuit used to move the earth in space. A pair of latitude and longitude is considered as the base or (zero) and the rest of the points are measured relative to that latitude and longitude. The location of this latitude and longitude for the reference could be considered anywhere on the Earth. Different versions of WGS presents up to now as are exist e.g. WGS 60, WGS 66, WGS 72 and WGS 84. WGS 84 system uses the same elliptical orbit around the Earth. The international elliptical dimensions of WGS 84 are determined by satellites and are very close to the Earth in the form of a globe. In WGS 84, third axis (z-axis) passes through the Earth's conventional pole (magnetic pole), and its X-axis is the interface between the Greenwich meridian plane and the equatorial plane. The Y axis is also adjusted so that the system is right-handed.

5.2.20 Spatial Resolution

The ability of each meter to identify the details of spatial phenomena at the ground level is defined as the power or spatial resolution. The smaller pixel's size, the greater number of networks (pixel density) and the better the detection of tolls, and consequently the larger the data volume. For example, if the pixels of each image are 15 × 15 meters, that is, each pixel covers 15 square meters of the earth's surface. Existing meters have a variety of spatial resolution, which are divided into three categories: low resolution (more than 60 meters), medium (between 10 and 30 meters) and high (between 30 cm and 5 meters).

5.2.21 Spectral Resolution

The ability of each meter to identify different spectra of electromagnetic waves is defined as the spectral power or resolution of a spectrum, in which the number of bands and the bandwidth of each image band are very important.

5.2.22 Radiometric Resolution

The number of bits that the meter assigns to receive energy is called the radiometric resolution, or in other words, the number of meters that the meter can assign to the energy received to create the image is called the radiometric resolution. The higher radiometric resolution, the more energy it can detect. For example, if the radiometric resolution is an 8-bit satellite image, it means that it can generate electromagnetic energy in a range of 0-255 nm (NM). Distribute the nanometer (0 for black and 255 for white) or if the image is 16 bits, it can divide the energy reaching the sensor in a range between 0-65535 NM. Therefore, it should be noted that if the radiometric resolution is higher, the image quality will increase, which is not detectable by eye, but these changes can be detected in pixel values.

5.2.23 Geosynchronous Orbit

In this circuit, the speed of the satellite is the same as the speed of the earth's rotation, and it takes one day to walk this orbit. The approximate height of this orbit is 36,000 to 3,000 km above the equator. This circuit is used for satellites that have meteorological, telecommunications and media applications.

5.2.24 Sun-Synchronous Orbit

In this orbit, the satellite is orbiting from north to south, and the orbit is variable over time. The orbit is about 500 to 1,000 km above the Earth's equator. This circuit is used in remote sensing satellites because the images taken by the satellite have the same time.

5.2.25 Field of View

The viewing angle of the whole sensor is called the field of view (the angle at which the meter sweeps the earth's surface), which can be calculated from Eq. (5.1).

$$FOV = 2 \times \arctan\left(\frac{W}{2H}\right) \tag{5.1}$$

where FOV = field of view; W = sensor width of the meter and H = height of the satellite.

5.2.26 Ground Field of View

The ground width of the field of view is actually the same as the imaged width, which can be calculated from Eq. (5.2).

$$GFOV = 2 \times H \times \tan(\frac{FOV}{2}) \tag{5.2}$$

where $GFOV$ = ground field of view.

5.2.27 Ground Resolution Element

The ground resolution element is the smallest angle that the sensor captures at any given moment because no satellite has a fully stable and stable orbit, and its altitude varies throughout the orbit. The field of view of the moment is a function of the orbital height of the satellite, the focal length of the optical system, and the size and dimensions of the sensor.

5.2.28 Classification

Classification can be thought of as a decision-making process in which visual data is transferred to a specific classroom space. Classification methods are traditionally divided into two categories: supervised and unsupervised classifications.

5.2.29 Monitored Classification

The monitored methods require basic information such as the number of classes, their characteristics, as well as the amount of known samples from each class.

5.2.30 Ncontrolled Classification

There are automated methods that do not require known examples, and pixels decide on their classification based on their values.

5.2.31 Visual Interpretation

If we analyze and separate data that is vector, it is called visual interpretation. Visual interpretation is considered as one of the traditional methods in remote sensing, but due to its high accuracy, its use is common and time and manpower are of great importance in this method.

5.2.32 Digital Interpretation

If raster data analyzed with optical tools (armed eyes) or with computer tools (GIS), it is called digital interpretation.

5.2.33 Fragmentation

The division of an image into continuous sections that are ideally aligned with the effects on the ground is called fragmentation. In image fragmentation, pixels that are similar to each other in terms of criteria (spectral characteristics) are considered as a fragment of the image, and therefore the location of a pixel in the fragmentation is important. Factors such as the integration (or elimination) of tolls, poor detection of toll boundaries, ambiguity in identified boundaries, and noise sensitivity have prevented fragmentation as a common method for extracting information. In addition, fragmentation methods usually do not work well for images with low spatial resolution and do not have the required accuracy.

5.2.34 Validation of Results

Evaluating results is one of the most important steps after information processing. Providing processing results without any parameters that express the quality or accuracy of these results reduces their value and in some cases makes them useless. Therefore, it is important to note that in addition to processing, the results must always be evaluated. There are several ways to evaluate the accuracy of results. The most common way to evaluate processing accuracy is to select a number of known sample pixels and compare their class with the processing results. These known data are called terrestrial realities or reference data. Accuracy assessment results are usually presented in the form of an error matrix, in which case the types of parameters and values that indicate the accuracy or type of error in the results (such as overall accuracy or Kapa coefficient) are extracted from this matrix.

Also we can use other similarity metrics to evaluate the model outputs and remote sensing data e.g. Structural Similarity Index (SSIM), Goodman and Kruskal's lambda (Goodman and Kruskal 1954), Theil's uncertainty, EOF, and Cramér's V (Cramér 1946; Koch et al. 2015; Rees 2008) and spatial efficiency metric (SPAEF) (Demirel et al. 2018; Koch et al. 2018).

5.3 Fundamentals and Basics

All materials are composed of atoms and molecules with a specific composition. Therefore, each material absorbs, reflects, or spreads electromagnetic radiation in a single form and under a specific wavelength that is related to its internal energy balance i.e. known as the unit material properties or spectral properties. In other words, the properties of energies created based on the conditions and type of materials on Earth are very different. Some objects have a reflective property in front of a particular wavelength. However, they have the property of absorbing and transmitting energy in another wavelength. The combination of such phenomena on different images creates special colors and allows the eye to distinguish between different shapes in the images. For example, sunlight is affected, reflected, or absorbed by molecules and suspended particles in the atmosphere as it passes through the atmosphere. This method of changing and analyzing the intensity of sunlight creates colors. For example, the blue color of the sky during the day is due to the emission of a blue spectrum in the atmosphere (all shorter wavelengths are released after a distance and only longer wavelengths reach the earth's surface) or because the leaves of some plants appear green. Chlorophyll absorbs the blue and red spectra and reflects the green spectrum. The reason for the green color of vegetation is the greatest reflection of the green spectrum.

Remote sensing systems operate in one or more parts of the visible, infrared, or microwave spectrum of the electromagnetic spectrum. In other words, each sensor system is sensitive to specific areas of the electromagnetic spectrum and records some of the spectral characteristics of objects. Of course, not all parts of the electromagnetic spectrum are used in remote sensing, that important causes of this problem include severe atmospheric absorption and distribution at certain wavelengths, the importance and usefulness of the data type collected, and technical considerations. These factors have caused some parts of the electromagnetic spectrum not to be used in general or to be used infrequently. Due to its high application, it is embedded in almost all multi-spectrum meters.

The amount of energy that reaches the sensor depends on how the energy and the body interact. If for each object the amount of energy reflected from the total energy reached to the object is measured at different wavelengths and plotted as a graph, the resulting curve is called the spectral behavior curve. The horizontal axis of this curve is the wavelength and the vertical axis of the graph represents the percentage of return energy. These energies can be measured in the laboratory or in real environments. After drawing the spectral behavior curve, a lot of information can be obtained about the object and how it appears in the image.

As mentioned, the sensors used in remote sensing collect information in different parts of the electromagnetic spectrum, and these sections are often not limited to the visible part of the spectrum. Since common displays use RGB color space to display colors, a combination of sensing bands should be assigned to three colors: red, blue, and green in the visible spectrum. Since conventional displays use RGB color space to display colors. Therefore, a combination of sensing bands should be assigned to three colors: red, blue, and green in the visible spectrum. One of the most common combinations used is the false color composite. Non-metallic bands are also used in this color composite. A non-false color composite is not seen in those natural colors for objects, but by knowing exactly the order of the assigned bands and how the tolls behave in these bands, it is possible to distinguish them.

Colored compositions are used to create visual mosaics, but their most important uses are in traditional visual interpretation and information extraction. By knowing the color combination as well as the type of sensor, an experienced interpreter can detect many side effects on the image. The best reference for creating an optimal color combination is the spectral behavior curve. By studying the spectral behavior curve of the desired effects, it is possible to identify the parts of the electromagnetic spectrum in which the mentioned effects appear more clearly, and then select the relevant bands from the bands in the sensor.

The RGB color system uses the three primary colors red, green, and blue to produce all colors. Each color is determined and can be produced by determining the value of these three components for it. Considering a three-dimensional coordinate system (in the form of a cube), it is at the origin of the black color coordinate system (0.0.0) and gradually other colors are produced by adding values in three axes. In the opposite corner of the origin, where the maximum possible numbers can be generated for the three primary colors, it will be white. The diameter of the cube that connects black to the white dot is called the gray line, and on it, the value of all three components of red, green, and blue is equal for each point, thus producing different levels of gray from black to white. The gray degree of the image is referred to as the brightness of the image. A histogram is a descriptive image of how the degrees of gray distribution are distributed. For analysis, the minimum and maximum brightness distances of each material in each band are determined and the abundance of matter is examined. The horizontal axis of the histogram indicates the intensity of the reflection from the surface in the desired band and the vertical axis also indicates the frequency of radiation reflecting materials.

Data from remote sensing systems, including aerial photographs and scanner images (satellite images), have a variety of errors and should be corrected before they can be interpreted and analyzed. These errors can be divided into geometric and radiometric categories. Geometric errors are related to the position of the pixels in the image relative to other phenomena and its absolute position, and the radiometric error is related to the amount of reflection recorded in the image.

Radiometric corrections are used to reduce or eliminate two major types of errors: atmospheric errors and device errors. Atmospheric errors are caused by the absorption and scattering of atmospheric particles, which blur the details of the image and thus reduce the power of sensor's spatial segregation. The greatest atmospheric effect is related to the scattering, which is highly dependent on the wavelength, so the effect of the atmosphere on different bands of a sensor is not the same. As the wavelength becoming longer, the atmospheric distribution impact is more effective. Atmospheric errors usually appear heterogeneous in images taken from a large viewing angle or with a large capture width. At the edges of the image, there are more atmospheric errors than in the middle of the image, which is due to the longer path that electromagnetic waves must travel through the atmosphere for side pixels. Atmospheric correction methods can be divided into two general categories, which are detailed correction and bulk correction methods. Device errors are those errors that occur due to the design or performance of the meter. These types of errors are varied and vary from one meter to another based on the type of system used. The two main device errors include missing line errors and tape errors.

On the other hand, satellite images have no coordinates and must be supplemented with additional geometric corrections with the help of GIS, and match a standard basis in terms of coordinates and then be analyzed. Satellite data can be geometrically corrected using one of the methods of using ground control points, using satellite orbital parameters and correlation, and matching a basis. The basis can be an image or a map. If the base is an image, the image-to-image correction, and if the base is a map, will be an image-to-map correction. If the ground of adaptation itself is the reference earth, that process is called absolute geometric adaptation and otherwise relative geometric adaptation. The most common geometric matching method is the use of ground control points. Their coordinates are known and used to validate data and find unknown parameters. After selecting the control points, the location of the points on the image and the map is determined by creating a spatial correspondence between the image and the map with the help of GIS. Then, the coordinates of these points are determined in the map coordinate system as well as the satellite image coordinate system. After that, the geometric error model of the coordinate system and its characteristics are selected. Due to the fact that there may be different errors depending on the type of sensor, the models used vary from one meter to another. In summary, the remote sensing function and GIS can be described as Fig. 5.2.

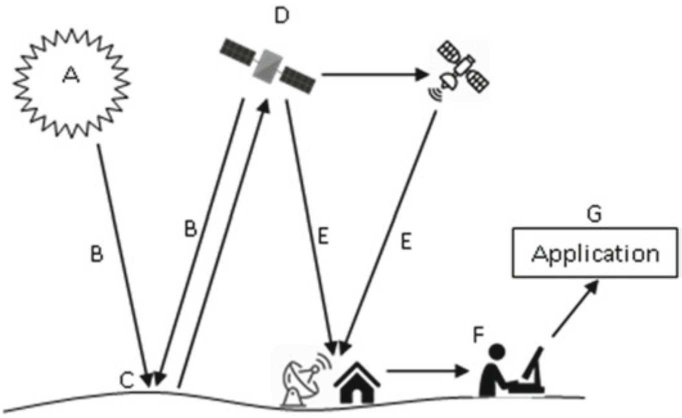

Fig. 5.2 The scheme of remote sensing

As you see in Fig. 5.2, RS components consist of seven different parts, which are located in part (A) of the electromagnetic energy source naturally (solar) or artificial (active sensors). In Section (B) of the energy sources, electromagnetic waves propagate toward the earth. In section (C), according to the material of the place where the waves hit the ground, they are divided into three states, which are absorption, reflection or diffusion. A number will be attributed to the amount of energy absorbed. Then (E) If the sensor is capable of sending information to Earth, the numerical information recorded by the sensor will be sent to Earth, otherwise the recorded digital information will be sent to a telecommunications satellite and transmitted to Earth by it. Section (F) examines the information received from the meter and applies the necessary corrections to it. And in section (G), the information evaluated by different users in the GIS is used to analyze the research and operations of their choice.

5.4 Importance and Necessity

Remote sensing as compared to other methods of information production, such as ground mapping, aerial photography, and local surveying have great advantages. Remote sensing rather than traditional methods has some advantages for instances, in remote sensing, scientists do not need to physical access to the study area, costly affordable and often are free and low time consuming. However, in traditional methods scientists must visit the study area physically and also these methods need lots of expertise for collecting and processing data and also time-consuming. This technology requires little (but specialized) manpower and very limited ground operations. However, it should be noted that if ground data are used to correct and validate data collected from remote sensing or GIS, it will increase the accuracy of the work.

Today, all data, processes, and outputs in remote sensing and GIS are digital, and this makes it possible to make the most of existing computer technology in performing analyzes and activities. Digital data is effective in creating a simple and easy connection between remote sensing and GIS, and speeds up processing and analysis in a variety of dimensions. This will examine all the various unknown aspects and phenomena whose effects have not yet been discovered, and identifying and being aware of them requires very costly and time-consuming research that may not be enough to last a lifetime.

One of the advantages of remote sensing is the availability of a variety of satellite imagery with different spatial and spectral characteristics, which allows experts to use this feature to obtain a more comprehensive and complete set of information in a shorter time than traditional methods. The presence of multiple sensors that perform a variety of imaging in different parts of the electromagnetic spectrum, in addition to the variety and increase of data, allows for multiple images for a specific location and more accurate, complete and multifaceted analysis can be performed simultaneously. In the remote sensing not only the analysis of the current and past situation can be examined, but also the future events can be predicted using different algorithms. The existence of these capabilities in remote sensing and GIS has led to getting out the monopoly of military and espionage systems and to serve practical and research purposes to control and be aware of what is happening.

5.5 Methods and Flowchart

In the studies, that uses remote sensing science and a GIS, an almost identical process is observed. The methods and process of remote sensing researches presented in Fig. 5.3.

In Fig. 5.3, the first step in remote sensing process is identifying appropriate input data. Then according to the conditions of case study, the optimal time interval (based on the required accuracy) and the optimal sensors (sensors that have images with desirable characteristics) are determined. As the next step, the required images are retrieved, the raw satellite images are corrected and the information is extracted and stored in the desired inputs of the GIS as digital layers. After verifying the results, the necessary maps are produced by the GIS and related software (such as ArcGIS, QGIS, ERDAS etc.).

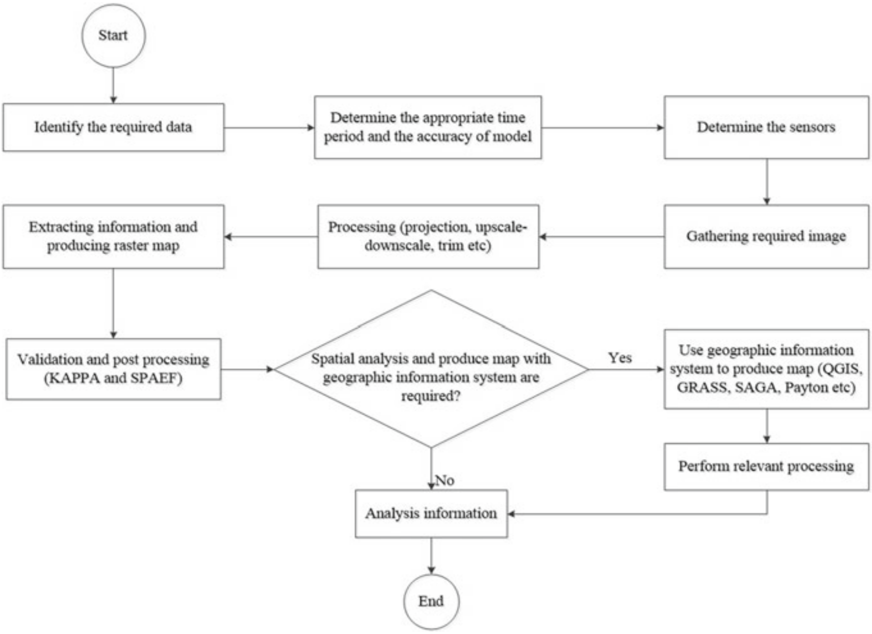

Fig. 5.3 The flowchart of RS and GIS process

5.6 Practical Examples

5.6.1 First Example

Demirel et al. (2019) collected groundwater point data and three different remotely sensed soil moisture products from the Advanced Microwave Scanning Radiometer on the Earth Observing System (EOS) Aqua satellite (AMSR-E), the European Space Agency Climate Change Initiative Soil Measure (ESA CCI SM v04.4), soil moisture active passive (SMAP), and remotely sensed total water storage anomalies from Gravity Recovery and Climate Experiment (GRACE) to constrain a lumped model (HBV) for the Moselle River Basin in Germany and France. Performance metrics ensured a good fit between observed and simulated streamflow as well as groundwater and soil moisture. Before model calibration, the most important parameters are identified using sensitivity analysis. Their comprehensive analysis showed substantial contribution of aggregated remote sensing products to the lumped model calibration. Additional new earth observations, such as groundwater levels from wells and satellite-based soil moisture data improved the model's physical behavior, while it kept a good water balance. Their results are in line with previous studies (Nijzink et al. 2018).

5.6.2 Second Example

Baghri (2016) investigated the identification of groundwater resources using satellite imagery. Groundwater resources, due to their cheap, easy and accessible extraction, are of good quality in case of sustainable use of the resource and are quite suitable for exploitation for sensitive uses such as drinking. In this regard, they are known as strategic water resources. The high volume of these resources, compared to surface water reservoirs and the low impact of climatic conditions, has made these resources a point of reference for water supply and development. In the current situation, a large percentage of the drinking water consumed by urban communities in the world is supplied by groundwater resources. Therefore, identifying and finding potential resources is essential for sustainable exploitation.

In this study, in addition to traditional methods of identifying groundwater resources such as geological surveys, geophysical and speculation, they used satellite imagery combined with new accreditation techniques. Researchers believe that soil characteristics, land use type, land slope and vegetation type can be used as a guide for locating groundwater resources, and the accuracy of such a guess has been investigated during this study. In this study, image of Landsat satellite and ASTER sensor, Terra satellite, ENVI and ArcGIS software have been used to process and access the required information. In order to identify the potential of groundwater resources, three methods have been used, which are artificial neural network, multivariate linear regression and analytical hierarchy process, and their accuracy has been evaluated. Talented areas for groundwater resources have been identified from data such as vegetation maps, land use, soil and slope.

Vegetation: Research shows that vegetation reduces rainfall and allows rain to slowly seep into the soil, and therefore the presence of dense vegetation in an area increases the likelihood of groundwater resources in that area. So the use of water resources, vegetation, meadows level increases and raises the water table. The vegetation map used in this study was extracted from the Landsat 8 satellite image and the vegetation density was determined by the vegetation index, which has the highest relationship with plant life volume among the vegetation characteristics.

The vegetation index is obtained from Eq. (5.3).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{5.3}$$

where, NIR = near infrared; RED = red band.

In this study, first in ENVI software, radiometric correction was performed and in order to reduce the effect of opacity, atmospheric correction was applied and NDVI index was calculated based on two bands 4 and 5 Landsat image and then using classification tools in the software ArcGIS The data obtained were classified into different classes.

Slope: The slope map of the area is prepared from the ASTER image height digital model with a spatial resolution of 30 m. The slope map is obtained by applying the slope function in the ArcGIS environment. The slope plays an important role in the accumulation and infiltration of water into the lower layers. The higher the slope of the area, the faster the surface water flows and the less likely it is that water will seep into the lower layers. Accordingly, areas with lower slopes are predicted to increase the likelihood of groundwater.

Soil: Soil map is one of the most important parameters in identifying water resources. In this study, the soil of the study area has been divided and evaluated into several classes in terms of water absorption capacity.

Each of these four factors has a special weight in identifying water resources. In this study, they concluded that the neural network had the highest accuracy and the AHP method had the lowest accuracy, but the standard deviation values were acceptable in all three methods. Therefore, these four factors can be used to identify groundwater resources.

5.7 Summary

Human beings have always tried to know their surroundings better and more, and despite the efforts made, sometimes natural events (hazards etc.) have surprised them. The growing trend of human societies and population growth necessitates more and more sustainable use of natural resources and resources to meet human needs and greater coordination with the natural environment. At the same time, human beings are expanding their living space day by day and making changes in the areas and exploiting the natural resources that were previously known as pristine places and areas. Therefore, it is necessary to collect information from these phenomena. On the other hand, field harvesting from the globe is continuous, regular, up-to-date, and with adequate spatial coverage, it is time consuming, costly, and sometimes impossible. In this regard, remote sensing science and GIS are very effective and efficient in achieving these goals as quickly as possible, so that it has removed the barriers to understanding nature with full coverage from the Earth's surface and with short-term intervals. The high resolution and wide resolution of satellites have led to the evaluation of the information obtained as one of the most important measurement tools. Remote sensing output data is an irreplaceable source of information input to the GIS so that accurate and timely layers can be prepared by remote sensing science and examined by the GIS to achieve the intended goals.

New remote sensing techniques are high-performance new tools that, along with new computational methods and the development of various physical, statistical, and black box models that use remote sensing data as input, open up human curiosity to learn and see more. They are more visionary and add to his experience. In general, the applications of remote sensing techniques in water resources studies can be classified into the following groups:

- Studies of water balance components such as rainfall estimation, evaporation and transpiration. (This category includes land use determination and estimation of drinking, industrial, agricultural, and environmental consumption, as well as hydrological studies of the body (catchment area) of catchments that lead to the modeling of resources and uses).

- Qualitative studies and water pollution.
- Groundwater identification and potential studies.
- Studies on river morphology and river engineering.
- Watershed management, erosion and sedimentation studies.

According to research in the field of water resources using remote sensing techniques and GIS, increasing the accuracy of methods and preparing guidelines and general principles for various studies seems necessary because the current process and results of studies are tested. Different methods and procedures indicate different goals, and recently there are signs of confidence in remote sensing techniques in the results that need to be accelerated. At the end, it should be noted that remote sensing science and GIS are very valuable due to increasing the speed of processing and collecting environmental information and data and need more investment and research in their use and application for full access and knowledge of the environment. That will increase the level of well-being, awareness of the danger, how changes will take place in the surrounding natural environment and the optimal use of available resources.

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