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Review of the Role of Remote Sensing Technology in Water Resources Management

Gashaw Gismu Chakilu
College of Agriculture and Environmental Science, Debark University, Po box 90, Debark, Ethiopia

Abstract
The human race through the ages has striven to locate and develop water resources. One of the main challenges in sustainable management and utilization of both surface and ground water resource is obtaining accurate hydrological, meteorological and topographic information which are essential inputs in identification of opportunities and treats. Remote monitoring, via satellite assets and distributed in situ sensors, may help meet many of the challenges of information asymmetry and data gaps in developing countries. Total suspended soils (sediment concentration), oil pollution, eutrophication, municipal and industrial discharge and other water quality deteriorating factors can be observed through using remote sensing technologies. Obtaining accurate precipitation data for hydrological simulations and predictions is a challenging task in developing countries and regions with complex terrains that have no or sparse rain gauge networks. Recently, the rapid development of satellite remote sensing technology has provided hydrologists an unprecedented opportunity to better estimate precipitation for hydrological applications. Remotely sensed data acquired by operational satellites are more and more widely used for the identification, monitoring and delineation of lake mapping at regional or global scales. Currently different remote sensing satellites like: AQUA/TERA (MODIS), QuickBird , SPOT 1-5, IKONOS 1-2, LANDSAT 7. NOAA-GEOS, NOAA-POES and others are being used for obtaining the information about floods inundation areas and flood damage assessment. Even though ground water potential can be identified by different methods, remote sensing technique provides an advantage of having access to large coverage, even in inaccessible areas.

1. Introduction

The human race through the ages has striven to locate and develop water resources. Most of the habitations and cities are developed close to the rivers. Over ninety percent of liquid fresh water available at given moment on the earth lies beneath the land surface. Groundwater, unlike surface water, is available in some quantity almost everywhere. Groundwater has long been regarded as the pure form of water compared to surface water, because of purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange. This is one of the reasons for the excessive consumption of groundwater [23].

"Remote sensing (RS) 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 the object area, or phenomenon under investigation"[19**].** Remote monitoring, via satellite assets and distributed in situ sensors, may help meet many of the challenges of information asymmetry and data gaps in developing countries, including unreliable (and time-consuming) survey data and reliance on spot checks to assess accurate reporting and performance **[20].** Remote sensing techniques make it possible to obtain and distribute information rapidly over large areas by means of sensors operating in several spectral bands, mounted on aircraft or satellites. A satellite, which orbits the Earth, is able to explore the whole surface in a few days and repeat the survey of the same area at regular intervals, whilst an aircraft can give a more detailed analysis of a smaller area, if a specific need occurs. The spectral bands used by these sensors cover the whole range between visible and microwaves. Rapid developments in computer technology and the Geographical Information Systems (GIS) help to process Remote Sensing (RS) observations from satellites in a spatial format of maps - both individually and along with tabular data and "crunch" them together to provide a new perception - the spatial visualization of information of natural resources. The integration of information derived from RS techniques with other datasets - both in spatial and non-spatial formats provides tremendous potential for identification, monitoring and assessment of droughts and floods [1].

Remote sensing provides critical data for water resource mapping. Satellite remote sensing techniques can make continuous and up-to-date measurements with global coverage depending on their orbital features, while they count on ground observations for algorithm development and validation **[35].** Besides water resource mapping, remote sensing can also quantitatively measure hydrological fluxes, such as precipitation, evapotranspiration, river stages and discharges. Ground-based radar such as the US Next Generation Weather Radar (NEXRAD) has been used to quantitatively measure precipitation on US territory since 1990s at relatively high accuracy, and has been widely applied to monitoring precipitation locally and regionally worldwide [18,19]. The remote sensing and GIS technologies are being practiced for water resources development and management since the first Landsat satellite was launched in 23 July 1972 by NASA [40]. In this paper I have reviewed the role of remote sensing on the management and developmental activities of water resources.

2. The role of remote sensing in water quality assessment process

Water quality is a general descriptor of water properties in terms of physical, chemical, thermal, and/or biological characteristics. It is difficult to define a single water quality standard to meet all uses and user needs. For example, physical, chemical, and biological parameters of water that are suitable for human consumption are different from those parameters of water suitable for irrigating a crop. Water quality is affected by materials delivered to a water body from either point or nonpoint sources. Point sources can be traced to a single source, such as a pipe or a ditch. Nonpoint sources are diffuse and associated with the landscape and its response to water movement, land use and management, and/or other human and natural activities on the watershed. Agriculture, industrial, and urban areas are anthropogenic sources of point and nonpoint substances. Polluting substances that lead to deterioration of water quality affects most freshwater and estuarine ecosystems in the world [5].

Spectral properties of water vary with wavelength of incident radiation not only due to the molecular structure, but also due to impurities present in the water body. Hence, Remote Sensing for mapping or monitoring water quality becomes quite complex. The water surface behaves as a partially diffused and partially specular reflector. Specular reflection is uniform at all wavelengths, but absorption and back scatter produce distinctive spectral signature or spectral response pattern. Solar energy that is not specularly reflected is reflected downward into the water body. This refracted energy is either absorbed or get scattered. The remaining signal is indicative of water quality, which is volumetric reflectance or back scattered energy caused by the material in water. In case of deep water, where the bottom reflectance is negligible, the reflectance comes from the surface of water body. However, for shallow water, the total reflectance is a function of both surface and bottom reflectance [4].

In order to monitor water quality through Remote Sensing, the relationship between water quality parameters and spectral reflectance must be determined. As the reflectance changes with the modified value of water quality parameters, an empirical formula may be used. However, the formula may not be valid in multi temporal domain as the type of constituents in water may not remain constant. Sun elevation angle and atmospheric composition change with time and will affect the relationship between water quality parameter and spectral reflectance [4**].**

Table 1: Remote sensing techniques in water quality monitoring

SN.	Water quality parameters/water pollution parameters	Remote sensing technique employed	Remarks
1	Total suspended solids	Visible spectral region of EMR	Reflectance increases with the increase in sediment concentration, empirical relationship could be established for TSS estimation
2	Temperature	Thermal infrared and passive microwave regions of the EMR	Infrared radiometers (in 8-14 regions) based on Aircraft/ satellite can be used to estimate temperature of water body, the characteristics of temperature change depends upon nature of pollutants and effluents.
3	Agricultural runoff	B&Wand colour infrared (CIR) photography	Change in vegetation can be identified and monitored through CIR; B&WIR imagery can also be used to identify the source of agricultural pollution.
4	Eutrofication of lakes	Colour infrared (CIR) photography	Monitoring of floating algae identification and delineation of potential areas of algal blooms are possible with CIR image. Water transparency, color, chlorophyll, algal blooms and aquatic vegetation of lake eutrophication can be monitored
5	Oil pollution	Ultraviolet (UV) photography Thermal infrared (TIR)scanners Passive microwave sensors	Good weather condition and low altitude aerial survey is required to monitor oil pollution, limited to day time monitoring. All weather, day and night capability. All weather, day and night capability.
6	Water depth	Blue/Green portion of visible spectrum Aerial photogrammetric methods LASSER profile technique (LIDAR)	In clean water, blue light penetration up to 15-20m and green light penetrates up to 1-2m measures of parallax in stereo pair photographs with at least three reference targets. LIDAR systems can be used to measure accurate profile water depths.

SN.	Water quality parameters/water pollution parameters	Remote sensing technique employed	Remarks
7	Municipal and industrial discharge	Satellite/ Airborne TIR imagery	Temperature difference between the effluents and the water (in which the effluent is discharge) can be identified and monitored as dispersal pattern of effluent plumes.
8	Colour/ material insulation	LASSER spectrometers	May not be possible to detect through satellite imagery; ground based LASER spectrometers can be used for identification of chemical composition of the solution/ water.

Source: (D. Bagchi & R. Bussa, 2016)

3. Application of remote sensing in rainfall monitoring

Precipitation is an important component of the hydrological cycle. Accurate observation or estimation of precipitation is critical to flood forecasting and warning, drought monitoring, and water resources management [19]. The accuracy of the precipitation input significantly influences the performance of hydrological models. Obtaining accurate precipitation data for hydrological simulations and predictions is a challenging task in regions with complex terrains that have no or sparse rain gauge networks. Recently, the rapid development of satellite remote sensing technology has provided hydrologists an unprecedented opportunity to better estimate precipitation for hydrological applications.

Precipitation inputs are essential for hydrological simulation, whereas in the data-sparse regions, the availability of accurate precipitation is restricted by sparse gauges. Especially it is more useful in inaccessible areas and the regions which have not meteorological rain gauge stations in developing countries. As alternatives, satellite-based precipitation products, with the massive growth during the last decade, could provide high temporal and spatial resolution quasi global precipitation estimates [17]. The Tropical Rainfall Measuring Mission (TRMM) was the first satellite to measure the global mid-latitude precipitation at unprecedented 0.25◦ and 3-h product since 1998, e.g., the Multi-satellite Precipitation Analysis (TMPA), and the Global Precipitation Measurement (GPM) products have even been able to provide global near-real time precipitation estimates of 0.1◦ and30-minproductssince2014,e.g.,theIntegrated Multi-satellite Retrievals of GPM (IMERG) [36,15].

There are numerous quasi-global satellite-based precipitation products, such as the Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis (TMPA; Huffman et al. 2007), the Climate Prediction Center morphing technique (CMORPH; Joyce etal.2004), and the Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) method (Sorooshian et al. 2000). The evaluation of satellite-based precipitation products is necessary as to provide feedbacks for the retrieval algorithm improvement (Yong et al. 2015) and give implications to select the precipitation dataset for local hydrological applications [36].

Rainfall data from conventional sources (rain gauges) are often inadequate. Salient points include the following: 1) The density of rain gauges is usually much too low for many purposes; 2) The supply of data from existing rain gauges is liable to a number of possible deficiencies, involving their accuracy, reliability, availability and timeliness; 3) There is widespread evidence that the supply of rain gauge data is becoming generally less than previously, though the picture is very varied and improvements, while relatively rare, are not unknown; 4) The particular characteristics of rainfall ensure that, even where and when it is reasonably well observed by rain gauge networks, the processes of isohyetal map construction and depth/area (volumetric) assessment of rainfall are fraught with difficulty. In short, rainfall distributions, being characteristically disjointed, cannot be constructed with complete confidence from existing rain gauge networks, so that whatever the mathematical contouring procedures used, doubts inevitably surround the results obtained.

4. Application of remote sensing in lakes and reservoir management

The water stored in lakes and reservoirs plays a vital role in the economic development and many services that contribute to the well-being of communities up to kilometers downstream (even across administrative borders) and in close proximity to lakes and reservoirs [19]. A solid understanding and quantification of the water balance of lakes and reservoirs is essential for many applications, including hydrological modeling, effective water resources management, and climate change studies, etc. To achieve the quantification of the water balance of lakes and reservoirs, relevant data on each component (inflow, precipitation, water level/volume, and outflow, etc.) are required, ideally from ground measurements. However, such required data are often not readily available because of, for example, the following situations: (1) variables are not measured at all, which is the case in ungauged basins and inaccessible regions; or (2) measured data are not freely shared. The surface outflow from lakes and reservoirs, a measure of water supply, is a particular variable of high importance for downstream multiple sectors. Unfortunately, the responsible agencies for lake, reservoir, and dam operations are usually not keen to share these outflow data with other agencies and neighboring countries [40]. Because of the strategic importance of stored water resources in lakes and reservoirs, institutions responsible for dam operations are often not transparent in their reporting. Poor communications and information cause distrust and tension between multiple water use sectors.

Changes in the coastline and water level of lakes mainly reflect changes in precipitation, evaporation, runoff and human activities integrated over the lakes and their basins. In that sense, these fluctuations constitute a sensitive indicator of past and present climate and human activity changes at a local and regional scale. Remotely sensed data acquired by operational satellites are more and more widely used for the identification, monitoring and delineation of lake mapping at regional or global scales. The availability of multiband, multitemporal and multisensory images and advances in digital processing and analysis have enabled research scientists to gather information about the spatial and temporal evolutions and sensitivities of alterations due to natural and anthropogenic events [2,15,21,30].

In recent years, remote sensing and photogrammetry have been used in a widespread manner for the purpose of following the change in the coastal area management and the use of the coast. Remote sensing allowed monitoring the reservoir water level by estimating its surface extension. Surface extension has been estimated using different approaches, employing both optical (Landsat 5 TM, Landsat 7 ETM+ SLC-Off, Landsat 8 OLI-TIRS and ASTER images) and Synthetic Aperture Radar (SAR) images (Cosmo SkyMed and TerraSAR-X) (Claudia P., et al, 2018)). A change could be revealed as a result of assessing the images or photographs on different time zones by taking old and new photographs of the region which are chosen in order to follow the change on the coast. Following the change on the coastal line with the help of photogrammetry, remote sensing is much more practical compared to topographic measurements. With these methods, developmental route of the environmental problems which experienced in the past could be observed step by step. By this means, it is possible to calculate the dimensions and effects of the change [2, 6, 18, 29].

5. Application of remote sensing in flood forecasting and management

Space and Air based observations of earth provide a unique vantage point for monitoring and assessing the floods and other disasters. The traditional floods mapping and studies were based on conventional surveys and historical flood records. In this regard, space technology has made substantial contribution in every aspect of flood disaster management such as preparedness, prevention and relief [25].

Assessment of the flood impact is a complex problem that can only be solved through interdisciplinary research and a stepwise approach. The first step is to estimate the dimensions of a possible (likely) flood. Through the application of 1) dimensional flood models, design hydrographs can be constructed that give an indication of possible discharges for a given catchment at a certain location for a predefined climatologic event. The second step is to assess the consequences of such a (peak-) discharge for an area of special interest. The final step is to estimate how the flood interferes with human activities in the affected area. How many people will suffer from the floodwater by losing their life, their health, their home or their livelihood? What will be the damage to crop yield, industrial production or to houses? Also aspects of civil protection need to be considered, like when people need to be evacuated and which transportation lines are still available in the inundated area. All three steps in the flood risk assessment process require up-to-date and accurate information on the terrain topography and the use of the land. Remotely sensed images from satellites and aircrafts are often the only source that can provide this information for large areas at acceptable costs. Digital Elevation Models can be constructed quickly or can be improved by using e.g. the Aster images. Furthermore all kinds of parameters that are important for hydrological modeling is related to the land cover, e.g. permeability, interception, evapo-transpiration, surface roughness, etc. And since land cover mapping using satellite images is already common practice, the spatial distribution of these values can be easily estimated. However satellite imagery is not only useful to derive input data for the hydrologic models, but offers also good possibilities to validate the output of the models when a flooding disaster has struck. The observed extent of the flood can then be compared with the modeled prediction. Perhaps the most promising application of RS is its use for elements at risk analysis. High resolution images offer great opportunities to identify individual structures. Recognition of the function of these structures is important for the assessment of their vulnerability and their importance and value. Especially for cities that experience fast and uncontrolled expansion into hazardous areas like floodplains, this offers an opportunity to monitor the increasing risks and impacts and to use it in their decision making process [7]. Different remote sensing satellites are being used for obtaining the information about floods inundation areas and flood damage assessment. The major remote sensing and satellites used for flood studies are given in table 2.

Table 2: Remote sensing satellites (IRS) in support of flood and disaster management

System	Status	Capabilities
AQUA/TERA (MODIS)	Existing	Optical 36 bands in VIS, IR SWIR, TIR
DMSP	Existing	Optical, IR
INVISAT	Existing	Radar, optical, IR
ERS1 and 2	Existing	Radar 5-500 km swath, 25m resolution
IKONOS 1-2	Existing	Optical 1 and 4m resolution
KVR -1000	Existing	Optical 150 km swath, 2m
EO1 ALI, Hyperion	Existing	Optical, VIS, IR, SWIR, TIR 10m to 30m multispectral (ALI) to Hyperspectral (Hyperion)
LANDSAT 7	Existing	Optical, IR 158 km swath 30m, 80m
NOAA-GEOS	Existing	Optical, AVHRR
NOAA-POES	Existing	In-situ visible and IR observation
OrbView	Existing	Optical 1,2, and 4m
QuickBird	Existing	Optical 1m resolution
RADARSAT 1	Existing	C-band Radar (SAR) 45-510 km, 9-63m
TERASAR-X	Existing	X-band Radar (SAR) 10-510km, 1-50m
ALOS (PALSAR)	Existing	L-band Radar (SAR) 40-350km, 7-100m
TRMM	Existing	Microwave radiometer, rain radar, Thermal MI
Resurs-03	Existing	Optical 34-600m
SeaWiFS	Existing	Optical, IR 1-4m sea observations
SPOT 1-5	Existing	Optical 60km swath, 10m, 30m

Source: (S. P. Aggarwal, et al, 2009).

6. Identification of ground water potential using remote sensing technology

Groundwater is one of the most valuable natural resources, which supports human health, economic development and ecological diversity. Because of its several inherent qualities (e.g. consistent temperature, wide spread and continuous availability, excellent natural quality, limited vulnerability, low development cost, drought reliability, etc.), it has become an immensely important and dependable source of water supplies in all climatic regions including both urban and rural areas of developed and developing countries [37]. Particularly, ground water is emerging as a formidable poverty-alleviation tool, which can be delivered direct to poor community far more cheaply, quickly and easily than canal water [11]. Of the 37 Mkm^3 of freshwater estimated to be present on the earth, about 22% exists as ground water, which constitutes about 97% of all liquid fresh water potentially available for human use [41].

Groundwater occurrence being a subsurface phenomenon, its identification is indirectly based on the analysis of some directly observable terrain features. The interpretation of satellite data in conjunction with sufficient ground information makes it possible to delineate various terrain features such as geomorphology, land use, geological structures, etc, and their hydraulic characters. Groundwater development requires the analysis of extensive spatial terrain characteristics such as geomorphology, geology, soil, drainage, topography, land use/ land cover, etc. The revolution in computer technology, the advent of Remote Sensing (RS) and Geographic Information System (GIS) offers great scope for handling and analyzing spatial data including the delineation of groundwater prospect zones [13, 24, 38, and 33].

There are several methods such as geological, hydrogeological, geophysical and remote sensing techniques, which are employed to delineate groundwater potential zones. Remote sensing technique provides an advantage of having access to large coverage, even in inaccessible areas. It is rapid and cost-effective tool in producing valuable data on the like geology, geomorphology, lineaments, slope, a number of geomorphic units such as Inselberg, moderately buried pediplain, Pediment, Inselber complex, Pediplain, and Pediment Valley have been observed. A composite groundwater potential map has been generated as very high, high, medium, low and very low based on the groundwater availability in study area etc. that helps in deciphering groundwater potential zone. A systematic integration of these data with follow up of hydrogeological investigation provides rapid and cost-effective delineation of groundwater potential zones. Although it has been possible to integrate these data visually and delineate groundwater potential zones, however, it becomes time consuming, difficult and introduces manual error. In the recent years digital technique is used to integrate various data to delineate not only groundwater potential zone but also solve other problems related to groundwater. These various data are prepared in the form of thematic map using geographical information system (GIS) software tool. These thematic maps are then integrated using ‘‘Spatial Analyst’’ tool. The ‘‘Spatial Analyst’’ tool operators is then used to develop model depending on objective of problem at hand, such as of groundwater potential zones [28].

Working procedure for the preparation of a hydrogeological map is shown on table (3).

Table 3: Working procedure for the preparation of a hydrogeological map.

Step	Description
Data collection	Collection of existing data Field investigation to complete data Preparation of remote sensing map
Data processing	Preparation of basic maps • Topography • Surface water • Well data • Ground extraction • Geology
Data interpretation	Preparation of interpretation maps • Base of aquifer • Piezometric contours • Salinity contours • Aquifer units Preparation of inset maps and cross sections Compilation of hydro geological maps: joint basic and interpretation map to form one map
Printing	Transferring data to digital format, using the GIS /ArcINFO Printing of maps Preparation of explanatory notes

Source: Khalil and Mebius [16].

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