Environmental Monitoring and Assessment – Remote Sensing Approach

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Abstract: - Environmental monitoring and assessment includes a wide spectrum of study that overlaps many disciplines, all of which are independent. This paper illustrates several broad subjects related to environmental constraints including water pollution, effects of atmospheric contamination, strip mining, and natural disasters. Remote sensing can provide complementary information to existing ground-based environmental monitoring systems. Remote sensing can be used to meet the need for timely information and can provide synoptic cross-boundary information also. Data and information obtained through Earth Observation Satellites (EOS) can be used within geographic information systems for overlay and comparison with other geo-referenced information.

Key-Words: - Remote Sensing, water pollution, temperature variation detection, atmospheric pollution, strip mining, and natural hazards.

1 Introduction

The human dimensions of global environmental change consist of the driving forces and the resultant actions of mankind capable of affecting the Earth system and its processes. From a fundamental perspective, the relevant types of human actions are those that have accompanied the historical development of civilization and technology, and that now are reaching epic proportions due to the continually expanding human population.

Remote sensing techniques permit an evaluation of physical, chemical, and biological environments for beyond the imagination and capabilities available only few years ago. In particular, data obtained from sophisticated electronic sensors aboard spacecraft now permit study of large areas viewed during a single instant in time. Furthermore, the same area can be viewed repetitively, the time span depending on the frequency of the spacecraft overflight.

From an environmental viewpoint, remote sensing technology allows us to examine various parts of the ecosystem-close at land, at a moderate distance, or form great altitude. These permit detailed studies combined with regional examinations which, in turn, provide a broad understanding of existing environment. Discussed below are the remote sensing approaches to effectively use in relation to environmental factors.

2 Water Pollution

Despite the wealth of information available in the literature, it is still not possible either to accurately delineate all areas of water pollution or to quantify the impacts of many environmental stresses. The body of quantitative water-quality data generally available consists almost entirely of point source analyses of physical, chemical, and biological parameters. The study of hydrology concerned largely with changes in water quantity and quality characteristics. However, to measure the continuing impact of environmental stress on water, it is necessary to observe the distribution of quality characteristics spatially and also observe the distribution of quality characteristics with time.

Traditional water quality monitoring depends on in situ measurements or sequent laboratory analysis of the samples. These type of point sampling methods may give accurate measurements, but they are time and money consuming. Further and most importantly, they can’t give the real-time spatial overview that is necessary for the global assessment and monitoring of water quality. Satellite remote sensing may provide suitable ways to integrate limnological data collected from traditional in situ measurements. Since the 1980s, with improvement
of sensor spatial and spectral resolution, satellite remote sensing has been used to monitor inland water by using correlation between broad-band reflectance and other properties of the water column, including chlorophyll concentrations, pigment load, total suspended sediments, temperature and water quality data analyzed in a laboratory [18], [4], [19], [22], [6], [7], [10] and [11].

At present, it is possible to relate remotely sensed data spatially only to the point measurements of selected physical parameters such as temperature, and turbidity. One can also infer the distribution of certain chemical quality characteristics from the physical data, for example, where the discharging fresh river water and the brackish or saline water of an estuary have different temperatures. In this case, the distribution of radiant energy is used to determine the surficial distribution of chloride. Although, it would be more desirable to remotely measure chloride or any other dissolved chemical constituent directly, such as capability does not presently exist. Ground data are still necessary in this case because it is impossible to simply rely on remotely sensed data, showing reflected or emitted radiation, to distinguish differences in the chloride content of fresh water, brackish estuary water, sea water, or brine discharging from desalinization plant.

It is not always necessary to measure the traditional quality parameters directly in order to assess the effects of a specific stress on the environment, because remote sensing technology is many instances, provides the capability of observing such effects. For example, polluted water commonly has determined effects on the ecosystem. In certain instances these effects can be measured by changes in reflectance with span of time, or by noting the differences between stressed and unstressed species.

Thermal band imagery is extremely useful in creating the river and lake temperature maps that are necessary for some environmental and biological related projects. Images acquired from both airborne and spaceborne sensors are used for this purpose. These models are then applied to water covered areas in the image, enabling generation of surface water quality maps. These maps show patterns in water quality that can easily be missed if only point or transect samples are acquired. The spatial nature of the water quality maps allows the resource manager to have a snapshot in time of the water conditions over an entire lake or reservoir. These maps can be used to document baseline conditions, determine areas of significant point or non-point source water pollution, or document the management activities intended to improve lake or reservoir water quality.

The strength of remote sensing techniques lies in their ability to provide both spatial and temporal views of surface water quality parameters which may not be typically possible from in situ measurements. Remote sensing makes it possible to monitor the landscape effectively and efficiently, identifying water bodies with significant water quality problems. These water quality parameters, often, can be quantified using remote sensing techniques allowing management plans to be formulated to reduce movement of substances from catchments to water bodies thus reducing the effects of the pollutant on water quality. Remote sensing also has a potential role in selection of sub-ecoregion reference sites and in defining historical conditions. Examples of application remote sensing for detection suspended sediments, detection of oil spills and ocean dumps, and uses of temperature variation detection have been discussed below.

2.1 Suspended Sediments

Suspended sediments are the most common pollutant both in terms of weight and volume in surface fresh water of freshwater systems. Suspended sediments may serve as a surrogate contaminant in agricultural watersheds due to phosphorus, insecticides, and metals adhering to fine sediment particles.

Suspended sediments increase the radiance emergent from surface waters (Fig. 1) in the visible and near infrared proportion of the electromagnetic spectrum. Airborne platforms using photography, line scanners, multispectral scanners, and video can all be used to study suspended sediment patterns. Since the late 1970’s remote sensing studies of suspended sediments have been made using data from satellite platforms [16].

Fig. 1 Relation of the reflectance of suspended sediments and wavelength
Most research that had a large range (0-200+ mg/l) of suspended sediment concentration has found a curvilinear relationship between suspended sediments and radiance or reflectance [16], [3] because the amount of reflected radiance tends to saturate as suspended sediment concentrations increase. The point of saturation is wavelength dependent (Fig. 2) with the shorter wavelength saturating at low concentrations. If the range of suspended sediments is between 0 and 50 mg/l, reflectance from almost any wavelength will be significantly related to suspended sediment concentrations. As the range of suspended sediments increases to 200 mg/l or higher, specific relationships have to be developed with reflectance in the longer wavelength.

![Fig. 2 Reflectance of the suspended sediments](image)

2.2 Detection of Oil Spills and Ocean Dumps

Oil spills can destroy marine life as well as damage habitat for land animals and humans. The majority of marine oilspills result from ships emptying their ballage tanks before or after entering port. Large area oilspills result from tanker ruptures or collisions with reefs, rocky shoals, or other ships. These spills are usually spectacular in the extent of their environmental damage and generate wide spread media coverage. Routine surveillance of shipping routes and coastal areas is necessary to enforce maritime pollution laws and identify offenders.

Remote sensing offers the advantage of being able to observe events in remote and often inaccessible areas. For example, oil spills from ruptured pipelines, may go unchecked for a period of time because of uncertainty of the exact location of the spill, and limited knowledge of the extent of the spill. Remote sensing can be used to both detect and monitor spills.

For ocean spills, remote sensing data can provide information on the rate and direction of oil movement through multi-temporal imaging, and input to drift prediction modeling and may facilitate in targeting clean up and control efforts (Fig. 3). Remote sensing devices used include the use of infrared video and photography from airborne platforms, thermal infrared imaging, airborne laser fluorosensors, airborne and space-borne optical sensors, as well as airborne and spaceborne SAR. SAR sensors have an advantage over optical sensors in that they can provide data under poor weather conditions and in darkness. Their purpose is to record the rate of oil slick drift, determine its aerial extent, and predict when and where the contaminant and cleanup can be initiated. In many instances the differences in temperature between petroleum discharge from a leaking well and the receiving waters are sufficient to be measured by thermal scanners. Ultraviolet detectors have shown ever greater promise for monitoring oil spills [15]. Maps constructed from the satellite data can be used to determine the surface movement of the wastes, the location of the major water mass boundaries, and dilution effects. In figure the dark areas off the coast represent the areas where oil is present and areas of lighter tone directly south are areas where dispersant was sprayed on the oil to encourage emulsification. Oil, which floats on the top of water, suppresses the ocean's capillary waves, creating a surface smoother than the surrounding water. This smoother surface appears dark in the radar image. As the oil starts to emulsify and clean-up efforts begin to take effect, the capillary waves are not as effectively damped and the oil appears lighter. Size, location and dispersal of the oil spill can be determined using this type of imagery.

![Fig. 3 Radarsat image taken a week after the spill, showing the extent of oil spill and spread](image)
2.3 Uses of Temperature Variation 

Detection

Variations in water temperature can be due to both natural and artificial causes. Their variations can be detected by thermal scanners, in some cases by a black-and-white aerial photograph and, indirectly, by multispectral scanners. Detection of the causes and aerial extent of temperature anomalies in water are important from a variety of environmental viewpoints.

The most common sources of thermal pollution is cooling water release from electrical power plants. Thermal discharge into streams, lakes and coastal waters from electrical power plants has been mapped with remotely sensed data [8]. Mapping thermal enrichment in streams, lakes, reservoirs, and coastal waters can be useful in managing thermal releases from electrical power plants and understanding aquatic ecosystems. Management of power plant releases can be designed to reduce the impact of thermal releases based on thermal patterns determined for different flow regimes from remotely sensed data. Improved quantitative estimates of surface water temperatures also provide input for interpreting outputs from mathematical models of thermal plumes. Aircraft mounted, thermal sensors are especially useful in studies of thermal plumes because of the ability to control the timing of data collection that is critical for studying thermal releases.

Thermal scanner flights can be used to detect underground effluent discharge points so that ground survey teams can minimize field time to collecting water samples. Thermal scanners can also be used to map the aerial extent and movement of thermal plumes originating from the discharge of heated cooling waters at electric generating plants. The temperature of groundwater is nearly uniform, reflecting the mean annual temperature of the region. Consequently, during the wintertime those stream stretches receiving a significant amount of groundwater discharge should be warmer than adjacent areas, which may be near freezing. Consequently, in the summertime the relatively cold groundwater, as it mixes with the warm surface water, tends to produce colder water.

3 Effects of Atmospheric Pollution

Air quality has become a pressing issue in recent years partly due to the scientific evidence linking fine aerosol with increasing mortality to human health. Standards have been set for the concentration of major pollutants (ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide). Until now, the study of air pollution relied primarily on ground-based measurements, intermittent field campaigns, and chemical transport models. Increasing the data required to forecast and assess air quality is growing to larger spatial scales. Over the next decade, the data for air pollution monitoring and control will need to cover large spatial domains in order to accommodate decisions for pollutants across the geopolitical and intercontinental boundaries. With significant advancement emerging in sensor capability in recent years, remote sensing is shown to be an important tool to monitor air pollution for global, regional, and local assessments. The integration of different remote sensing data sets from various platforms and scales allows a synergistic analysis of air pollution.

Air pollution not only decreases visibility but it may also have a profound effect on the chemical quality of rainfall, thus increasing ecological stress. This if exemplified by the decreasing pH of rain that is related to the increasing concentration of atmospheric gaseous contaminants, such as sulfur and nitrogen oxides, released by the burning of high sulfur fuels. Although acid rainfall is not of immediate danger to humans it does considerate damage to human-made structures and has serious implications for ecologic systems.

The study of atmospheric pollutants, mainly due to human activities, has received considerable attention in recent years all over the world because of two main reasons - (i) they influence the climate directly by altering the Earth's radiative budget and (ii) space-time variations of pollutants provide unique information on atmospheric behavior needed for environmental pollution, air quality assessment/forecast and operational programmes [5]. Fig. 4 shows the wildfires that ravaged southern California in 2003 which not only scarred the landscape but also dumped pollutants into the air. These fires provide an example of how satellite data can reveal the impact of intense local sources of air pollution on air quality on a regional or even global scale. This true-color image was taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's EOS Aqua satellite and clearly shows the smoke plumes of ten raging fires. MODIS data can assist monitoring the transport of aerosolized pollutants.
Natural disasters are the impact of a natural hazard upon a vulnerable community resulting in disruption, damage, and casualties that cannot be relieved by the unaided capacity of locally-mobilized resources (United Nations Disaster Relief Coordinator 1991). Disasters not only threat to the lives of the people but also affect them in several ways. Besides, damage to infrastructure built over years, it causes severe strain on the Government resources. Natural disasters have been there since the origin of the universe, but their impact on the human beings have increased due to expansion of population, forcing people to habitat hazardous and vulnerable areas on the one hand and increase pressure on the resources, leading to erosion of natural ecological balance, on the other hand.

Satellite images of coarse spatial, but high temporal, resolution can help identify and locate some of the impending disasters and thus, give us the little time required to “alert and warn” and take action. What we need is an “image scan” mechanism and system that will do round-the-clock screening. High-resolution images can be the source of detailed information for zoning disasters and also for planning emergency response mechanisms. Further, these images can be the sources of all information during relief stage. A good spatial database, built systematically at different scales can provide the much needed assessment and analysis for a disaster in terms of extent of strike and damage, loss to assets and properties and also help in a systematic recovery of administration in disaster areas. A good GIS database can be the backbone of conducting a vulnerability analysis using complex integrating models and also for easy representation of information as maps and charts (rather than tables and reports).

Using remote sensing data, such as satellite imageries and aerial photos, allows us to map the variabilities of terrain properties, such as vegetation, water, geology, both in space and time. Satellite images give a synoptic overview and provide very useful environmental information, for a wide range of scales, from entire continents to detail of a few meters. Many types of disasters, such as floods, droughts, cyclones, volcanic eruptions, etc. have certain precursors that satellite can detect. Remote sensing also allows monitoring the event during the time of occurrence while the forces are in full swing. The vantage position of satellite makes it ideal for us to think of, plan for and operationally monitor the event.

A complete strategy for disaster management is required to effectively reduce the impact of natural disaster, which is as referred to as disaster management cycle. Disaster management consists of two phases that takes place before disaster occurs, disaster prevention and disaster preparedness, a three phases that happens after the occurrence of a disaster i.e. disaster relief, rehabilitation and reconstruction. In disaster prevention phase, GIS is used to manage the large volume of data needed for the hazard and risk assessment. In disaster preparedness phase it is a tool for the planning of evacuation routes, for the design of centers for emergency operations, and for integration of satellite data with other relevant data in the design of disaster warning systems. In the disaster relief phase, GIS is extremely useful in combination with Global Positioning System in search and rescue operations in areas that have been devastated and where it is difficult to orientate. In the disaster rehabilitation phase GIS is used to organize the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction. Hence, GIS is the useful tool in disaster management if it is used effectively and efficiently (Pearson and others 1991). Some of the natural disasters have been discussed below.

4 Natural Disasters

Fig. 4 Satellite image showing the wildfires
4.1 Floods

Floods are the most common of natural hazards that can affect people, infrastructure, and the natural environment. They can occur in many ways and in many environments. Riverine floods, the most prevalent, are due to heavy, prolonged rainfall, rapid snowmelt in upstream watersheds, or the regular spring thaw. Other floods are caused by extremely heavy rainfall occurring over a short period in relatively flat terrain, the backup of estuaries due to high tides coinciding with storm surges, dam failures, dam overtopping due to landslides into a reservoir, and seiche and wind tide effects in large lakes. Occasionally an eruption on a glacier or snow-covered volcanic peak can cause a flood or a mudflow in which the terrain is radically changed and any agrarian development is totally destroyed, frequently with much loss of life.

It is impossible to define the entire flood potential in a given area. However, given the best remote sensing data for the situation and a competent interpreter, the evidence for potential flood situations can be found or inferred as the most obvious evidence of a major flood potential, outside of historical evidence, is identification of floodplain or flood-prone areas, which are generally recognizable on remote sensing imagery. The most valuable application of remote sensing to flood hazard assessments, then, is in the mapping of areas susceptible to flooding. (Fig. 5).

Fig. 5 Detail of the image along the Elbe river region. The rivers, the flooded areas and the towns are visible in blue. The pixel size of this downsampled image is around 400 m.

4.2 Earthquakes

Remote Sensing Aerial photography and GIS provide us with tools to carry out the earthquake disaster management plan. The assessment and demarcation of earthquake-affected area can be done through quick aerial photography after the earthquake. Classification of damaged areas into worst, moderate and least affected areas can be done through the use of different colour tones on the satellite imageries and aerial photographs. Safe habitation zones can be demarcated with the help of structural deformities visualized through satellite imagery taken after the earthquake. Usually these areas would be plain open areas free from crustal fractures, ruptures, folds etc. With the help of GPS the shortest alternate routes can be found out for reaching the affected areas.

Remote sensing technologies are emerging as useful post-earthquake damage evaluation tools. Recent studies in Japan, Europe and the U.S. demonstrate that satellite-based imagery can identify broad zones of damage following significant earthquake events. For example, Wesnousky and others [20] identify the damage caused by widespread liquefaction and fire following effects on low-resolution remotely sensed data. Damage sustained in urban environments has more recently been identified through visual inspection of optical [12], [2], [9], [13], [21], [17] and SAR [1], [9], [21] coverage.

Tectonic activity is the main cause of destructive earthquakes, followed by earthquakes associated with volcanic activity. Where the history of earthquakes due to seismic activity is present in an area, the faults associated with the activity can frequently be identified on satellite imagery. Where volcanic-activity based earthquakes occur, the source is generally not as obvious: it may be due to movement on a fault near the surface or deep within the earth, to caldera collapse, or to magma movement within the volcanic conduit.

In order to identify earthquake hazards it is necessary to have the expertise to recognize them and then determine the correct remote sensing tools to best delimit them. Landsat imagery has been effectively and widely used for this purpose since it is less expensive and more readily available than other remote sensing data. Airborne radar mosaics have been successfully used for the delineation of fault zones. Generally, two mosaics can be made of an area: one with the far range portion of the SLAR and the other with the near range portion. The former is best used in areas of low relief where the relief needs to be enhanced, and the latter in areas of high relief where the shadow effect is not needed or may be detrimental to the image.
4.3 Landslides

Landslides, or mass movements of rock and unconsolidated materials such as soil, mud, and volcanic debris, are much more common than is generally perceived by the public. An ideal map of slope instability hazard should provide information on the spatial probability temporal probability, type, magnitude, velocity, run out distance and retrogression, limits of the mass movements predicted in a certain area. On the other hand, natural hazard mapping is not restricted to the delineation of occurrence of phenomena such as mass movement in the past, but it is focused on the prediction about the occurrence of such phenomena in the future. Hazard maps outlining zones can be defined in the potentially damaging phenomena within a certain span of time.

Landslides are the result of a wide variety of geological, geotechnical, geomorphological and meteorological processes. The important terrain factors are lithology, structure, drainage, slope, landuse, and geomorphology. Geological and geotechnical factors are largely responsible for triggering landslides. It is necessary for any landslide study to carefully utilize the existing data from previous landslides in a particular lithological and structural set up to understand the effect of geological and geotechnical parameters.

Remote sensing has been used to study characteristic properties of ground surface due to the advantages of its synoptic view and its periodicity. The integration of GIS with remote sensing data and thematic map data may facilitate greatly the assessment and estimation of regional landslide hazards. The elevation and slope inclination can be determined from DEMs generated from aerial photographs. Underground water level information has been obtained from the combination of the above data. From these data, simple algorithms were used to classify the area into different risk zones. By combining all the risk maps using GIS techniques, final risk maps can be produced which take into account all the above factors.

For landslide susceptibility analysis, accurate detection of landslide location is very important, a field survey being the most exact method. However, finding all the landslides in a large area is very difficult and is expensive in time and money. This is especially true in mountainous areas where there are no roads, and access to the landslides is difficult or even impossible. As it would be very difficult to obtain sufficient data in this way for an accurate statistical analysis, a field survey can be used to verify the results of an aerial photo interpretation and satellite image analysis. Many high-resolution satellite images (IRS-P6 Resources sat, IKONOS and QUICK BIRD) which can be used to detect the landslide location are now available.

6 Conclusion

The remote sensing technologies have many actual and potential applications for assessing environmental resources and for monitoring the monitoring water pollution, effects of atmospheric pollution, and natural disasters. New satellites (IRS-P6 Resources Sat, SEAWIFS, EOS, MOS, OrbView, IKONOS, etc.) and sensors (hyperspectral, high spatial resolution) already launched or planned to be launched over the next decade will provide the improved spectral and spatial resolutions needed to monitor environmental parameters such as detection of water pollution, atmospheric pollution, strip mining, and natural disasters and so forth from space platforms. Research needs to focus on understanding the effects of water pollution on optical and thermal properties of surface waters so that physically based models can be developed. Hyperspectral data from space platforms will allow us to discriminate between water quality parameters and to develop a better understanding of light/water/substance interactions. Such information should allow us to move away from empirical approaches now being used and develop algorithms that will allow us to use the full resolution electromagnetic spectrum to monitor water quality parameters. Remote sensing and Geographical Information Systems can be better and more effective tools to study the environmental aspects in totality in very short time in a more accurate manner.

References:


